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INTEGRATING ANTHROPOGENIC MATERIAL STOCKS AND FLOWS INTO MODERN RESOURCE CLASSIFICATION FRAMEWORKS

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Introduction

The growing global demand for raw materials over the past decades has fuelled concerns about rising prices and future availability of geogenic (primary) resources. To alleviate raw material criticality issues and, thus, the dependency on monopolistic supply structures, governments and institutions have been increasingly promoting improvements in resource efficiency as well as in the utilization of so-called anthropogenic (secondary) resources (e.g. recycling of waste) (e.g. EC, 2011). In this study anthropogenic resources are defined as “stocks and flows of materials created by humans or caused by human activity, which can be potentially drawn upon when needed” (Winterstetter et al., 2015b). However, while the exploration and classification of primary deposits is a well-established discipline, the knowledge on anthropogenic resource deposits and their availability for reuse and recycling is still very limited. To obtain a comprehensive overview of existing and potentially extractable anthropogenic resource inventories, it is therefore vital to provide a methodological framework for the evaluation and classification of anthropogenic materials. This would also facilitate decision-making for political and private business stakeholders.

Conceptual background

Starting in the early 18th century in Europe, first reflections on a more sustainable use of natural resources were primarily motivated by the perception of dwindling key raw material deposits, such as wood and coal (Carlowitz, 1713, Jevons, 1906). Considered as the precursors to modern resource classification systems, their common feature is managing scarce commodities by making potential resource extraction projects comparable for involved stakeholders. Since then, most major mining nations as well as economies strongly depending on resource imports have developed their own national classification codes. But when the mining industry has started becoming more and more of a global business from the 1990s on, increased efforts have been made to harmonize those codes to create transparency and comparability in reporting primary raw materials. After the Soviet Union’s collapse the German Government proposed a new classification system to the UNECE Working Party on Coal to compare the vast resources in the formerly centrally planned economies to those in the market economies (UNECE, 2013).

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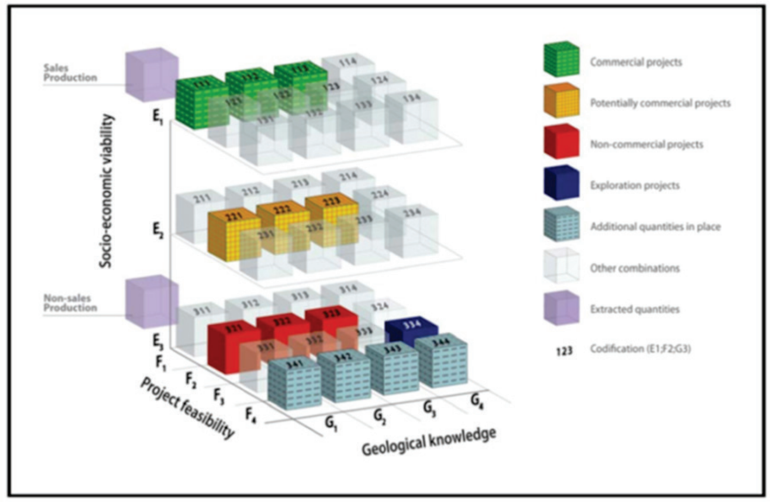

Figure 1: *United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009). Reproduced courtesy of the United Nations Economic Commission for Europe (UNECE, 2010) .*

The United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources (UNFC) has been initiated by the UN Economic Commission for Europe, and was revised in 2009, today being known as UNFC-2009. Under UNFC-2009 quantities are classified on the basis of three fundamental criteria, namely “socioeconomic viability” (E1 – E3), “field project status and technical feasibility” (F1 – F4), and “knowledge on composition” (G1 – G4), with E1F1G1 being the best category (cf. Figure 1) (UNECE, 2010). The globally recognized United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) offers a consistent classification system for various kinds of primary resources and related extractive activities, fulfilling both governmental as well as to a certain extent corporate stakeholders’ requirements. As the UNFC-2009 framework serves primarily classification purposes, it does not provide any criteria for the detailed evaluation steps of a mining project nor does it prescribe standardized methods to precisely distinguish between the different UNFC-2009 categories, e.g. “resources (E2)” and “materials without any prospects of future economic extraction (E3)” (UNECE, 2010).

Goals & Objectives

The goal of this study is to integrate anthropogenic resources into UNFC-2009, facilitating comparisons with geogenic resource inventories, and thus leading to better estimates of total stocks and recoverable fractions in consideration of various boundary conditions. This endeavour has been encouraged at the sixth session of the UNECE expert group on resource classification in April 2015 in Geneva (UNECE, 2015, Winterstetter et al. 2015c).

To show the UN framework’s applicability to anthropogenic resources in principle, an initial operative evaluation procedure has been developed for a case study on landfill mining (cf. Winterstetter et al., 2015a). To fine tune this first approach and to fit anthropogenic resources systematically into UNFC-2009, Winterstetter et al. (2015b) investigate factors influencing the classification of anthropogenic resources, on the one hand in comparison to geogenic resources, and on the other hand, considering various types of anthropogenic resources. At present, we are working on applying this general methodology to mining anthropogenic materials from 1) an old landfill, 2) waste electrical and electronic equipment (WEEE) and 3) in-use wind turbines. Based on those three showcases, stringent criteria to distinguish between different UNFC-2009 categories for different kinds of anthropogenic resources are being developed.

Heterogeneity of anthropogenic resources: An attempted systemization (cf. Winterstetter et al. 2015b)

The human impact on production, consumption and disposal, combined with significantly shorter time spans of renewal were identified as major differences compared to the genesis of geogenic resources. To facilitate the classification of mining specific materials from various different and decentralized human-made sources, which is often linked to big technical and legal uncertainties, influencing factors can be systemized according to their role during the individual phases of resource classification. The prospection phase is determined by 1) the deposit's status of availability for mining, discriminating between "in-use stocks" vs. "obsolete stocks" and "waste flows", 2) by the specific handling and mining condition (e.g. mining a landfill for resource recovery purposes represents a "pull situation", while extracting materials from WEEE is regulated by laws and so a "push situation") and 3) the system variables. While the status of availability and the specific handling condition represent the preconditions for potential mining activities by defining the setting for the following classification, system variables (e.g. the set-up of E-waste collection systems or specific technical choices to extract materials from wind turbines) determine the amount of technically extractable materials.

When prospecting anthropogenic resource deposits, there can be two types of conditions: In a push situation, like in the case of WEEE flows, anthropogenic materials have to be treated (this may include material recovery to reduce costs) due to legal requirements, whereas in a pull situation the materials are mined only if the initial socioeconomic evaluation is positive and otherwise left untouched, like in the case of mining a landfill for resource recovery, which comes close to mining geogenic resources. In a push situation optimal solutions within the given legal framework are sought (Winterstetter et al., 2015b).

System variables also play a major role during the exploration phase. To account for different (possible) sets of system variable values scenario analysis can be used, to check, for instance, different technological treatment options. During the actual socioeconomic evaluation of resource extraction and valorization the modifying factors are investigated. Modifying factors, e.g. commodity prices, have an immediate impact on the project's socioeconomic viability and can potentially move the classification status of a given material deposit along the E-axis of UNFC-2009 from "non-commercial" to "potentially commercial" (resource) to "commercial" (reserve). They can hardly be influenced, but may change over time (Winterstetter et al., 2015b).

Table 1: *Procedure for the classification of anthropogenic resources under UNFC-2009, based on Winterstetter et al. (2015b).*

Phases & UNFC-2009 axes	Influencing factors	
Prospection	**Availability**	• **In-use stock:** Currently not available for mining (e.g. Nd in wind turbines), but at some point in the future • **Obsolete stock:** Potentially available for mining, sometimes even required (e.g. old landfill) • **Waste flows:** Treatment required (e.g. WEEE)
	Mining / handling condition	• **Pull**: Deposit can be mined • **Push**: Materials must be extracted from the deposit due to system constraints
Prospection (G-Axis) **&** **Exploration (F-Axis)**	**System variables**	System variables determine the amount of potentially extractable materials Different sets of system variables can be considered via **alternative scenarios**, but throughout a specific evaluation process, the system variables are **exogenously given** (e.g. composition, extraction technology, laws).
Socioeconomic evaluation (E-Axis)	**Modifying factors**	Modifying factors have a direct impact on the project's economics. They can hardly be influenced, but may change over time (e.g. commodity prices, treatment costs).
Classification	Combination of all criteria & classification under UNFC-2009	

Illustrating examples: E-Waste vs. old landfill vs. in-use wind turbines

Treating waste flows, such as WEEE, typically represents a push situation. The management of WEEE flows in the European Union is mainly regulated and driven by laws, in particular by the EU directive 2012/19/EU, determining the annual collection, reuse and recycling targets. (Directive, 2012). So here the question appears on how to treat WEEE in a socioeconomically optimal way within the given legal constraints. The amount of potentially extractable materials contained in a WEEE flow is influenced by system variables, such as the waste flow's volume, the product type and size, the share of usable materials and potential hazardous substances, as well as the recyclability of the specific product type. The technical and project feasibility of mining WEEE is mainly determined by the set-up of the collection and recycling system. Apart from collection, the recycling chain for WEEE consists of further succeeding steps, i.e. sorting, dismantling, pre-processing, and end-processing. Various different treatment technologies are available, which can (potentially) address the specific needs of each product group. Methods with higher recovery efficiencies are more likely to be selected if markets for the output fractions exist and if expected price levels are high enough to justify higher treatment costs or if alternative treatment and disposal costs can be avoided, i.e. if modifying factors with direct impact on the economics are positive.

Mining stocks, such as old landfills, can either represent a push or a pull situation. In a pull situation, mining an old landfill requires positive socioeconomic prospects either for a private investor or a public entity, since the alternative of mining a landfill is regulated aftercare, where the closed landfill is simply left untouched. If the landfill represents an immanent threat to the environment, e.g. to groundwater, authorities will oblige the former landfill operator to act, i.e. the pull situation turns into a push situation, similar to mining a waste flow. When classifying a landfill-mining project in a pull situation, system variables, such as the landfill's location and size, its ash and water content, the share of valuables, combustibles, non-recyclables or even hazardous substances, and the contamination of the fine fraction, are considered as given for a certain scenario and the main focus is set on the modifying factors. Modifying factor with immediate impact on the economics differ, however, according to the chosen stakeholder perspective. A private investor is only interested in direct financial effects, while non-monetary effects tend to be ignored, if they are not internalized in form of subsidies. A public entity, on the other hand, is more interested in long-term effects, such as the elimination of a source of local soil and water pollution or the avoidance of long-term landfill emissions (Winterstetter et al. 2015a).

In-use stocks of NdFeB materials in wind turbines are currently not available for mining, but will become waste flows in the future. Most probably the recycling of wind turbines will represent a push situation, as permanent magnets and / or NdFeB materials will have to be extracted from wind turbines. To classify potential future mining projects of in-use stocks, gaining in-depth knowledge on a deposit's resource potential has priority over the following socioeconomic evaluation. The economics are obviously linked to high uncertainties, due to not (yet) existing commercially proven technologies. The in-use stock's composition and its potentially extractable share of materials within the defined boundary conditions is determined by type, size, location and the total number of the wind turbines and the contained permanent magnets, as well as the ease of dismantling wind turbines. Uncertainties arise from the technical feasibility of recycling permanent magnets, since manufacturers typically do not publish detailed reports or data on their individual recycling processes (Gattringer, 2012). Therefore, information on recovery efficiencies, investment and operating costs can practically not be found. The choice of specific methods and technologies for processing and separating rare earths from the magnets, influences the final amount of recovered materials, as well as investment and operating costs. Similar to WEEE, costly technologies are more likely to be chosen if modifying factors are positive, e.g. if expected price levels for output materials justify higher treatment costs.

Conclusions & Outlook

Factors influencing the classification of anthropogenic material deposits can be divided into the status of availability (in-use or obsolete stocks, waste flows), mining / handling condition (push vs. pull situation), system variables and modifying factors, according to their role during the individual phases of resource classification (prospection, exploration and socioeconomic evaluation). Exemplarily, the influencing factors of mining anthropogenic resources from an old landfill (obsolete stock), from E-waste (waste flow) and wind turbines (in-use stock) were analysed. In order to obtain a comprehensive overview of existing and potentially extractable anthropogenic resource inventories and to allow the full integration into UNFC-2009, specific guidelines are still to be defined and need to be demonstrated via case studies, to account for the heterogeneous nature of anthropogenic resources. This will facilitate decision-making for political and private business stakeholders and allow for meaningful comparisons between anthropogenic and geogenic mineral resources, promoting the efficient use of resources.

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