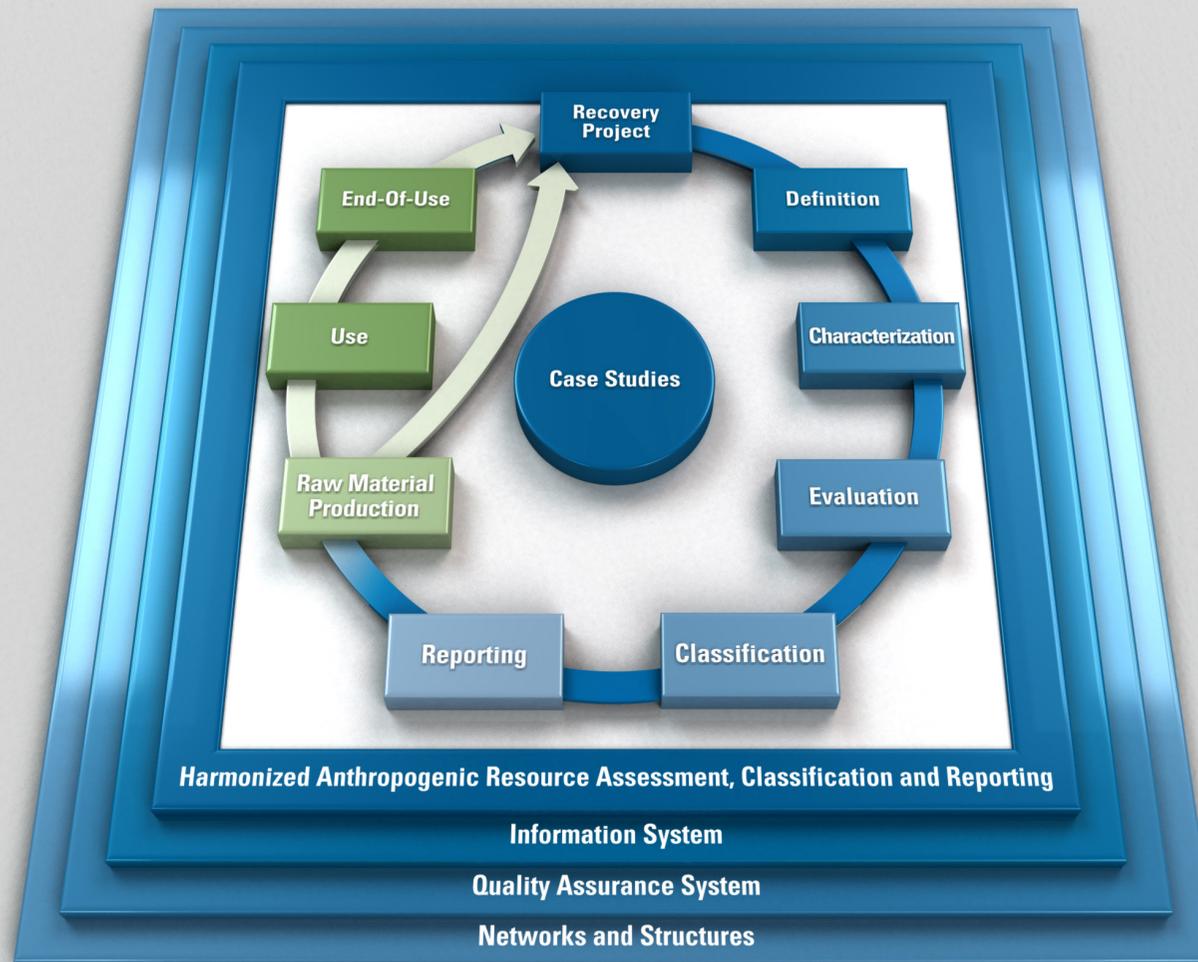




Strategic roadmap for SUSTAINABLE MANAGEMENT OF ANTHROPOGENIC RESOURCES



APRIL 2020 (MINEA deliverable)

CREDITS

Authors:

(in alphabetical order)

Soraya Heuss-Aßbichler, Zoltan Horvath, Ulrich Kral, Amund Løvik, Sandra Mueller, Mark Simoni, Julia A. Stegemann, Patrick Wäger, Andrea Winterstetter

Final review, proof-reading and approval:

Zoltán Horváth and Cost MINEA WG Leader Teresa Carvalho made a final review; proof-reading by Andrew Clarke. The report was approved by the MINEA Management Committee.

Recommended citation:

Heuss-Aßbichler, S., Z. Horváth, U. Kral, A. Løvik, S. Mueller, M. Simoni, J. Stegemann, P. Wäger, and A. Winterstetter (2020). Strategic Roadmap on Sustainable Management of Anthropogenic Resources. Deliverable 3 of COST Action Mining the European Anthroposphere. DOI: <http://dx.doi.org/10.5281/zenodo.3739269>.

License:

This document is licensed under CC BY-SA-NC 4.0 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>).

More details on COST Action Mining the European Anthroposphere:

- (1) <http://www.minea-network.eu/>,
- (2) <https://www.cost.eu/actions/CA15115/>

Acknowledgements:

This publication is based upon work from COST Action Mining the European Anthroposphere (MINEA), supported by COST (European Cooperation in Science and Technology).

COST is a funding agency for research and innovation networks. Our Actions help connect research initiatives across Europe and enable scientists to grow their ideas by sharing them with their peers. This boosts their research, career and innovation.

Front image source:

Created by Soraya Heuss-Aßbichler; redesign and 3D visualization by HEUREKA!DESIGN

Layout, Graphic Design:

HEUREKA!DESIGN, Reventloulallee 17, 24105 Kiel, Germany, <https://www.heureka-design.de/>

Contact:

Technische Universität Wien
Research Center for Waste and Resource Management
Karlsplatz 13/226, 1040 Vienna, Austria

+43.1.58801.22641, info@minea-network.eu, <http://www.minea-network.eu/>

CONTENT

1 INTRODUCTION	4
2 CONTEXT	5
2.1 Vision	5
2.2 Anthropogenic Resources in the context of Sustainable Resource Management	8
2.3 United Nations Framework Classification for Resources (UNFC)	9
2.4 Future needs	12
3 STRATEGIC ROADMAP	13
3.1 Introduction	13
3.2 Developing case studies	13
3.2.1 Status	13
3.2.2 Recommended actions	13
3.3 Harmonizing and developing anthropogenic resource assessment, classification and reporting	16
3.3.1 Status	16
3.3.2 Recommended actions	16
3.4 Providing information systems	18
3.4.1 Status	18
3.4.2 Recommended actions	18
3.5 Implementing quality assurance systems	19
3.5.1 Status	19
3.5.2 Recommended actions	21
3.6 Establishing supporting networks & structures	23
3.6.1 Status	23
3.6.2 Recommended actions	24
3 CONCLUSIONS AND OUTLOOK	27
LITERATURE	28
APPENDICES	34
Appendix A: Quality assurance	34
Appendix B: History of the report's development	35

1 INTRODUCTION

Secure, reliable and unhindered access to raw materials is crucial for our society. Raw materials are fundamental for the prosperity of nations, healthy competitive industries and human well-being [1]. Securing the supply of materials from natural sources is becoming increasingly difficult and expensive for practical and (geo)political reasons. The continuing demand growth for resources is reflected in current resource extraction in the order of 6×10^{10} tonnes per year globally, which equates to nearly 8 tonnes per year per person [2]. In the EU, with a high standard of living, the annual material consumption per person is 16 tonnes [3]. A large proportion of this material is accumulated in buildings, infrastructure or various products that remain in use for longer periods of time. However, as a result of products reaching their end-of-life, about 6 tonnes per person are annually declared as waste, with half of this going to landfill [4]. A reduction in material consumption is essential since technical dependencies and a lack of feasible substitutes make the availability of certain materials crucial [5]. Demand growth, supply constraints, and social and environmental benefits motivate material recovery from anthropogenic sources. For example, the market growth for recovery of lithium from end-of-life batteries is expected to exceed \$6 billion by 2030 [6]. Nevertheless, the Circularity Gap Reporting Initiative announced during the World Economic Forum Annual Meeting 2019 in Davos that only 9 % of the global economy is circular [7].

One of the main United Nations Sustainable Development Goals (SDG 12, sustainable consumption and production) requires sustainable management and efficient use of natural resources, including environmentally sound management of chemicals and all wastes throughout their life cycles, together with minimized emissions to the environment and diminished adverse impacts on human health [8]. The implementation promotes the “3Rs”, i.e., waste reduction, reuse and recycling, in addition to prevention of waste generation. The implementation of the SDGs also includes prescriptions for policy coherence for sustainable development to enhance global macroeconomic stability and encourages multi-stakeholder partnerships with the aim of mobilizing and sharing knowledge, expertise, technology and financial resources. With respect to SDG 12, we need to start by assessing and optimizing the sustainability of raw material value chains. Systems for economically efficient management of natural resource exploitation from the geosphere (e.g. coal, petroleum, minerals) are well-established, but this is not the case for resource recovery from the anthroposphere. A sustainable and diversified supply of raw materials requires the development of integrated systems for the management of anthropogenic resources together with natural resources which take environmental, social and economic consequences into account.

This strategic roadmap formulates a vision for the “sustainable management of anthropogenic resources” (Section 2). It is a “Desired End Point” that can be achieved by the interaction of industry, academics and governments through public, public-private and civil society partnerships. The vision is followed by means of a strategic roadmap with five fields of action (Section 3.1) and eleven specific actions within them (Sections 3.2-3.6). The actions chosen for the roadmap are drawn from the experiences and practices in the primary raw material sector, discussions during Workshops held by MINEA Working Group 4 (WG4) on Anthropogenic Resource Classification, and MINEA Deliverables D1 [9-11] and D2 [12]. With this report, we provide ideas for the sustainable management of resources. The granularity of the strategic planning and the actions can be refined by future stakeholder involvement. Your feedback (please text a message to info@minea-network.eu) is highly appreciated.

2 CONTEXT

2.1 Vision

Many activities of the OECD, UNEP and its International Resource Panel, and various projects under Horizon 2020, focus on the development of an international knowledge base for material stocks and flows, including resource productivities, with the aim of achieving sustainable resource management. The Circular Economy Package of the European Commission promotes Europe's transition from a linear (take-make-dispose) economy to a Circular Economy, with the ideal that all wastes resulting from human activity be viewed as prospective anthropogenic resources, which includes consideration of the levels of the waste hierarchy (prevention, reuse, recycling, energy/other recovery) [4]. A Circular Economy pursues the goal of maintaining the value of products and materials for as long as possible in the system, while minimizing the utilization of natural resources, promoting reduction of waste and emissions and optimizing the reuse of end-of life products [13].

The **need** for sustainable resource management, including resource circularity, is based on the following observations:

- **Security of supply and availability of critical materials** are essential for our society, and the relevant EU policy focuses on resource efficiency. To reduce import dependencies and other supply risks, sustainable raw material sourcing, with reliable estimates of future resource potential in terms of availability and recoverability of materials, are promoted in many actions of the European Commission. The Circular Economy Action Plan⁴ set out 54 ways to “close the loop”, including the development of a Raw Materials Information System (RMIS) [14] to promote the uninterrupted supply of economies at all scales. Many platforms, initiatives and strategies are on-going in the European Union to fill the gaps. This includes various activities through the Raw Materials Initiative (RMI), Eurostat, the European Innovation Partnership (EIP), the European Institutes of Innovation and Technology (EIT), the Raw Materials Knowledge and Innovation Community (KIC) and various projects funded herein.
- One of the key elements of the RMIS is a **knowledge base for raw materials** (EURMKB), which builds on the outcomes of projects for raw materials from natural sources (e.g. Minerals4EU [15]), raw materials from anthropogenic sources (e.g. ProSUM [16]), or both (e.g. MICA [17]). The project SNAPSEE [18] prepared multi-sectoral analysis and guidance, with a vision for an integrated management of different mineral and anthropogenic aggregate resources. The MinFutre project provides a framework for the description and monitoring of the physical economy using Material Flow Analysis (MFA) to support the development of robust strategies for sustainable resource management, and the ORAMA project [19] focused on optimizing data collection for natural and anthropogenic materials in the EU. In the final report of the project [20], the authors point out the lack of harmonized data at European level and emphasize the absence of standard metrics for environmental and social impacts. In particular, they recommend the exclusive use of the United Nations Framework Classification for Resources (UNFC), which goes beyond mere data collection. However, there is still a need for a common data model with decentralized databases that include standardized information on resources at local to regional scales, worldwide.
- The serious environmental and social impacts of wasteful use of resources over their life cycles, from extraction to end-of-life, are becoming increasingly apparent. Moving Europe towards zero-pollution is one of the ambitions of the European Green Deal [21]. However, keeping materials in circulation affects global resource and industrial

symbiosis networks. It entails not only opportunities but also new risks, such as the accumulation or dispersion of hazardous substances funded by the Horizon 2020 and other contaminants in recovered materials, and/or unacceptable business or community impacts.

- There is a clear tendency towards bringing the financial sector on board in terms of 'socially responsible investment'. The European Commission's Action Plan for a greener and cleaner economy states that [22] *"Investment decisions are typically based on several factors, but those related to environmental and social considerations are often not sufficiently taken into account, since such risks are likely to materialise over a longer time horizon. It is important to recognise that taking longer-term sustainability interests into account makes economic sense and does not necessarily lead to lower returns for investors."*[22] The action plan on sustainable finance considers following three objectives:

- "1. reorient capital flows towards sustainable investment in order to achieve sustainable and inclusive growth;*
- 2. manage financial risks stemming from climate change, resource depletion, environmental degradation and social issues; and*
- 3. foster transparency and long-termism in financial and economic activity."*

The World Economic Forum has stated that investors need widely available and comparable data with better quality of information on sustainability and performance to make informed decisions [23]. They also point to the need for disclosure standards to support the tracking and reporting of such information. In general, stakeholders with different perspectives need to be able to quantify, measure and compare the economic, environmental and social impacts of anthropogenic and geogenic resources according to their differing interests, including:

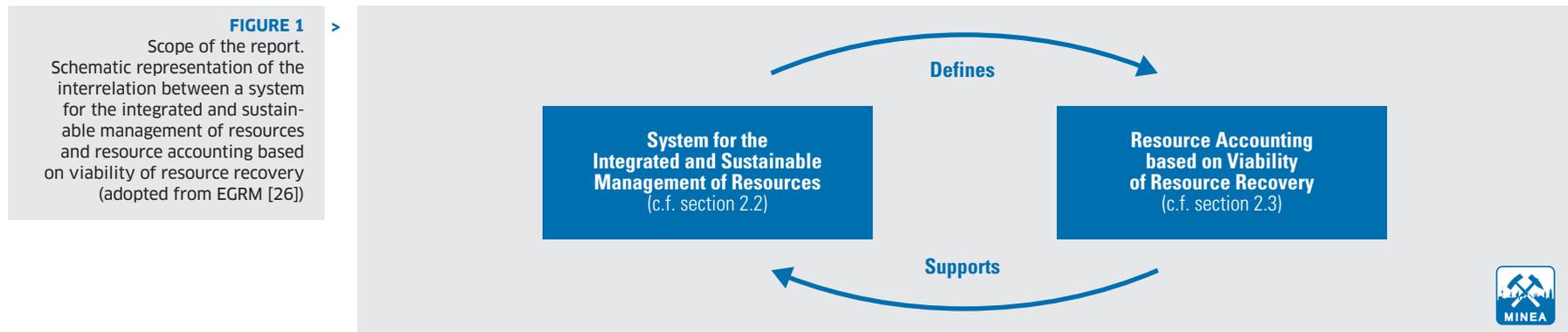
- recycling companies, which are looking for business opportunities to recover and sell raw materials derived from anthropogenic sources;
- producers, which are interested in a continuous and cost-efficient supply of high-quality materials, and may generate waste that has a potential for use;
- municipalities and governments, which need instruments to approve sustainable resource exploitation from natural sources as well as resource recovery from anthropogenic sources in accordance with the waste hierarchy and Waste Framework Directive (2008/98/EC; [24]);
- policy makers, who need to provide the legal frameworks for the recycling and production of raw material from anthropogenic sources and to harmonize national and EU policies and regulations, including end-of-waste and by-product criteria;
- authorities, who are responsible for resource accounting in their region;
- investors, who are mainly interested in a return on investment, but also want to comply with sustainable investment guidelines; and
- consumers, who require transparency and consistency in decision-making with clear criteria to protect human health and the environment.

Major **barriers** to implementation of a sustainability resource management influenced Circular Economy include uncertainties regarding the source, composition, quantity, quality and regulatory status of end-of-use materials. The HARMONI project [25] brought together the relevant stakeholders in the processing industry with the aim of identifying the bottlenecks that hamper innovation processes and their market acceptance. They identified the following barriers regarding the Circular Economy:

- public acceptance issues,
- regulatory issues including, among others, lack of traceability criteria for waste streams,
- unharmonized end-of-waste criteria or lack of proper life-cycle analysis,
- standardization of common rules to create trust and security.

New **solutions** are required to meet the needs, overcome the barriers and create a system for the sustainable management of resources which address:

- environmental, social and governance (ESG) issues for the supply, utilization and recycling of raw materials,
- stakeholder views from government, industry, the financial and scientific community as well as society,
- interaction with top-down policy approaches for support of business cases at the resource recovery project level.
- An integrated system for sustainable management of resources (Section 2.2) should use resource accounting to develop resource recovery projects and resource policies (Section 2.3) (FIGURE 1).



Sustainable resource management under governance of the United Nations Economic Commission for Europe (UNECE) is now at its beginning. In this context, we use this report to formulate a Desired End Point for sustainable anthropogenic resource management. The Desired End Point is that the

Sustainable management of anthropogenic resources is established on a common footing with natural resources

We feel that the vision (Desired End Point) can be achieved by implementing the actions from the strategic roadmap, as presented in Section 3.

2.2 Anthropogenic Resources in the context of Sustainable Resource Management

Natural Resources include useful or valuable “primary” materials such as wood, coal or minerals that exist in the natural environment. In the case of mineral resources, they comprise solid materials that occur in or on the earth's crust (geosphere). Classification of mineral resources reflects different levels of confidence in the geological knowledge of the source and different degrees of technical and economic feasibility of their extraction. The term “Resource” is used for materials concentrated in a form and amount that makes economic extraction currently or potentially feasible [27]. The term “Reserve” is restricted to resources that “meet specified physical and chemical criteria related to current mining and production practices” [28].

The term “**Anthropogenic Resources**” has been defined and/or used by experts in the field [e.g. 29, 30-34] and has also been defined in the “Specifications to apply the UNFC to anthropogenic resources” [35]. Generally speaking, it applies to all materials that are produced, used and disposed of in the anthroposphere, i.e., all wastes, residues and by-products from human activities. In general, throughout history, waste has always been considered a possible resource for valuable materials. In recent decades, however, we have become so good at extracting raw materials from the earth that anthropogenic resources have become neglected, and the linear sequence of extraction - production - use - disposal is common practice. As expressed in the Waste Framework Directive, our main concern with waste has been to manage it without endangering human health or harming the environment [24]. The Waste Framework Directive provides criteria for management of wastes that are consistent with these intentions, but does not specifically include explicit criteria for material recovery.

The European Commission has set various new ambitious goals to achieve higher recycling rates [4]:

- *“simplification and harmonisation of definitions and calculation methods and clarified legal status for recycled materials and by-products;*
- *reinforced rules and new obligations on separate collection (bio-waste, textiles and hazardous waste produced by households, construction and demolition waste);*
- *minimum requirements for Extended Producer Responsibility;*
- *strengthened waste prevention and waste management measures, among others, for marine litter, food waste, and products containing critical raw materials”*

The paradigm shift to viewing waste as a resource has regulatory, environmental, social and financial consequences. Sustainable resource management requires rethinking the entire waste management system, including waste generators, processors, transporters and disposal operators. However, incompatibilities in the legal frameworks for managing waste and regulating resource recovery lead to uncertainties for those who want to develop or invest in anthropogenic resource recovery projects [36]. The importance of resolving regulatory issues to enable resource recovery was the topic of the EC’s resolution of 13 September 2018, which addressed the interface between chemical, product and waste legislation.

Recently, efforts have been made to develop a United Nations Resource Management System (UNRMS) applicable to the life cycle and value chains of all materials resources [26] (see [FIGURE 1](#), left box). It demands a transformation to integrated resource management to improve resource efficiency for both natural and anthropogenic resources in line with the UN SDGs. One of the main aims is to enable decision making that considers the complexity of competing interests at multiple scales over whole material life cycles. Shifting the perspective of resource management from a project to a “bird’s-eye” scale promotes a holistic approach and strategic assessment at regional or national levels [26].

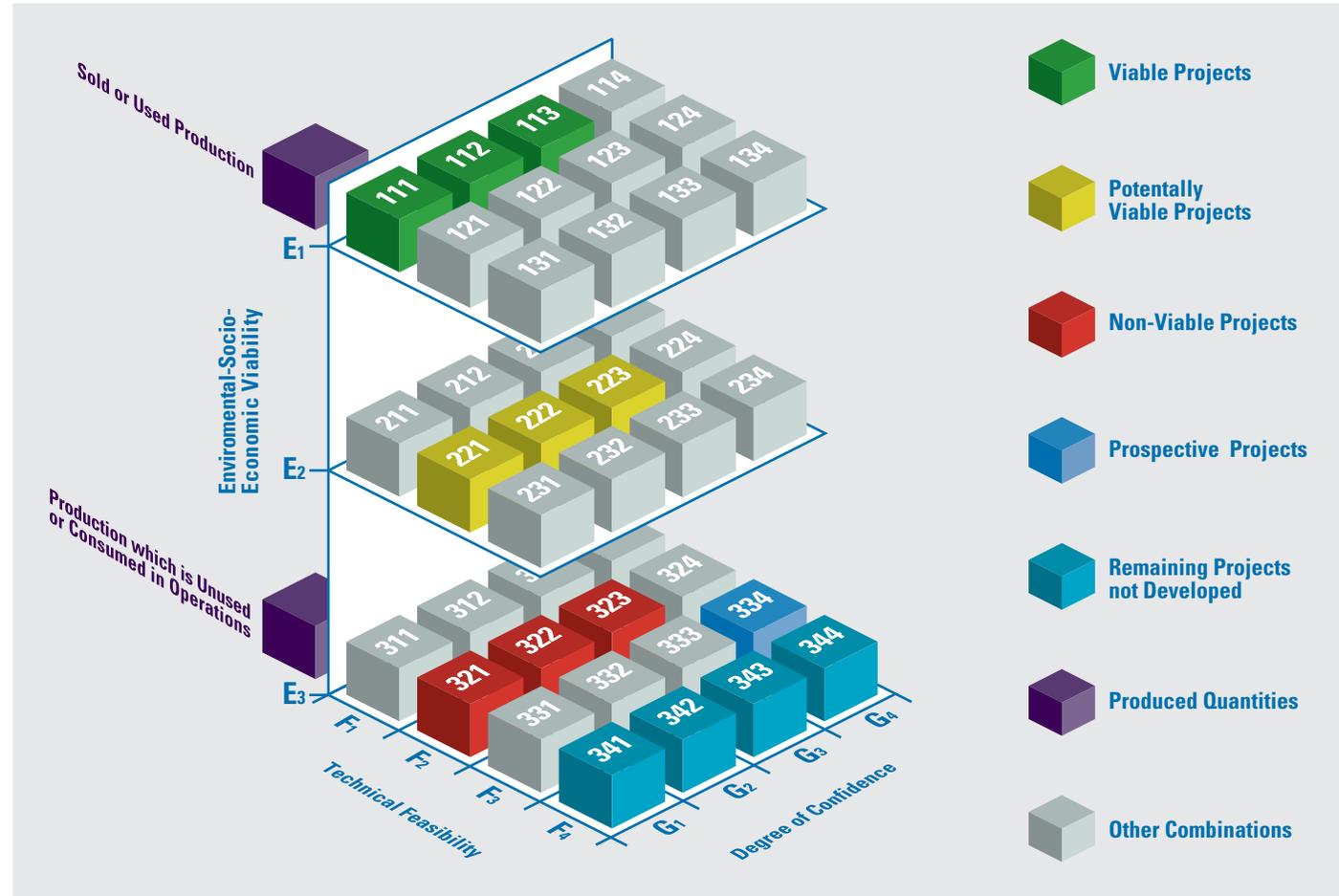
The UNRMS is designed as a voluntary global standard that is uniformly applicable to all resources and is intended to be used by government, industry, capital investment entities, academics and non-profit organisations. It is expected to include the following elements: fundamental principles, concepts and terms to define a structure and specifications needed to enable projects to progress; data, methods and standards to assess, compare options, make choices and monitor performance; and guidance on how to reach decisions [26].

2.3 United Nations Framework Classification for Resources (UNFC)

For natural mineral resources, classification of resources is carried out to determine the recovery potential of resources that are particularly relevant for private companies and investors. It is conducted on the basis of individual development projects, and has mainly been developed to estimate and communicate the availability of natural resources to stock exchange markets, corporate decision boards and governments based on standard procedures. Such standard classification procedures are currently not established for anthropogenic resource recovery projects. Consequently, anthropogenic resource recovery projects experience a barrier to investment, which is not the case for natural resource development. It is therefore desirable to have a framework that is applicable to both natural and anthropogenic resources for reasons of comparability and to support holistic resource management.

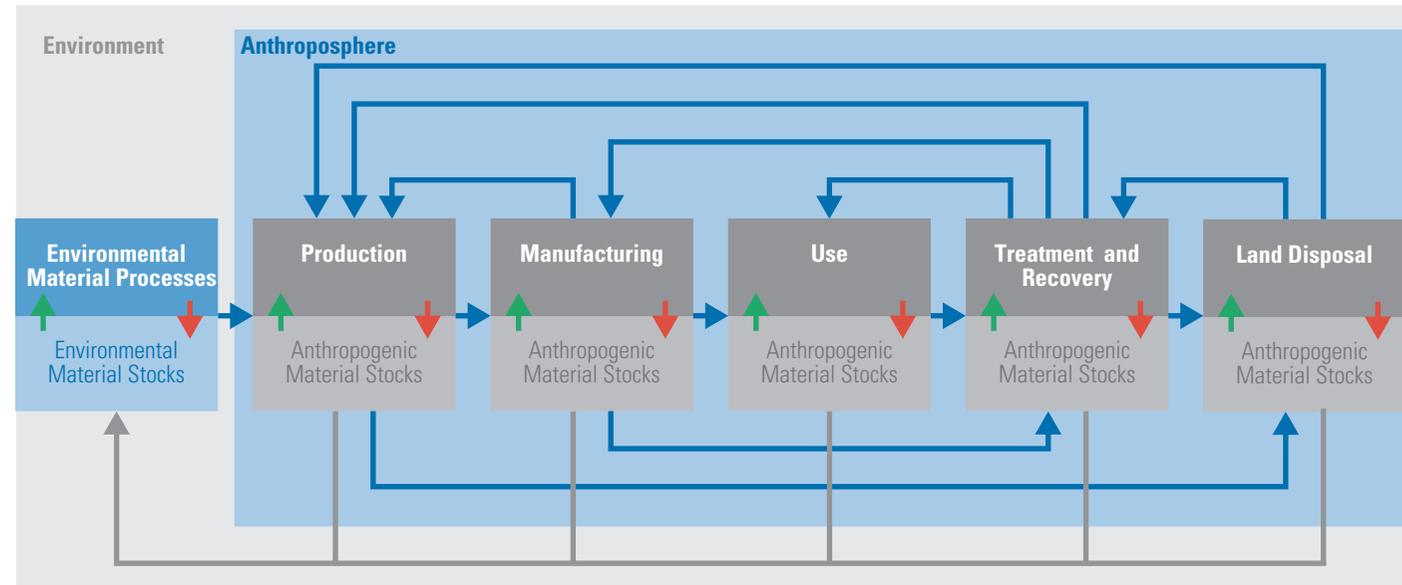
The United Framework Classification for Resources (UNFC) is a universally acceptable and internationally applicable scheme for the classification of energy and mineral resources. It was developed to converge all resource classification systems worldwide (e.g., CRIRSCO, JORC, PERC, PRMS) [25, 37] under one umbrella in order to address a variety of stakeholder needs. UNFC provides a generic framework that classifies the viability of a project based on an evaluation of its characteristics according to three fundamental criteria, shown in [FIGURE 2](#) has three axes [38]: Environmental-Socio-Economic Viability (E-axis), Technical Feasibility (F-axis), and Degree of Confidence (G-axis). A numerical coding system is used to sub-divide the three axes into categories. Categories E1 to E3 denote the degree of favourability of social, economic and environmental conditions in establishing the viability of the project, with E1 being the best. It includes various aspects, including market prices and relevant legal, regulatory, environmental and social conditions, among others. Categories F1 to F4 reflect the technical feasibility of the project, with F1 being the most feasible. Categories G1 to G4 indicate the level of confidence in the product quantities associated with a project, with G1 showing the best conditions and the highest degrees of certainty. Combination of the appropriate categories or sub-categories from all three criteria leads to assignment of a specific Class, e.g., Class 221.

FIGURE 2 >
 United Nations Framework Classification for Resources (UNFC) with the different UNFC Categories for Environmental-socio-economic Viability (E-axis), Technical Feasibility (F-axis), and Degree of Confidence (G-axis). In colour, examples of various UNFC Classes that stand for the viability of resource recovery on a site-specific resource recovery project basis. Picture adopted from UNECE [38]



A preliminary adaptation of the UNFC for anthropogenic resources was undertaken by the UNECE Expert Group of Resource Management in close cooperation with members of the COST Action MINEA. They developed “**Specifications for the application of the UNFC to Anthropogenic Resources**” [35], which were presented in Geneva in April 2017 and endorsed by the UNECE Sustainable Energy Committee in September 2018. This document defines the principles and terms for communication purposes. The UNFC remains a project-based system and the definition of the recovery project represents a sub-system of material flows and stocks in the anthroposphere (FIGURE 2). Such subsystems for anthropogenic resources are more complex in comparison with those for natural mineral deposits because dynamic flows have to be considered as well as stocks, and the composition of the materials may vary considerably within a stock or flow at a given time, and over time. For consistency with the ethos of a Circular Economy, it is also essential to consider wider impacts on the sustainability of the overall value chain, which is usually not considered in the current application of the UNFC.

FIGURE 3
Value chain (life cycle) for materials resources in the anthroposphere (white Box) embedded in the environment (green box). Resource recovery projects relate to sections of the resource value chain, e.g. Treatment & Recovery, and therefore have to be defined as a subsystem in the anthroposphere. Figure adopted from Heiberg [35].



- Anthropogenic Material Processes
- ➡ Anthropogenic Material Flows, entering or inside the Anthroposphere
- ➡ Anthropogenic Material Flows, leaving the Anthroposphere
- ➡ Material Flows leaving Material Stocks
- ➡ Material Flows entering Material Stocks

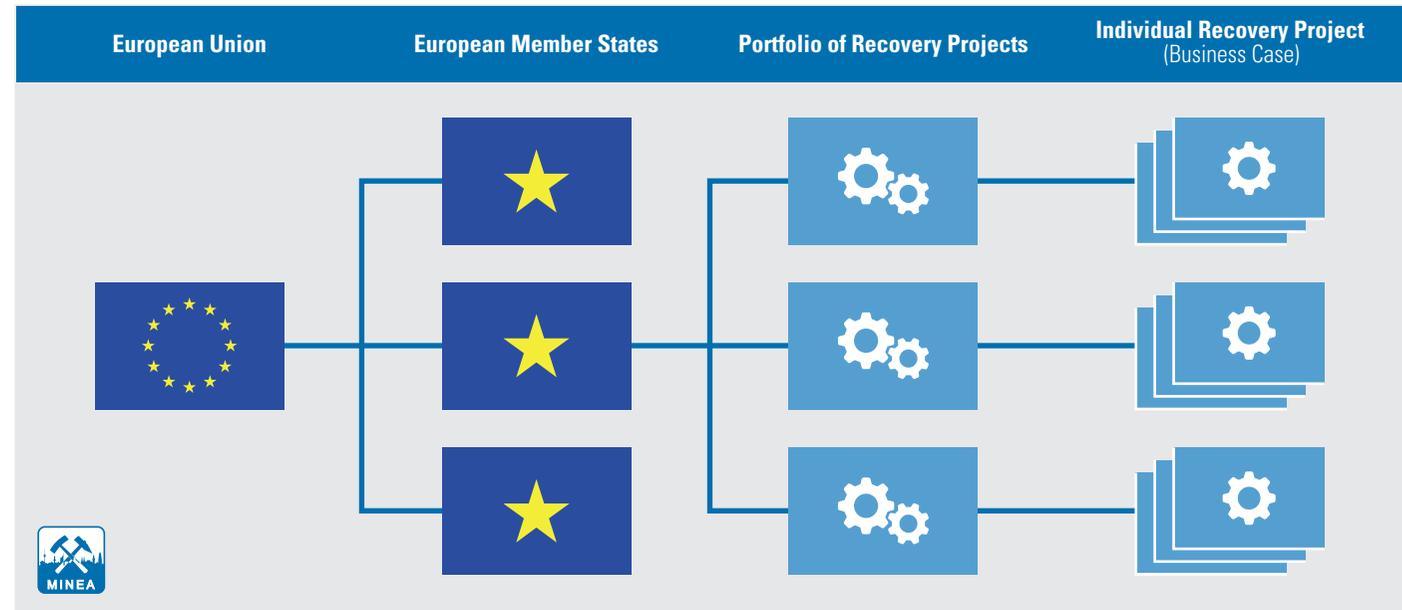
A major shortcoming in the application of the UNFC to anthropogenic resources is the lack of guidance on how to implement assessment and classification of the social and environmental impacts that need to be taken into account in resource classification [39]. There are approaches that reflect the whole life cycle of a material (e.g., Whole-Life Costing, Environmental Life Cycle Assessment [LCA] and Social Life Cycle Assessment [SLCA]), but they are not directed at classification of the viability of anthropogenic resource recovery projects.

Since it is designed for investors in specific resource exploitation projects, the UNFC is explicitly project-based, without an intention or mechanism to aggregate the project-based results for resource accounting. Yet effective resource management in the context of a Circular Economy requires such resource accounting beyond the project on local, regional, national and global scales to enable identification of resource exploitation potentials and to monitor achievement of resource efficiency targets by stakeholders other than investors. FIGURE 4 shows the perspectives on different levels of anthropogenic resource management. A **bottom-up** approach accumulates all individual projects in an area, region or nation. All stocks and flows for projects in a particular area are summed to capture them at the next level of accounting, and the estimation is achieved by summing all stocks and flows. As shown in FIGURE 3, it is also possible to proceed **top-down** by means of data collection and evaluation for a whole region or nation in order to identify the most

promising intervention points for resource recovery, without considering the details for individual projects. This approach is not considered under the UNFC, but it is conceivable that the UNFC classification approach could be modified for application from a top-down perspective.

The RMIS promoted by the European Commission includes top-down and bottom-up data. For instance, data from a top-down approach originates from the EC Raw Material System Analysis (MSA) study [40] and the Urban Mine Platform [41], and data on a site-specific recovery project level originate from a bottom-up approach as followed in the EU project Minerals4EU [42, 43].

FIGURE 4 Perspectives on different levels of anthropogenic resource management (courtesy of Eddy Wille, PublicWaste Agency of Flanders (OVAM)).



2.4 Future needs

In summary, there is a need to develop an internationally harmonized and agreed upon standard procedure for the assessment and classification of resources, to: (1) estimate and communicate the availability of anthropogenic resources in parity with natural resources, and (2) enable comparison and aggregation of information about the economic, environmental and social sustainability of resource recovery projects.

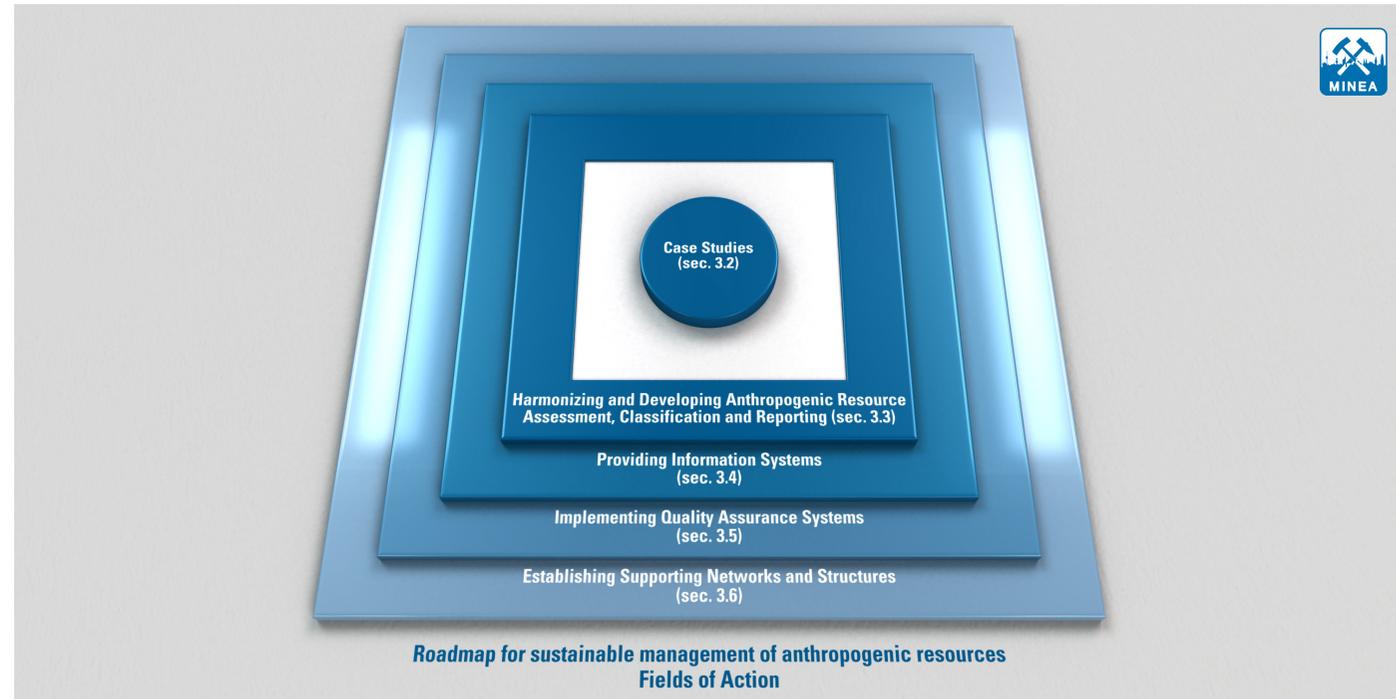
This procedure should be: (i) part of a comprehensive resource strategy that integrates the use of both natural and anthropogenic resources, (ii) applicable to all relevant stakeholders from different sectors at different levels of action (local / regional / national / international), (iii) transparent and consistent, and (iv) replicable and comparable. Agreement on this procedure should be achieved through wide consultation of end-users and other stakeholders, e.g., project developers, investors, geological surveyors, decision-makers, authorities and academia. The procedure should also include strategies for its implementation and associated reporting by end-users.

3 STRATEGIC ROADMAP

3.1 Introduction

The strategic roadmap for sustainable management of anthropogenic resources includes 11 actions, which are grouped into five fields of action, as illustrated by [FIGURE 5](#). Details are given in the sections 3.2 to 3.6.

FIGURE 5 >
Roadmap with five key fields of action to facilitate the sustainable management of anthropogenic resources.



3.2 Developing case studies

3.2.1 Status

One key principle of sustainable resource management is the circularity of materials, which requires the recovery of raw materials from anthropogenic resources through successful evidence-based initiation and development of site-specific recovery projects. A knowledge-base for four different potential sources of raw materials is given in MINEA Deliverable 2 [12]. MINEA Deliverable 2 also includes 49 case studies that demonstrate the use of resource estimates and assessments in combination with resource classifications. Of these case studies, 76% cover extractive industries residues and 24% post-consumer residues.

3.2.2 Recommended actions

Based on the review of the case studies in MINEA Deliverable 2 [12], we propose the following four specific actions:

- Action 1: Mapping and bridging of the case studies to align with the UNFC
- Action 2: Development of new pioneering case studies
- Action 3: Updating existing case studies
- Action 4: Extending the scope of case studies.

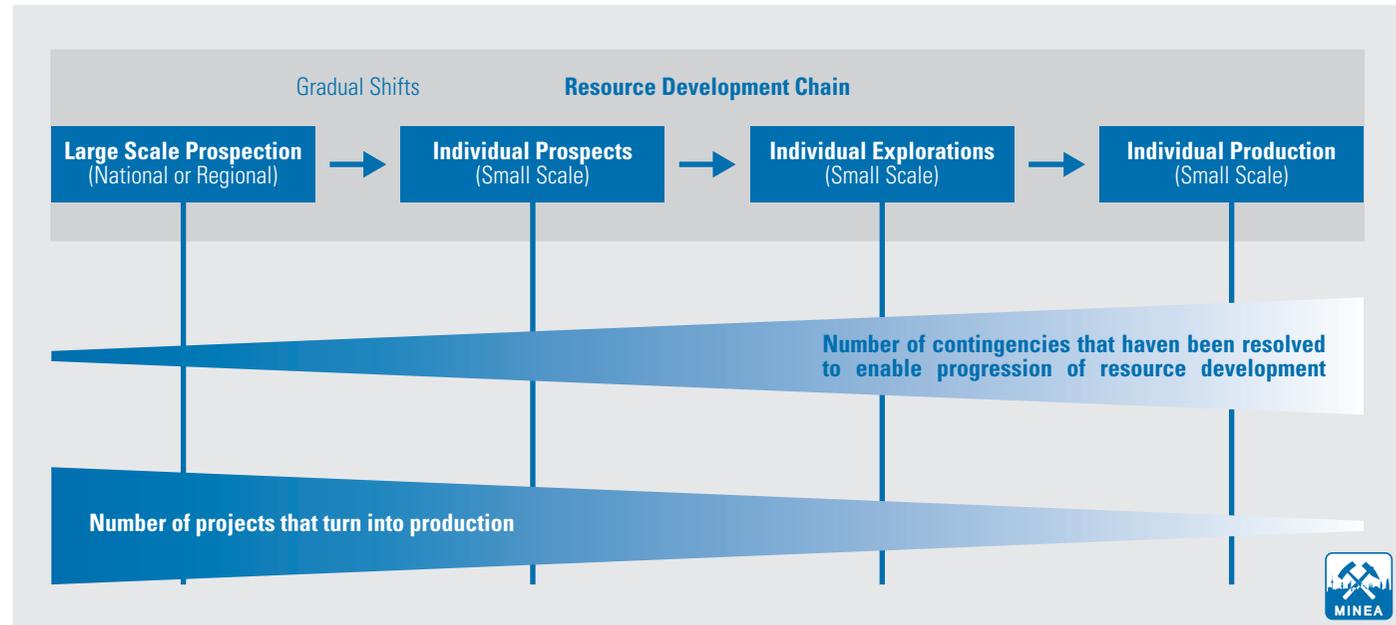
Action 1: Mapping and bridging of the case studies to align with the UNFC. The extractive industry sector uses standards and codes such as JORC, SAMREC and NI 43-101 to report resource/reserve data to clients. As these standards and codes use different terms and principles, the results of the individual case studies cannot be compared and aggregated. To overcome the lack of comparability, the UNECE has developed procedures to map and bridge resource/reserve data to UNFC [44, 45]. We propose picking out case studies on residues from the extractive industries that have used traditional classifications and then bridging them to UNFC.

Action 2: Development of new pioneering case studies. Additional case studies are urgently needed to test the applicability of the UNFC and to develop approaches for resource assessment and classification. In recent years, the classification of anthropogenic resources has been developed largely in analogy to natural resources. However, there is still much room for further methodological development and consolidation. From a broader range of methodological challenges, we give five examples:

- The UNFC is used to classify **site-specific recovery projects**. As far as we know, it has never been used to communicate recovery potentials at the regional level, as has been done for resource/reserve estimates according to McKelvey [46]. We believe that the application of the UNFC at the regional level will enable the strategic identification of valuable recovery potentials, which can form the basis for later development of site-specific recovery projects.
- A UNFC guideline recommends a specific multi-criteria method **to aggregate multiple environmental-socio-economic factors into a single E-axis category** [47]. Given the inadequate state of development and integration of methods for the assessment of environmental and social impacts in the UNFC, we suggest that different multi-criteria methods should be considered, e.g. methods with the weighting of factors, such as stakeholder priorities [c.f. 48].
- Resource assessment and classification is used to estimate the **future recoverability** of resources. This requires forecasts about the generation of residues, technological progress and environmental impact. This implies the need for case studies that integrate forecasting methods [c.f. 49] into resource assessments and classifications, for instance, prospective material flows studies.
- Existing case studies are related to one specific stage in the resource recovery chain (FIGURE 6). We suggest developing case studies to demonstrate the **progression of resource recovery**, which implies that resource assessment and classification are applied at stage 1 and 2 of the resource recovery chain. A Stage 1 case study would start with the large-scale prospection of potential sources and give recommendations for small scale or site-specific prospecting and explorations. Stage 1 case studies are already available [31, 50]. Based on the recommendations from a Stage 1 case study, a Stage 2 case study would use a site-specific resource assessment that includes all contingencies that potentially affect the recoverability of materials.
- The UNRMS [26] (section 2.2) strives for integrated management of natural and anthropogenic resources. Pioneering case studies are also needed to assess and compare the viability of natural resource development and **anthropogenic resource recovery from a value chain perspective**. Exemplar case studies could be the gypsum supply from natural deposits and recycled plasterboards, or the optimization of the raw material supply for cement production, taking natural deposits and anthropogenic sources into consideration.

FIGURE 6

The resource development chain covers four stages. At each stage, resource assessment and classification can be applied to estimate recoverable material quantities from anthropogenic sources. Picture taken from Blasenbauer *et al.* [12]



- **Action 3: Updating existing case studies.** Resource assessments and classifications represent snapshots of the status of a recovery project. Updates are needed when more precise knowledge about the characterization of the anthropogenic resource (quantity, quality, location) is available and/or the factors that affect the viability of the project (e.g. economic or technological factors) change. We recommend updating existing case studies to perform assessment and classification with the new knowledge. This approach would demonstrate dynamic effects on the viability of resource recovery and help in identifying barriers and developing strategies to overcome them. On the one hand, repeated analyses over time can provide lessons for the future development of recovery projects and, on the other, help gain insight into the dynamics of the development of anthropogenic raw materials and thus the long-term availability of anthropogenic resources. Such analyses may also help to improve the assessment and classification procedure.
- **Action 4: Extending the scope of case studies.** Up to now, less than 20 case studies for anthropogenic resources include resource assessment in combination with classification. We encourage the research community, authorities and funding agencies to develop more case studies, e.g., for further commodities, different contextual boundary conditions, or to gain a better understanding of reproducibility of the analysis for similar projects. More case studies are needed to demonstrate the benefits of resource classification, to test various methodologies for assessing and classifying resources, and to facilitate the development of quality assurance documents. More case studies can be developed for the site-specific level (e.g., for the development of an individual recovery project), on the sectoral level (e.g., for recovery portfolio management in the gypsum industry), and on the national or other regional levels (e.g., for the optimization of raw material supply from natural and anthropogenic sources to the region).

3.3 Harmonizing and developing anthropogenic resource assessment, classification and reporting

3.3.1 Status

Currently, there are substantial ongoing international efforts to harmonize the generation of classification data¹. The harmonization of classification data is needed to *aggregate* the estimated recoverable quantities of individual recovery projects and to *compare* the estimates in order to facilitate resource management. Aggregability and comparability of classification data are substantial needs for evidence-based raw material management and policy.

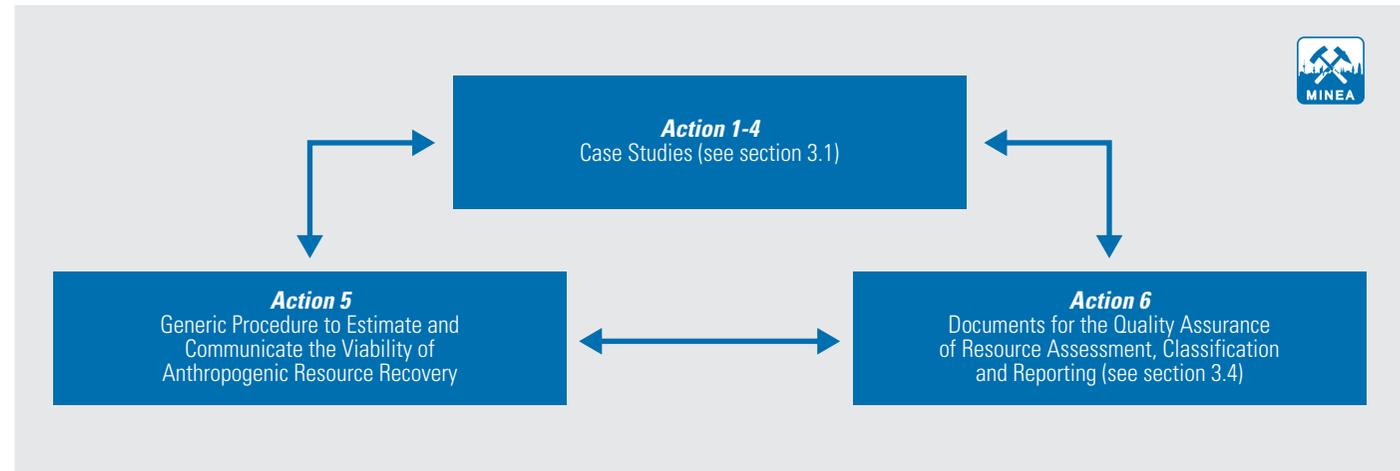
In the mining sector, more than 150 different classification and reporting systems have evolved over time; three of them have been used to classify **extractive industry residues, and could be used for aggregation or comparison**. At the same time, we found that the case studies on **post-consumer residues** differ to an extent that does not allow the aggregation and comparison of the classification data generated. These case studies are driven by distinctly different motivations, used differently and, from a sustainability perspective, limited sets of recoverability criteria, and use different classifications than are used by the mining sector [12, section 3.5.2]. To enable *aggregation and comparison* of classification, this community must harmonize the generation of classification data as soon as possible.

3.3.2 Recommended actions

To achieve aggregable and comparable resource classification results, we suggest **Action 5: Development of a generic harmonized procedure to estimate and communicate the viability of resource recovery projects**.

It is noted that Action 5 has to be complemented by quality assurance systems that offer guidance for resource assessment, classification and reporting (Action 6), and case studies that make use of Action 5 and 6 results (see [FIGURE 7](#)).

FIGURE 7
Linkage of Action 5 (this action) to the Actions 1-4 and 6.



¹Examples are the UNFC to harmonize classification in addition to resource/reserve estimates (section 2.3), and the ORAMA project to harmonize collection of resource/reserve data.

Based on a synthesis of the existing case studies [12], MINEA WG4 developed a procedure with four different steps (FIGURE 8) that should be used to design research on future case studies. At this stage, the four key steps are high-level guidance for assessing and classifying anthropogenic resources, without defining methods and data collection procedures. However, we feel that the generic procedure is an efficient approach to standardize resource availability estimates. We recommend the establishment of an international agreement (e.g., using the mechanism of an International Organisation for Standardization, ISO, International Workshop Agreement, Section 3.5.1) to enable broad consultation on the details of the individual steps of resource assessment, classification and reporting.

FIGURE 8
 Procedure to estimate and communicate the viability of anthropogenic resource recovery, including its main steps (left) and a brief description of the activities (right).

Procedure to Estimate and Communicate the Viability of Anthropogenic Resource Recovery	
Step	Description
Goal and Scope Definition	Define the client and intended purpose of the results as well as key settings like target materials, recovery technologies, source materials, geographical scope, and lifetime of the recovery operation.
Resource Assessment	Resource assessments are used to estimate recoverable quantities under specific boundary conditions. The selection of resource assessment methodologies and datasets depends on the goal and scope definition. A knowledge base on resource assessment is given in MINEA D2.
Resource Classification	The results of resource assessments are the starting point to classify the resource quantities and communicate the findings to clients. We suggest using the UNFC or using alternative classifications before bridging and mapping these results to UNFC.
Resource Reporting	A resource report includes mandatory information on resource assessment and classification to inform clients (stock exchange markets, governments, resource policy makers, recovery project developers, non-governmental organizations) and via the JRC RMIS.



3.4 Providing information systems

3.4.1 Status

Estimates of mineral resources (i.e. resource/reserve data, UNFC data) are provided by countries and published in national and/or international information systems [e.g. 43, 51]. Substantial European efforts have been undertaken to harmonize the estimates and the reporting procedures as well as mapping classification data compliant with INSPIRE [e.g. 15, 19]. The review of case studies for anthropogenic resource assessment in combination with resource classification [c.f. 12] found that 38 case studies classify extractive industry residues with JORC, SAMREC and NI 43-101. In contrast to natural resources, the classification data are not published on a single communication platform. The remaining seven case studies for post-consumer residues are too diverse for presentation in a single format. The relatively short history of case studies on post-consumer residues and the absence of quality assurance (Section 3.5) or governance (Section 3.6) could explain the lack of a central communication platform for classification data. Centralized, consistent and transparent information systems are needed to enable reporting of UNFC data to support resource policy making.

3.4.2 Recommended actions

We recommend the following specific **Action 6**: creation of an information system to support the harmonised collection of results from assessments and classification by Competent Persons [52], and the reporting of classification data to end-users. The purpose, benefits, content, virtual hosts and information providers differ for information systems for classification, and resource reporting (TABLE 1).

TABLE 1
Information systems for resource assessment, classification and reporting.

	Resource assessment and classification	Needs
Target group	Competent Persons, researchers.	Resource reporting.
Purpose	Standardized collection of, e.g., UNFC data for resource reporting	Communicate the resource estimates to end-users to facilitate the development of recovery projects and national resource strategies
Benefits	Decreasing efforts for data collection and modelling; transparent and harmonized formatting	Centralized access to transparent and harmonized data, e.g. UNFC data, as well as technical and public reports
Content	Characterisation, evaluation data and quality analysis data for anthropogenic resources <ul style="list-style-type: none"> • Guidance for/documentation of data acquisition • Models • Case studies 	<ul style="list-style-type: none"> • Machine-readable UNFC data • Technical and public reports that document the generation of UNFC data
Virtual hosts	Examples: <ul style="list-style-type: none"> • Industrial Ecology Data Commons prototype [53] • Urban Mine Platform [41] 	Raw Materials Information System (RMIS). Addition of UNFC anthropogenic resource data to resource/reserve data already included in RMIS country profiles
Information providers	Resource generators, recovery project developers, academic researchers and institutions (Section 3.6.2).	Regional Centers for Sustainable Resource Management (Section 3.6.2).

Data on the composition and constitution of anthropogenic resources, including products and materials, is needed to identify opportunities for recycling, to determine risks related to the supply of raw materials, and to understand the environmental impacts of products. Studies with these objectives, e.g. using MFA, LCA or Input/output analysis, often depend heavily on such data, which are collected from scattered sources or obtained through sampling and analysis. Apart from the urgent need for such data by industry and government, there is a strong interest in the research community to have access to such data through a centralized database [54]. In general, there is a need for harmonization through standardized data formats to facilitate cumulative research, to enable data to be used by those in other fields, and to meet the requirements of funding agencies regarding long-term data management. A data repository specifically

designed for compositional data for anthropogenic resources, including products and materials, would satisfy these needs and interests. More than 2000 online research data repositories already exist, most of them discipline-specific [55]. To our knowledge, the Industrial Ecology Commons Prototype [53] is the only data repository that uses a systematic architecture for composition data on anthropogenic resources. The IECP is a community driven database with machine-readable data on anthropogenic material stocks, flows and process descriptions. The data are publicly accessible and have been retrieved from the literature.

Next to data repositories are research-driven information portals. For instance, the Urban Mine Platform (UMP) [41] was created from the large amount of composition data collected and harmonized in the ProSUM project. The UMP displays data on the stocks and flows of electrical and electronic products, batteries and passenger cars in European countries, including the materials contained in these products.

3.5 Implementing quality assurance systems

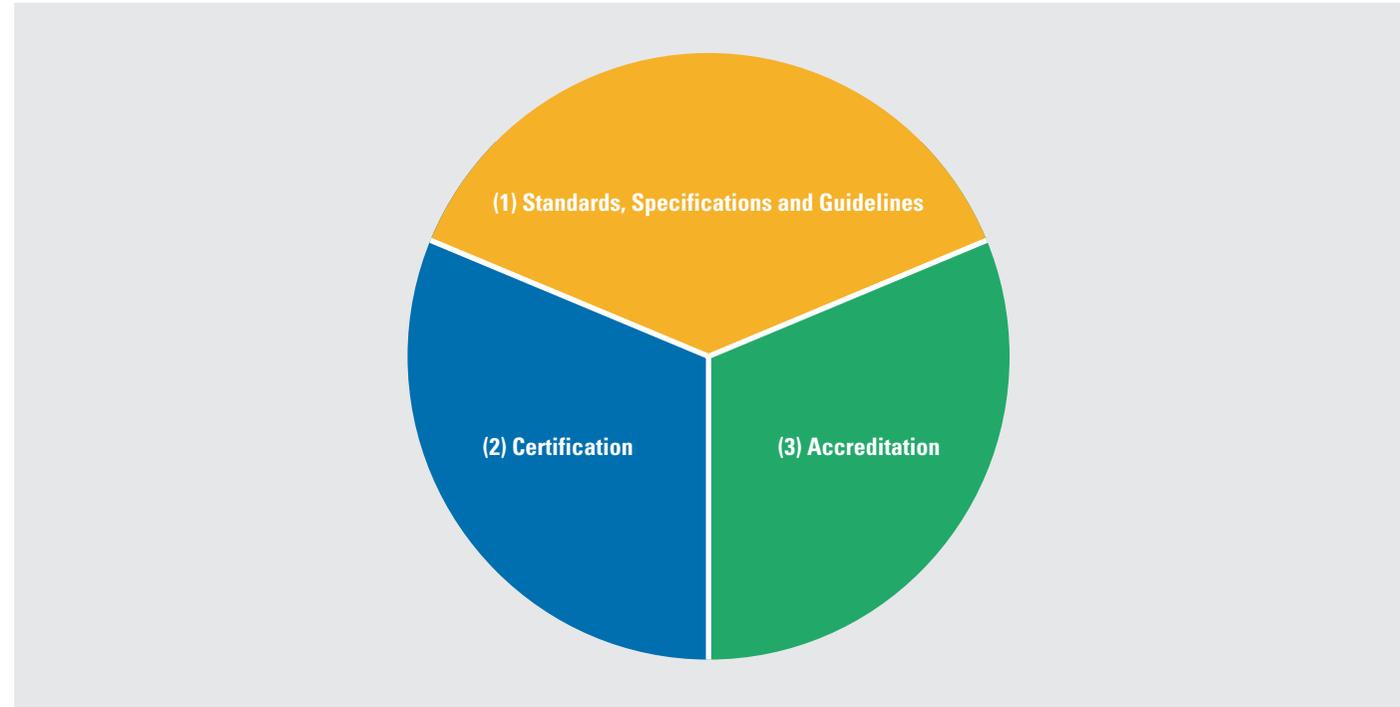
3.5.1 Status

Credibility and trust are key prerequisites for a successful dissemination and application of evidence-based anthropogenic resource assessment, classification and reporting. One way of achieving this is to implement a quality assurance system consisting of at least the following three elements: (1) specifications, guidelines, standards, (2) third party certifications of conformance, and (3) accreditations, i.e. a formal recognition by an authoritative body.

The mining sector has already introduced a quality assurance system to generate and report reliable classification data for investors and national authorities. Experts certified as Competent Persons² use reporting templates, standards and codes to report the data for mineral deposits and extractive industry residues. For post-consumer residues, an analogous quality assurance system is still needed. Such a quality assurance system is a prerequisite for generating reliable, comparable and transparent data that can be communicated on platforms such as the JRC RMIS and to users such as stock exchange markets, national governments and the European Union. Overall, it is accepted that the UNFC can serve as a framework for quality-assured data on recoverable quantities. This information is needed to acquire investments to develop the material recovery projects as well as to inform resource planning authorities on the future availability of raw materials. Such information is essential for setting boundary conditions that help industry and nations to ensure the future raw material supply.

In the following, we introduce three key elements of a quality assurance system (FIGURE 9).

FIGURE 9 >
Quality assurance system with the 'tripartite standards regime' (TSR), including standards setting, certification and accreditation, according to Loconto *et al.* [56].



(1) Specifications, Guidelines, Standards: Specifications set out requirements needed to describe recovery projects and to assess and classify resources. They include definitions of terms and descriptions of principles and rules. **Guidelines** provide explanations of how to apply the rules or principles, and recommend best practice for performing resource assessment and classification. According to ISO [57]. **Standards** are documents established by consensus and approved by a recognised body that provides, for common and repeated use, rules, guidelines or characterisation for activities or their results, aimed at the achievement of an optimum degree of order in a given context. Public standards are issued by national standardization organization such as the French Standardization Association (AFNOR), the British Standards Institute (BSI), the German Institute for Standardization (DIN), and are often based on international standards issued, for example, by the International Organization for Standardization (ISO), the European Committee for Electro-technical Standardization (CENELEC) or the European Committee for Standardization (CEN).

In areas where the ISO does not have existing technical structures or experts, it provides a workshop mechanism allowing market players to respond more rapidly to requirements for standardization. The outcome of this process is an International Workshop Agreement (IWA), which includes an indication of the participating organizations involved in its development and has a maximum lifespan of six years, after which it either can be transformed into another ISO deliverable or is automatically withdrawn.

(2) Certification: Whereas informal standards are generally maintained through social interaction, formal standards usually require a governing authority which includes: (1) processes for certifying compliance, (2) processes for accrediting the certifiers, and (3) relatively clear sanctions for violation. Accordingly, these formal standards are intimately involved in what Loconto et al. [58] termed a 'tripartite standards regime' (TSR), i.e., a regime that includes standards setting, accreditation, and certification (see [FIGURE 9](#)). Technical professionals commonly refer to these processes, which in practice pervade and integrate public and private spheres both within and across nations, as "conformity assessment".

(3) Accreditation: In many economic sectors, objective tests, calibrations, inspections or certifications are required to guarantee the quality requirements of goods and services and to meet all legislative requirements. According to the United Kingdom Accreditation Service, "accreditation is the formal recognition by an authoritative body of the competence to work to specified standards." The result of accreditation is usually the issuance of a status, recognition or licence for the activity within a time-limited period of validity.

3.5.2 Recommended actions

The review of case studies revealed that the authors used different approaches to assess and classify the case studies and that therefore these examples cannot be compared. Quality assurance instruments can strongly support the classification process as well as the dissemination and application of estimates on anthropogenic resource.

As an outcome of the discussions held within the COST MINEA WG 4, we recommend the following action as part of the quality assurance system:

- Action 7: Development of methods for estimating and reporting recoverable quantities
- Action 8: Certification of people and institutions
- Action 9: Certification of raw material supply chains

Action 7: Development of methods for estimating and reporting recoverable quantities. In general, we recommend the development and use of Specifications, Standards and Guidelines to support the reliable assessment of anthropogenic resource availability, with an emphasis on appropriate consideration of economic, environmental and social impacts. First, we suggest development of an internationally agreed procedure for harmonized anthropogenic resource assessment that allows comparison and aggregation of recovery projects and that supports its adoption by end-users (Section 3.4.2). Second, we suggest focusing on further development of the individual steps of resource availability assessments and development and use of either generic or resource-specific Specifications, Standards and Guidelines. These documents should be used to develop cases studies for application of the UNFC. We are fully aware that the range of standardization efforts is very broad and includes a lot of aspects that can and should be standardized. It is beyond the scope of this report to give a full picture of the quality assurance needs, but we give some examples in [TABLE 2](#).

TABLE 2
Examples of Specifications, Standards and Guidelines needed for estimating and reporting recoverable quantities.

Step	Description and examples												
Characterization	<ul style="list-style-type: none"> Methodologies for sampling, sample preparation and analysis of residues [e.g. 59, 60, 61]. Best-practices for data collection (e.g. network approach to collect data from MSWI plants across Europe) 												
Evaluation	<p>In order to evaluate the recoverability of resources, contingencies that potentially affect the recoverability (briefly called factors, see also [47]) have to be defined and assessed. We suggest compliance with guidelines, specifications and standards as relevant factors to assess the environmental-socio-economic dimension (UNFC E-axis) for classifying resources. Examples of existing or currently-being-developed guidelines, specifications and standards as well as certification schemes are:</p> <ul style="list-style-type: none"> Standards on WEEE treatment [62]. See also Appendix A: Quality assurance OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas [63], Conflict mineral ordinance [64]. Certification scheme for raw material value chains [65] <p>Should it not be possible to retrieve certificates, we suggest defining the factors based on the identification of stakeholders and their needs. A practical example for landfill mining is given by Einhäupl <i>et al.</i> [66] or for bottom-ash from MSWI by Mueller <i>et al.</i> [67]. The assessment of the factors should follow, if available and practicable, standardized methods. For instance:</p>												
	<table border="1"> <thead> <tr> <th><i>Factors (examples)</i></th> <th><i>Methods (examples)</i></th> </tr> </thead> <tbody> <tr> <td>Environmental impacts</td> <td>Life Cycle Assessment [68] Environmental Risk Assessment</td> </tr> <tr> <td>Economic performance</td> <td>Cost & Benefits Analysis</td> </tr> <tr> <td>Maturity of recovery technologies</td> <td>Technology Readiness Level [69]</td> </tr> <tr> <td>Social acceptance</td> <td>Public opinion polls [c.f. 70, 71, 72]</td> </tr> <tr> <td>Utilization of raw materials</td> <td> <ul style="list-style-type: none"> Limit values for the utilization of recycled C&D wastes in Austria [73, 74] Positive list of the cement industry. National situation in Germany, Switzerland and Austria [74] Legal situation for bottom-ash utilization in Europe [75] </td> </tr> </tbody> </table>	<i>Factors (examples)</i>	<i>Methods (examples)</i>	Environmental impacts	Life Cycle Assessment [68] Environmental Risk Assessment	Economic performance	Cost & Benefits Analysis	Maturity of recovery technologies	Technology Readiness Level [69]	Social acceptance	Public opinion polls [c.f. 70, 71, 72]	Utilization of raw materials	<ul style="list-style-type: none"> Limit values for the utilization of recycled C&D wastes in Austria [73, 74] Positive list of the cement industry. National situation in Germany, Switzerland and Austria [74] Legal situation for bottom-ash utilization in Europe [75]
	<i>Factors (examples)</i>	<i>Methods (examples)</i>											
	Environmental impacts	Life Cycle Assessment [68] Environmental Risk Assessment											
	Economic performance	Cost & Benefits Analysis											
	Maturity of recovery technologies	Technology Readiness Level [69]											
Social acceptance	Public opinion polls [c.f. 70, 71, 72]												
Utilization of raw materials	<ul style="list-style-type: none"> Limit values for the utilization of recycled C&D wastes in Austria [73, 74] Positive list of the cement industry. National situation in Germany, Switzerland and Austria [74] Legal situation for bottom-ash utilization in Europe [75] 												
Classification	<ul style="list-style-type: none"> Providing guidance for linking the characterization and evaluation results to UNFC. Examples are: <ul style="list-style-type: none"> Resource-specific guidelines to use multi-criteria assessments for selecting E-Axis categories based on multiple environmental-socio-economic factors [c.f. 48], which, for instance, allow weighting factors based on stakeholder preferences to be considered. It is noted that the UNECE Expert Group on Resource Management also provides guidance for taking environmental-socio-economic factors into account [39, 47]. Resource-specific guidelines for commodity-specific definition of the “level of confidence” (G-Axis) Resource-specific guidelines for determining the technical feasibility of recovery (F-Axis) UNFC guidance documents for comparing and summarizing UNFC data, which have been generated in individual site-specific project estimates. To bridge and map from CRIRSCO to UNFC [37]. UNFC [38], Commodity Specifications [35], Guidelines for various UNFC aspects [76] 												
Reporting	<p>Existing reporting templates, standards and codes are not based on UNFC [45]. We suggest following the UNECE guidance [77] and developing a UNFC compliant reporting template, which is accepted by and agreed upon by all stakeholders (stock exchange, national governments, European Union). A standardized format is used as an interface to inform users about the recoverable materials in a reliable, unambiguous and organized fashion. It includes a common agreement on standard definitions, rules and codes. Transparency and competence are underlying principles for technical and public reporting. Therefore, preparation of such reports requires expertise and the confirmation of credibility by a certified expert (see TABLE 3).</p>												

It is noted that (i) a guideline for assessing landfill mining projects has been proposed by Winterstetter *et al.* [78], (ii) Quina *et al.* [79] regard the application of the UNFC to residues from MSWI as a “promising approach” and detail current knowledge level and gaps, and (iii) a MINEA WG4 subgroup submitted the ITN proposal DIRECTIONS4CE in January 2020, which aims to develop the scientific fundamentals for such standards.

Action 8: Certification of people and institutions. We suggest certifying experts in anthropogenic resource reporting in analogy to Competent Persons for natural resources², who would use accredited laboratories for the characterization and issuing of certificates for the residues tested (TABLE 3).

TABLE 3
People and institutions subject to certification and accreditation.

Topic	Certified subjects	Accreditation
Resource Reporting	<p>We recommend the certification of experts responsible for the reporting of resource estimates. Such experts perform the assessment and classification of anthropogenic resources and preparing and/or signing public reports. The suitability of these persons should be institutionally guaranteed. This requires compliance with specific education and training, sufficient professional experience and relevant codes of ethics and conduct.</p> <p>It is noted that the UNECE provides Guidance Notes to support the UNFC Specification for Evaluator Qualifications [52].</p>	Accreditation institutions (e.g. European Federation of Geologists)
Resource assessment – characterization	Whenever meaningful, the testing, characterisation and certification of residues should be carried out by accredited laboratories and companies (i.e. compliance assessment bodies or accredited certification bodies).	National accreditation institutions (e.g. DAkkS in Germany [80])

Action 9: Certification of raw material supply chains. Raw materials and raw material supply chains should be subject to certification in order to build trust among sellers and buyers of raw materials [81]. We suggest that schemes such as CERA [65] require the UNFC data as an additional criterion or source of information to certify raw material value chains.

3.6 Establishing supporting networks & structures

3.6.1 Status

In contrast to mineral resources, estimates of anthropogenic resource availability are not typically compiled, and thus not used in policy making. There is neither a publicly accessible inventory for anthropogenic resources and their recovery potentials, nor a governance structure in place to generate such data. We feel that there is a need for a bottom-up approach to generate the data and to govern the data management and communication on national and supranational levels.

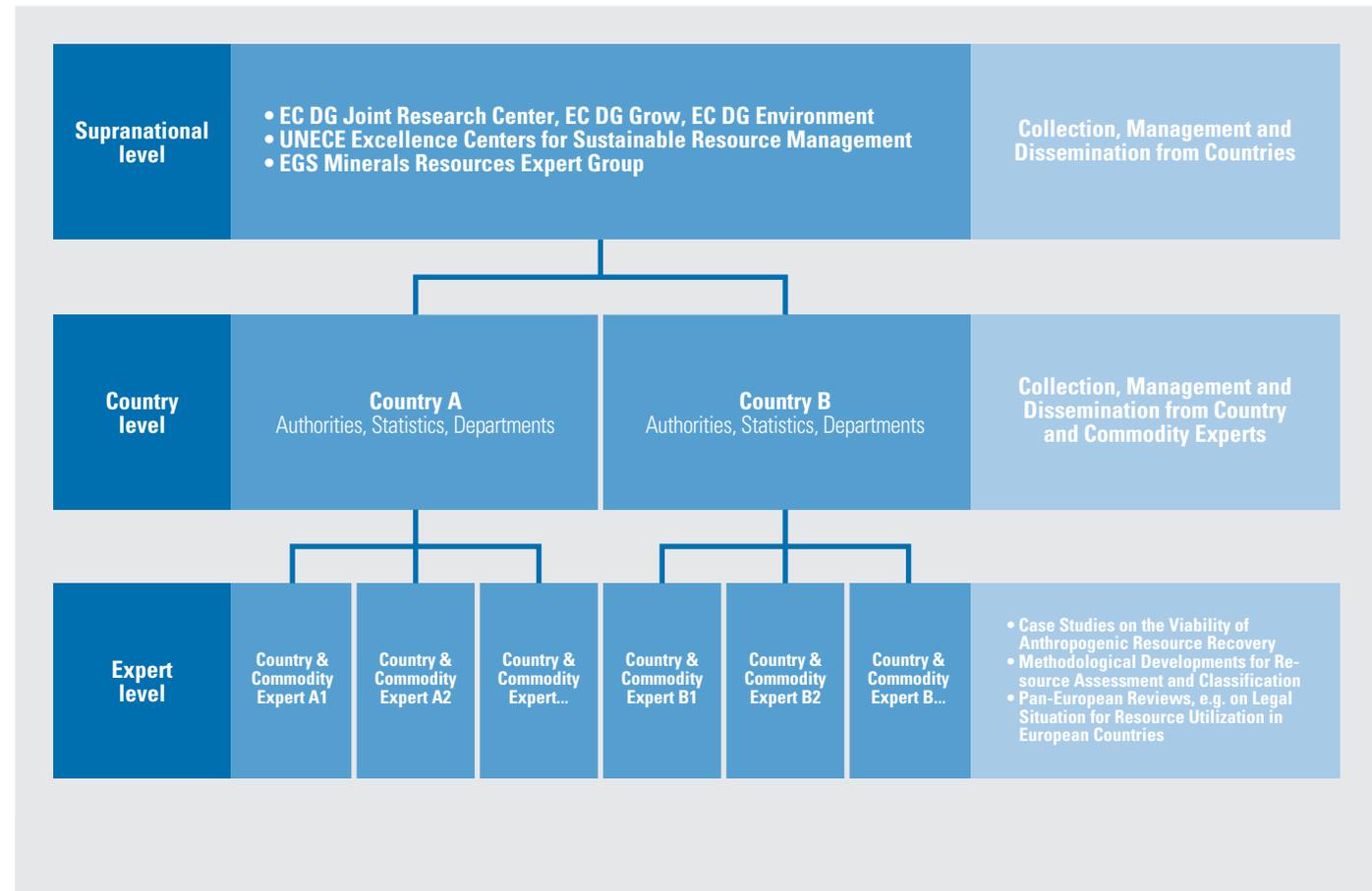
3.6.2 Recommended actions

We recommend the following actions:

- Action 10: Establishment of a European Network of Excellence
- Action 11: Establishment of Regional Centers for Sustainable Resource Management

Action 10: Establishment of a European Network of Excellence. To report the viability of anthropogenic resource recovery to resource policy makers, we propose formalizing and institutionalizing pan-European collaboration, inspired by US Geological Survey (USGS) practices and the proposal from Lederer *et al.* [82] on a network structure for the generation and publishing of resource inventory data. In short, under the governance of a supranational institution, the European member countries should collect and manage knowledge that has been generated by an individual country and commodity experts. The proposed network structure is shown in **FIGURE 10**.

FIGURE 10
Proposed governance structure and tasks. The figure has been adopted from Lederer *et al.* [82].



The **country and commodity experts** are highly experienced in resource assessment and classification. The experts or expert teams are specialized in the sampling and analysis of residues, the evaluation of technical recoverability and sustainability assessments. They are familiar with the UNFC and report the UNFC data to the country level. They also develop new methods for resource assessment and classification, and support their standardization. The **individual countries** are responsible to collect, manage and disseminate the information to the supranational level, and support the country and commodity experts by offering training and financial support connected with their work. On the **supranational level**, the (for example) EC Joint Research Centre compiles the country and commodity specific information and publishes the UNFC data via the RMIS, implements measures for quality assurance, and provides evidence-based assistance to resource policy makers. The JRC also incorporates the latest updates on the UNRMS and UNFC from the UNECE Expert Group of Resource Management and the UNECE Excellence Centers for Sustainable Resource Management.

Action 11: Establishment of Regional Centers for Sustainable Resource Management. Raw materials are critically important for implementing the 2030 Agenda for sustainable development. While it is widely recognized that closing resource loops by recovering raw materials from anthropogenic resources is essential for future raw material security [83], there is (i) a general lack of tools and knowledge to inform and direct circular economy and resource efficiency strategies, and (ii) a big gap between international standardization efforts and national data collection and harmonization workflows.

Regional Centers can address the following challenges:

- The provision of guidelines for resource evaluators on how to appraise the availability of anthropogenic resources and the future production potential of raw materials from recovery projects.
- The harmonization of data collection procedures, resource assessment, classification and reporting to make resource/reserve estimates for primary mineral resources [84] compatible with resource/reserve estimates for anthropogenic resources such as mining waste [85] or Waste Electrical and Electronic Equipment (WEEE) [86] in order to promote reporting according to UNFC.
- The site-specific and regional knowledge needs with respect to data quantity, quality and location of resources, as well as the details on the contextual boundary conditions for converting potentially extractable anthropogenic resources into (secondary) raw materials (MINEA Deliverable 2) [87].
- Bringing together local and regional stakeholders to pool required information for making reliable and comparable estimates.

We thus suggest establishing Regional Centers for Sustainable Resource Management (RC-SRM) as cross-sectoral knowledge hubs to pool and consolidate expertise on a regional level. RC-SRMs can strengthen national priorities and development ambitions by, (a) collecting and consolidating relevant regional stakeholder competencies under a common umbrella with an international mandate, (b) leveraging domestically funded expertise for standardization efforts, (c) linking fragmented local knowledge with the international context, and d) supporting countries to promote sustainable anthropogenic resource management.

We suggest that the primary focus of RC-SRMs is on involving resource policy makers, geological surveys, research institutions, industry, and companies to support countries in achieving the following main objectives:

- Enhancement of integrated resource management through the application of a UNFC tailored to national or regional needs and priorities [c.f. 26].
- Promotion of the harmonization between national standards, international reporting codes such as those outlined by the International Council on Mining and Metals (ICMM) and by the UNFC.
- Provision of methods, data and tools for both natural and anthropogenic resource assessment, classification and reporting to facilitate sustainable resource management.
- Application of the UNFC to anthropogenic resource case studies (Section 3.2).
- Development of guidelines for (i) defining the recovery project in cooperation with private-public stakeholders, (ii) characterizing specific types of anthropogenic resources, (iii) evaluating recoverability of anthropogenic resources, and (iv) applying the UNFC to anthropogenic resources (Section 3.6.2).
- Provision of training for the application of the UNFC through workshops and training schools.
- Assistance in establishing a quality assurance system for resource estimates (Section 3.5).
- Coordination of a country/commodity expert network (Action 10).

The establishment of regional centers for sustainable resource management has the advantage that these centers can act as intermediaries between the global initiatives and country-specific needs defined by domestic policy and legislation.

4 CONCLUSIONS AND OUTLOOK

Responsible governance of the material resources required for human health and well-being is essential for the achievement of sustainable consumption and production (SDG12). Extraction of natural resources and utilization of residues can be optimized to achieve the SDGs, but we need to develop systems to enable sustainable practice. The systems we currently use to manage natural resources are entirely different from those used to manage anthropogenic resources derived from wastes; security of supply and economic profitability are the focus of the former while prevention of harmful impacts on human health and the environment are the focus of the latter. Anthropogenic resources are consequently negatively perceived by key stakeholders, including developers, investors, government regulators and planners, to their disadvantage in the marketplace. This report by COST Action MINEA Working Group 4 on Anthropogenic Resource Classification develops a Strategic Roadmap to realize the vision (Desired End Point) of a sustainable management of anthropogenic resources established on a common footing with natural resources. The Strategic Roadmap traverses a landscape in which a number of supportive elements already exist, including, firstly, the Circular Economy Package of the European Commission, which has led to the development of a Raw Materials Information System (RMIS) [14] through the Circular Economy Action Plan [4] and, secondly, a considerable number of research projects funded by the Horizon 2020 programme, which have collected relevant data about anthropogenic resources. The recommendations associated with the Strategic Roadmap can be linked to the planned development of the United Nations Framework Classification for Resources (UNFC) to form the core of a new globally relevant United Nations Resource Management System (UNRMS). The UNFC was developed as a consistent and transparent framework for the reporting of information about natural mineral resource exploitation projects to investors. Through the work of MINEA WG4, it has been extended to include *Specifications for the application of the UNFC to Anthropogenic Resources* [35]. This represents a first step in enabling development of anthropogenic resources, with the Strategic Roadmap providing guidance for the next steps:

Development of case studies to demonstrate the UNFC and to test its applicability to a wide variety of anthropogenic resources, with feedback for further development of the UNFC and UNRMS to address a wide range of materials and enable application of its principles to assessment and classification of resource recovery potentials at regional scales, as well as for individual projects;

- Harmonisation of resource assessment, classification and reporting;
- Development of information systems for standardized collection of resource assessment and classification data, and for consistent and transparent reporting to end-users;
- Implementation of quality assurance systems, including: development of standard specifications, methods and guidelines for resource assessment; classification and reporting, with an emphasis on appropriate consideration of economic, environmental and social impacts; certification of experts to apply these standards; accreditation of institutions to certify these experts; certification of raw material supply chains, and
- Establishment of supporting institutions in the form a European Network of Excellence for the Sustainable Management of Anthropogenic Resources, and Regional Centers for Sustainable Resource Management.

It is essential that following the Strategic Roadmap involve stakeholders from all sectors to ensure that all perspectives are represented in the development of a robust sustainable anthropogenic resource management system.

LITERATURE

1. Risch, B.W.K. (1978). *The raw material supply of the European Community: The importance of secondary raw materials*. Resources Policy. 4(3): p. 181-188. DOI: [https://doi.org/10.1016/0301-4207\(78\)90045-4](https://doi.org/10.1016/0301-4207(78)90045-4)
2. Krausmann, F., D. Wiedenhofer, C. Lauk, W. Haas, H. Tanikawa, T. Fishman, A. Miatto, H. Schandl, and H. Haberl (2017). *Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use*. Proceedings of the National Academy of Sciences. 114(8): p. 1880-1885. DOI: <https://doi.org/10.1073/pnas.1613773114>
3. EC (2011). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Roadmap to a Resource Efficient Europe*. COM(2011) 571 European Commission (EC).
4. EC (2019). Report on the implementation of the Circular Economy Action Plan. European Commission (EC): Brussels. online: https://ec.europa.eu/commission/sites/beta-political/files/report_implementation_circular_economy_action_plan.pdf
5. Schrijvers, D., A. Hool, G.A. Blengini, W.-Q. Chen, J. Dewulf, R. Eggert, L. van Ellen, R. Gauss, J. Goddin, K. Habib, C. Hagelüken, A. Hirohata, M. Hofmann-Antenbrink, J. Kosmol, M. Le Gleuher, M. Grohol, A. Ku, M.-H. Lee, G. Liu, K. Nansai, P. Nuss, D. Peck, A. Reller, G. Sonnemann, L. Tercero, A. Thorenz, and P.A. Wäger (2020). *A review of methods and data to determine raw material criticality*. Resources, Conservation and Recycling. 155: p. 104617. DOI: <https://doi.org/10.1016/j.resconrec.2019.104617>
6. Jamasmie, C. (2019). *Recycled lithium batteries market to hit \$6 billion by 2030 - report*. online: <https://www.mining.com> (Access: 5 Feb 2020)
7. PACE (2019). *The Circularity Gap Report 2019: Closing the Circularity Gap in a 9% World*. online: <https://www.legacy.circularity-gap.world/2019>
8. UN (2015). *Transforming our world: the 2030 Agenda for Sustainable Development* United Nations (UN). online: http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E (Access: 20 May 2018)
9. Krook, J., P. Cleall, R. Rosendal, and T. Carvalho (2018). Recovery technologies for waste in landfills. MINEA Deliverable. Mining the European Anthroposphere (MINEA). online: <https://doi.org/10.5281/zenodo.3768961> (Access: 30 April 2020)
10. Saez, P., M. Osmani, and P. Vitale (2018). Recovery technologies for construction and demolition waste. Mining the European Anthroposphere (MINEA). online: <https://doi.org/10.5281/zenodo.3760465> (Access: 30 April 2020).
11. Leder, J., M. Syc, L. Biganzoli, A. Bogush, E. Bontempi, R. Braga, G. Costa, V. Funari, M. Grosso, J. Hyks, P. Kameníková, M. Quina, E. Rasmussen, S. Schlumberger, F.-G. Simon, and G. Weibel (2018). Recovery technologies for waste incineration residues (MINEA Deliverable). Mining the European Anthroposphere (MINEA). online: <http://www.minea-network.eu/upload/D31Report.pdf> (Access: 10 September 2019)
12. Blasenbauer, D., A. Bogush, T. Carvalho, P. Cleall, C. Cormio, D. Guglietta, J. Fellner, M. Fernández-Alonso, S. Heuss-Aßbichler, F. Huber, U. Kral, M. Kriipsalu, J. Krook, D. Laner, J. Lederer, B. Lemièrre, G. Liu, R. Mao, S. Mueller, M. Quina, D. Sinnett, J. Stegemann, M. Syc, K. Szabó, T.T. Werner, E. Wille, A. Winterstetter, and G. Žibret (2020). Knowledge base to facilitate anthropogenic resource assessment (MINEA Deliverable). COST Action Mining the European Anthroposphere (MINEA). online: <https://doi.org/10.5281/zenodo.3739164>
13. EC (2020). *Circular economy*. online: https://ec.europa.eu/growth/industry/sustainability/circular-economy_en (Access: 24 March 2020)
14. European Commission (2018). *European Raw Material Information System (RMIS)*. online: <http://rmis.jrc.ec.europa.eu/> (Access: 29 Mai 2018)
15. Minerals4EU (2020). *Minerals Intelligence Network for Europe (EU Project)*. online: <http://www.minerals4eu.eu/> (Access: 24 March 2020)
16. ProSUM (2020). *PROSUM (EU Project)*. online: <http://www.prosumproject.eu/>

17. MICA (2018). *Mineral intelligence Capacity Analysis (MICA)*. EU Project. online: <http://www.mica-project.eu/> (Access: 24 March 2020)
18. SNAP-SEE (2013). *Sustainable Aggregates Planning in South East Europe (SNAP-SEE)*. Project. online: <http://www.snapsee.eu>
19. ORAMA (2020). *Optimising data collection for Primary and Secondary Raw Materials (ORAMA)*. Project. online: <https://orama-h2020.eu/> (Access: 24 March 2020)
20. Wagner, M., T. Bide, D. Cassard, J. Huisman, P. Leroy, S. Bavec, M. Ljunggren-Söderma, A. Løvik, P. Wäger, J. Emmerich, K. Sperlich, C.P. Baldé, F. Schjøth, J. Tivander, T. Brown, E. Petavratzi, F.T. Whitehead, P. Mähltz, V. Nikolova, and Z. Horváth (2019). Optimising quality of information in RAW MATERIALS data collection across Europe (ORAMA). Technical Final Report & Recommendations. Brussels, Belgium.
21. EC (2019). The European Green Deal (COM/2019/640 final). 11 December 2019. European Commission (EC): Brussels, Belgium. online: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:640:FIN> (Access: 24 March 2020)
22. EC (2018). Action Plan: Financing Sustainable Growth (COM/2018/097 final). 8 March 2018. European Commission (EC): Brussels, Belgium. online: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0097> (Access: 20 March 2020)
23. WEF (2019). Seeking Return on ESG: Advancing the Reporting Ecosystem to Unlock Impact for Business and Society. World Economic Forum (WEF): Cologny, Geneva. online: http://www3.weforum.org/docs/WEF_ESG_Report_digital_pages.pdf (Access: 20 March 2020)
24. EU (2008). *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives*.
25. Henley, S. (2017). *CRIRSCO and UNFC*. online: <https://eurogeologists.eu/wp-content/uploads/2017/07/CRIRSCO-and-UNFC-2013.pdf> (Access: 20 March 2020)
26. EGRM (2020). *United Nations Resource Management System Concept Note: Objectives, requirements, outline and way forward*.
27. U.S. Geological Survey (2011). Mineral commodity summaries 2011. online: <http://minerals.usgs.gov/minerals/pubs/mcs/2011/mcs2011.pdf>
28. USGS (1980). Principles of a resource/reserve classification for minerals.
29. Cheng, K.L., S.C. Hsu, C.C.W. Hung, P.C. Chen, and H.W. Ma (2019). A hybrid material flow analysis for quantifying multilevel anthropogenic resources. *Journal of Industrial Ecology*. 0(0). DOI: <https://doi.org/10.1111/jiec.12940>
30. Winterstetter, A. (2016). *Mines of Tomorrow. Evaluating and Classifying Anthropogenic Resources: A New Methodology*, Phd Thesis. Technische Universität Wien: Vienna.
31. Lederer, J., D. Laner, and J. Fellner (2014). A framework for the evaluation of anthropogenic resources: the case study of phosphorus stocks in Austria. *Journal of Cleaner Production*. 84(0): p. 368-381. DOI: <https://doi.org/10.1016/j.jclepro.2014.05.078>
32. Lederer, J., F. Kleemann, M. Ossberger, H. Rechberger, and J. Fellner (2016). *Prospecting and Exploring Anthropogenic Resource Deposits The Case Study of Vienna's Subway Network*. *Journal of Industrial Ecology*. 20(6): p. 1320-1333. DOI: <https://doi.org/10.1111/jiec.12395>
33. Habib, K. (2019). A product classification approach to optimize circularity of critical resources - the case of NdFeB magnets. *Journal of Cleaner Production*. 230: p. 90-97. DOI: <https://doi.org/10.1016/j.jclepro.2019.05.048>
34. Schiller, G., K. Gruhler, and R. Ortlepp *Continuous Material Flow Analysis Approach for Bulk Nonmetallic Mineral Building Materials Applied to the German Building Sector*. *Journal of Industrial Ecology*. p. n/a-n/a. DOI: <https://doi.org/10.1111/jiec.12595>
35. Heiberg, S., S. Heuss-Aßbichler, J. Hilton, Z. Horváth, U. Kral, J. Krook, D. Laner, F. Müller, S. Mueller, O. Mohamed, J. Stegemann, P. Wäger, A. Winterstetter, and D. Wittmer (2018). Specifications to apply the UNFC to Anthropogenic Resources. United Nations Economic Commission for Europe (UNECE): Geneva. online: <https://doi.org/10.5281/zenodo.3759026>

36. Delgado-Sancho, L., A.S. Catarino, P. Eder, D. Litten, Z. Luo, and A. Villanueva-Krzyzaniak (2009). *End-of-Waste Criteria*, in *EUR - Scientific and Technical Research Reports*. European Commission (EC); Brussels, Belgium.
37. UNECE (2015). Bridging document between the CRIRSCO Template and the UNFC-2009. United Nations Economic Commission for Europe (UNECE). online: https://www.unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/UNFC_specs/Revised_CRIRSCO_Template_UNFC_Bridging_Document.pdf (Access: 30 March 2020)
38. UNECE (2020). United Nations Classification for Resources: Update 2019. United Nations Economic Commission for Europe (UNECE): Geneva.
39. UNECE (2018). Accommodating Social and Environmental Considerations in UNFC: Concepts and Terminology (ECE/ENERGY/GE.3/2018/4). United Nations Economic Commission for Europe (UNECE): Geneva. online: https://www.unece.org/fileadmin/DAM/energy/se/pp/unfc_egrc/egrc9_apr2018/ece.energy.ge.3.2018.4_e.pdf (Access: 30 March 2020)
40. Fabrizio, P., L. Ciacci, P. Nuss, and S. Manfredi (2018). Material flow analysis of aluminium, copper, and iron in the EU-28. *EUR - Scientific and Technical Research Reports*. Publications Office of the European Union: Brussels, Belgium. online: <http://publications.jrc.ec.europa.eu/repository/handle/JRC111643> (Access: 30 March 2020)
41. Huisman, J., P. Leroy, F. Tertre, M. Söderman, P. Chancerel, D. Cassard, A.N. Løvik, P. Wäger, D. Kushnir, V.S. Rotter, P. Mährlitz, L. Herreras, J. Emmerich, A. Hallberg, H. Habib, M. Wagner, and S. Downes (2018). *Urban Mine Platform*. online: <http://www.urbanmineplatform.eu> (Access: 2 June 2018)
42. European Commission (2015). *Minerals Intelligence Network for Europe (Minerals4EU)*. online: <https://cordis.europa.eu/project/rcn/109373/factsheet/en> (Access: 30 March 2020)
43. Minerals4eu (2018). *European Minerals Yearbook*. online: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html (Access: 20 May 2018)
44. Blystad, P. (2015). *Mapping and Bridging to UNFC-2009*. UNFC National Workshop to Cuba, 7-9 December 2015, Havan, Cuba. online: https://www.unece.org/fileadmin/DAM/energy/se/pp/unfc/ws_unfc_Cuba_Dec.2015/10_Mapping_and_Bridging_to_UNFC__P_Blystad.pdf
45. Henley, S. (2015). *Reporting standards, codes, templates, and classifications: conversion, bridging, and mapping*. *European Geologist*. 39: p. 40-42.
46. USGS (1995). 1995 National Assessment of United States Oil and Gas Resources (U.S. Geological Survey Circular 1118). U.S. Geological Survey: Washington.
47. UNECE (2018). Draft guidance for accommodating environmental and social considerations in UNFC (ECE/ENERGY/GE.3/2018/3). United Nations Economic Commission for Europe (UNECE): Geneva. online: https://www.unece.org/fileadmin/DAM/energy/se/pp/unfc_egrc/egrc9_apr2018/ece.energy.ge.3.2018.4_e.pdf (Access: 10 April 2020)
48. Department for Communities and Local Government (2009). *Multi-criteria analysis: a manual*. Communities and Local Government Publications: Wetherby, West Yorkshire, GB.
49. Hyndman, R.J. and G. Athanasopoulos (2018). *Forecasting: principles and practice*. online: <https://otexts.com/fpp2/> (Access: 13 March 2020)
50. Fellner, J., J. Lederer, A. Purgar, A. Winterstetter, H. Rechberger, F. Winter, and D. Laner (2015). *Evaluation of resource recovery from waste incineration residues - The case of zinc*. *Waste Manag.* 37: p. 95-103. DOI: <https://doi.org/10.1016/j.wasman.2014.10.010>
51. Geoscience Australia (2020). *Australia's Identified Mineral Resources 2019*. online: <http://www.ga.gov.au/> (Access: 12 April 2020)
52. UNECE (2017). *Guidance Note to support the United Nations Framework Classification for Resources Specification for Evaluator Qualifications*. United Nations Economic Commission for Europe (UNECE): Geneva, Switzerland. online: https://www.unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/UNFC-Guidance-Notes/Revised_UNFC_Guidance_Note_to_support_UNFC_Specification_for_Evaluator_Qualifications.pdf (Access: 30 March 2020)

53. Pauliuk, S. (2020). *Industrial Ecology Data Commons prototype (IEDC)*. online: <http://www.database.industrialecology.uni-freiburg.de/> (Access: 30 March 2020)
54. Pauliuk, S. (2017). *Task force on data transparency*. online: <https://is4ie.org/announcements/48> (Access: 30 March 2020)
55. re3data.org (2020). *Registry of research data repositories*. online: <https://www.re3data.org> (Access: 30 March 2020)
56. Loconto, A. and L. Busch (2010). *Standards, techno-economic networks, and playing fields: Performing the global market economy*. Review of International Political Economy. 17(3): p. 507-536. DOI: <https://doi.org/10.1080/09692290903319870>
57. ISO (2020). *Standards in our world*. online: https://www.iso.org/sites/ConsumersStandards/1_standards.html (Access: 12 April 2020)
58. Loconto, A., J.V. Stone, and L. Busch (2012). *Tripartite Standards Regime, in The Wiley-Blackwell Encyclopedia of Globalization*, G. Ritzer, Editor.
59. Skutan, S., R. Gloor, and L. Morf (2014). Sampling, sample preparation and analysis of solid residues from thermal waste treatment and its processing products. Development center for sustainable management of recyclable waste and resources (ZAR): Zürich.
60. ASTM (2015). *Standard Practice for Sampling Waste Streams on Conveyors (ASTM D7204-15)*. ASTM International: West Conshohocken, PA.
61. BSI (2006). *Characterization of waste. Sampling of waste materials. Framework for the preparation and application of a sampling plan (BS EN 14899:2005)*. British Standards Institution (BSI).
62. CENELEC (2020). *European Standards for Waste Electrical and Electronic Equipment (WEEE)*. Brussels, Belgium. online: <https://www.cenelec.eu/news/publications/publications/weee-brochure.pdf> (Access: 30 March 2020)
63. OECD (2016). *OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas: Third Edition*. O. Publishing: Paris. online: <http://dx.doi.org/10.1787/9789264252479-en>
64. EU (2017). *Regulation (EU) 2017/821 of the European Parliament and of the Council of 17 May 2017 laying down supply chain due diligence obligations for Union importers of tin, tantalum and tungsten, their ores, and gold originating from conflict-affected and high-risk areas*. Publications Office of the European Union: Luxembourg.
65. CERA (2020). *The Certification of raw materials (CERA: EU Project)*. online: <https://www.cera-standard.org> (Access: 30 March 2020)
66. Einhäupl, P., J. Krook, N. Svensson, K. Van Acker, and S. Van Passel (2019). *Eliciting stakeholder needs – An anticipatory approach assessing enhanced landfill mining*. Waste Management. 98: p. 113-125. DOI: <https://doi.org/10.1016/j.wasman.2019.08.009>
67. Mueller, S.R., U. Kral, and P.A. Wäger (2020). *Developing material recovery projects: Lessons learned from processing municipal solid waste incineration residues*. Journal of Cleaner Production. 259. DOI: <https://doi.org/10.1016/j.jclepro.2020.120490>
68. ISO (2006). *Environmental management – Life cycle assessment – Principles and framework (ISO 14040:2006)*.
69. EC (2014). *Horizon 2020 - Work programme 2014-2015, Annex G: Technology readiness levels (TRL)*. European Commission (EC), Brussels,.
70. Weisberg, H., J.A. Krosnick, and B.D. Bowen (1996). *An Introduction to Survey Research, Polling and Data Analysis*. Sage: Thousand Oak, London, New Delhi.
71. EC and TNS (2014). *Attitudes of Europeans towards Waste Management and Resource Efficiency. Flash Eurobarometer 388*. Publications Office of the European Union: Brussels. online: https://ec.europa.eu/comm-frontoffice/publicopinion/flash/fl_388_en.pdf
72. EURELCO (2019). *Public acceptance of mining and recycling in Europe: six recommendations*. online: <https://eurelco.org/2019/12/13/public-acceptance-of-mining-and-recycling-in-europe-six-recommendations/> (Access: 30 March 2020)

73. Republik Österreich (2015). *Verordnung des Bundesministers für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft über die Pflichten bei Bau- oder Abbruchtätigkeiten, die Trennung und die Behandlung von bei Bau- oder Abbruchtätigkeiten anfallenden Abfällen, die Herstellung und das Abfallende von Recycling-Baustoffen. (Recycling-Baustoffverordnung – RBV). StF: BGBl. II Nr. 181/2015*. Wien.
74. Hoenig, V., C. Seiler, N. Bodendiek, and H. Hoppe (2015). Einsatz alternativer Rohstoffe im Zementherstellungsprozess: Hintergrundwissen, technische Möglichkeiten und Handlungsempfehlungen. Verein Deutscher Zementwerke: Düsseldorf. online: https://www.zement.at/downloads/downloads_2016/Einsatz_alternativer_Rohstoffe_im_Zementherstellungsprozess.pdf (Access: 10 March 2020)
75. Blasenbauer, D., F. Huber, J. Lederer, M.J. Quina, D. Blanc-Biscarat, A. Bogush, E. Bontempi, J. Blondeau, J.M. Chimenos, H. Dahlbo, J. Fagerqvist, J. Giro-Paloma, O. Hjelm, J. Hyks, J. Keaney, M. Lupsea-Toader, C.J. O'Caollai, K. Orupöld, T. Pająk, F.-G. Simon, L. Svecova, M. Šyc, R. Ullvang, K. Vaajasaari, J. Van Caneghem, A. van Zomeren, S. Vasarevičius, K. Wégner, and J. Fellner (2020). *Legal situation and current practice of waste incineration bottom ash utilisation in Europe*. Waste Management. 102: p. 868-883. DOI: <https://doi.org/10.1016/j.wasman.2019.11.031>
76. UNECE (2016). Guidance Note to support the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009. Definition of a Project. United Nations Economic Commission for Europe (UNECE): Geneva. online: https://www.unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/UNFC-Guidance-Notes/UNFC.Project.Guidance.Note_15.07.2016.pdf
77. UNECE (2017). Guidance Note on Competent Person Requirements and Options for Resources Reporting. United Nations Economic Commission for Europe (UNECE). online: https://www.unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/UNFC-Guidance-Notes/Guidance_Note_on_Competent_Person_Requirements_and_Options_for_Resource_Reporting.pdf
78. Winterstetter, A., E. Wille, P. Nagels, and J. Fellner (2018). *Decision making guidelines for mining historic landfill sites in Flanders*. Waste Manag. 77: p. 225-237. DOI: <https://doi.org/10.1016/j.wasman.2018.03.049>
79. Quina, M., E. Bontempi, A. Bogush, S. Schlumberger, G. Weibel, R. Braga, V. Funari, J. Hyks, E. Rasmussen, and J. Leder (2018). *Technologies for the management of MSW incineration ashes from gas cleaning: new perspectives on recovery of secondary raw materials and circular economy*. Science of The Total Environment. 635: p. 526-542. DOI: <https://doi.org/10.1016/j.scitotenv.2018.04.150>
80. DAkKS (2020). *Homepage of Deutsche Akkreditierungsstelle (DAkKS)*. online: <https://www.dakks.de/> (Access: 20 March 2020)
81. Young, S.B., D. Schrijvers, and G. Sonnemann (2019). *Responsible Sourcing: A supply-chain management approach to critical materials*. SusCritMat PhD Summer School, online: <https://suscritmat.eu> (Access: 3 April 2020)
82. Lederer, J., M. Šyc, A. Bogush, and J. Fellner (2017). *A network approach towards a secondary raw material inventory for Europe applied to waste incineration residues*. in *16th International Waste Management and Landfill Symposium*. 2.-6. October 2017. Forte Village, Santa Margherita die Pula.
83. IRP (2019). *Global Resources Outlook 2019: Natural Resources for the Future We Want. A Report of the International Resource Panel (IRP)*. U.N.E.P. (UNEP): Nairobi, Kenya.
84. Bide, T., Z. Horvath, T. Brown, N. Idoine, A. Lauko, L. Sores, E. Petavratzi, E. McGrath, S. Bavec, D. Rokavec, T. Eloranta, and K. Aasly (2018). ORAMA project deliverable 1.2. Final analysis and recommendations for the improvement of statistical data collection methods in Europe for primary raw materials. Brussels. online: <http://nora.nerc.ac.uk/id/eprint/522208/>
85. Wagner, M., S. Bavec, L. Herreras, J. Huisman, J. Emmerich, A. Løvik, M. Söderman, K. Sperlich, J. Tivander, K. Baldé, P. Wäger, P. Mähltitz, L. Sörös, P. Leroy, J. Mogollon, Z. Horvath, J. Kiss, K. Szabo, K. Hribernik, and A. Vihtelič (2019). *Technical Guideline Tools for harmonization of data collection on Mining Waste*. online: https://orama-h2020.eu/wp-content/uploads/ORAMA_WP4_1_Guidance_To_Data_Harmonization_For_SRM_for_Mining_Waste.pdf (Access: 13 April 2020)

86. Wager, M., S. Bavec, L. Herreras, J. Huisman, J. Emmerich, M. Söderman, K. Sperlich, J. Tivander, K. Baldé, P. Wäger, P. Mähltitz, L. Sörös, P. Leroy, J. Mogollon, Z. Horvath, J. Kiss, K. Szabo, K. Hribernik, and A. Vihtelič (2019). Technical Guideline Tools for harmonization of data collection on WEEE/PV Panels. online: https://orama-h2020.eu/wp-content/uploads/ORAMA_WP4_1_Guidance_To_Data_Harmonization_For_SRM_for_WEEE-PV_Panels.pdf (Access: 13 April 2020)
87. Krook, J., P. Cleall, R. Rosendal, and T. Carvalho (2018). *Recovery technologies for waste in landfills. Deliverable 2.1*. COST Action Mining the European Anthroposphere (MINEA). p. 44.
88. EC (2019). *Standards on WEEE treatment*. 7 Aug 2019. online: https://ec.europa.eu/environment/waste/weee/standards_en.htm (Access: 13 Feb 2020)
89. PRé (2020). *Life Cycle-Based Sustainability - Standards & Guidelines*. Product Ecology Consultants (PRé). online: <https://www.pre-sustainability.com/download/Life-Cycle-Based-Sustainability-Standards-Guidelines.pdf> (Access: 12 April 2020)
90. MINEA (2019). Minutes of COST Action MINEA Workshop "Knowledge base for anthropogenic resources and reserves I". 24-25 January 2019. Mining the European Anthroposphere (MINEA): Prague.
91. MINEA (2019). Minutes of COST Action MINEA Workshop "Knowledge base for anthropogenic resources and reserves II". 20 March 2019. Mining the European Anthroposphere (MINEA): Brussels.

APPENDICES

Appendix A: Quality assurance

Examples for Guidelines, Specifications and Standards

- (1) **OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas** was developed as an internationally applicable guide with recommendations to help companies that potentially source minerals or metals from geopolitically conflict-prone and high-risk areas to respect human rights and not contribute to conflict through their decisions and practices when purchasing minerals. This guide can be applied to all mineral supply chains (<https://www.oecd.org/daf/inv/mne/mining.htm>).
- (2) The **Sustainable Recycling Industries (SRI) Guidance Principles** have been developed to ensure that sustainability aspects of secondary metals management (collection, recycling and disposal) are taken into account in the context of micro, small and medium enterprises and the informal sector in developing countries. They were formulated in the framework of an International Workshop Agreement (IWA), a consensus-building process within ISO. (<https://www.sustainable-recycling.org/sri-roundtable-overview>)
- (3) The **United Nations Framework Classification for Resources (UNFC)**, a global standard to communicate the availability of resources for the production of energy and raw materials. In cooperation with the UNECE Expert Group of Resource Management, the COST Action 15115 MINEA has developed specifications to apply UNFC to anthropogenic resources, which have been endorsed by UNECE in 2018 [35].
- (4) The **CENELEC standards EN 50574 and 50625** cover the treatment of waste from all products within the extended scope of the WEEE Directive and address the collection, transport and treatment, while future standards, which are currently under development, will also cover preparation for reuse of the WEEE. The standards should assist treatment operators in fulfilling the requirements of the WEEE Directive without placing unnecessary administrative burdens on operators of any size, including SMEs [88].
- (5) The **Life Cycle Assessment (LCA) standard ISO 14040** provide principles and framework life cycle assessment, and the **and ISO 14044** specifies requirements and provides guidelines for life cycle assessment [c.f.89].

Examples for certifications schemes

- (6) The currently being developed **Certification of Raw Materials (CERA)** certification scheme (<https://www.cera-standard.org/>) aims at providing means for sustainable production practices as well as traceability of sustainably sourced materials. CERA intends to be the first certification system that provides a comprehensive and consistent, universal and standardized evaluation of environmental, social and economic sustainability along the entire raw materials value chain. The CERA system brings together four consecutive standards under one certification scheme, with each considering a different aspect and stage of the raw materials value chain while building on each other: readiness, performance, chain of custody and final product.

- (7) **CEWASTE** is an ongoing two-year project funded by European Union's Horizon 2020 research and innovation program that aims at developing a voluntary certification scheme for waste treatment (<https://cewaste.eu/>). Specifically, the project will create, validate and launch the scheme for collection, transport and treatment facilities of key types of waste containing significant amounts of valuable and critical raw materials such as waste electrical and electronic equipment (WEEE) and batteries.
- (8) **Competent/qualified persons:** All classification and reporting systems in mining sector like CRIRSCO or PERC require a "**Competent Person**" or "**Qualified Person**" who must hold acceptable qualification titles as listed in all Reporting Codes and Reporting Standards (NRO Recognised Professional Organisations with enforceable disciplinary processes including the powers to suspend or expel a member) and is recognised by governments, stock exchanges, international entities and regulators. Competent Persons are professionals with long-year experience in a specific field, e.g. type of deposits, who are responsible for preparing and/or signing reports on exploration results and mineral resources and reserves estimates and who are accountable for the reports prepared and are subject to the Code of Professional Ethics.

Appendix B: History of the report's development

On 24-25 January 2019, the **kick-off event "Knowledge base for Anthropogenic material resources and reserves I"** was held in Prague. The Workshop basically covered two interactive sessions, one for discussing the mission for generating the knowledge base and one for getting an overview on the current knowledge of each WG. The following experts contributed to this workshop (alphabetical order): Teresa Carvalho (Portugal), Carlo Cormio (Italy), Christina Ehlert (Luxembourg), Soraya Heuss-Aßbichler (Germany), Jan Hrdlička (Czech Republic), Florian Huber (Austria), Dagmar Juchelkova (Czech Republic), Ulrich Kral (Austria), Joakim Krook (Sweden), Marek Kucbel (Czech Republic), Mohamed Osmani (United Kingdom), Michal Šafář (Czech Republic), Barbora Švédová (Czech Republic), Michal Syc (Czech Republic), Katalin Szabo (Hungary), Paola Villoria Sáez (Spain), Eddy Wille (Belgium), Gürkan Yildirim (Turkey). The minutes of this workshop are available online [90]. Based on the minutes, the 1st version Initial Draft Report was developed, including title and draft structure.

On 20 March 2019, the follow up **Workshop "Knowledge base for Anthropogenic material resources and reserves II"** was held in Brussels. The **1st version of the report** was developed further. The following experts contributed to this workshop (alphabetical order): Teresa Carvalho (Portugal), Carlo Cormino (Italy), Christina Ehlert (Luxemburg), Emilija Fidanchevski (Republic of North Macedonia), Soraya Heuss-Aßbichler (Germany), Ulrich Kral (Austria), Joakim Krook (Sweden), Sandra Mueller (Switzerland), Mohamed Osmani (United Kingdom), Danielle Sinnott (United Kingdom), Nemanja Stanisavljevic (Serbia), Julia Stegemann (United Kingdom), Katalin Szabo (Hungary), Patrick Wäger (Switzerland), Eddy Wille (Belgium), Andrea Winterstetter (Belgium), Gorazd Zibret (Slovenia). The minutes of this workshop are available online [91]. Based on the minutes, a **2nd version of report** was generated.

On 18-19 November 2019, at the **Workshop "Framework for assessment of anthropogenic resources III"** in London, and the MINEA WG4 developed the report further. The following experts contributed to this workshop (alphabetical order): Soraya Heuss-Aßbichler (Germany), Sandra Mueller (Switzerland), Mohamed Osmani (United Kingdom), Julia Stegemann (United Kingdom), Patrick Wäger (Switzerland), Andrea Winterstetter (Belgium). **The 3rd version of the report** was released.

The structure and content of the report have been developed during the **Workshop “Framework for assessment of anthropogenic resources IV”** Luxembourg, 7-8.11 2019. The group elaborated a vision for the roadmap and defined key actions. The following experts attended the Workshop (in alphabetical order): Soraya Heuss-Aßbichler (Germany), Ulrich Kral (Austria), Ruichang Mao (Denmark), Antonino Marvuglia (Luxembourg), Sandra Mueller (Switzerland), Julia Stegemann (United Kingdom), Patrick Wäger (Switzerland).

By 6 April 2020, the authors jointly develop the **4th version of the report**.

By 10 April 2020, the authors finally reviewed and approved the **5th version of the report** at 10th April 2020.

By 17 April 2020, Andrew Clarke made the proof-reading of the 6th version, Ulrich Kral resolved the revisions and released the **7th version of the report** at 17 April 2020.

On 23 April 2020, the 6th version was sent to the MINEA Management Committee for approval. It is noted that the MC approved the **final report** on 30 April 2020.

At the end of April 2020, the final report was published on the Zenodo repository under creative common license (<http://dx.doi.org/10.5281/zenodo.3739269>) and submitted the COST Association.