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Integrating anthropogenic material stocks and flows into UNFC-2009 – Challenges and potentials

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Abstract

This paper investigates how different types of anthropogenic resources could be classified under the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009). Compared to geogenic resources, anthropogenic deposits are more heterogeneous and more scattered. They are created and altered by human activities via the production, consumption and disposal of materials and goods, and renewed over drastically shorter time spans than geogenic resources. Due to various dynamics the planning of mining activities is linked to high uncertainties. Also, anthropogenic deposits often must be assessed not only under aspects of resource recovery, but with respect to alternative waste treatment and disposal options. To map different types of anthropogenic materials onto the three UNFC-2009 axes, various factors influencing the classification have to be considered. The challenges and potentials associated with classifying diverse types of anthropogenic materials into UNFC-2009 are illustrated by qualitatively discussing the application to three different cases: Mining an old landfill, representing an obsolete stock, is compared to mining e-waste, an example for mining a waste flow, and to hypothetically mining in-use wind turbines (in-use stock). Understanding the heterogeneity of anthropogenic resources will help to systematically classify them under UNFC-2009. Ultimately, this will allow for a meaningful comparison of anthropogenic with geogenic mineral resources, promoting efficient resource use.

Keywords: Anthropogenic resources; Urban mining; United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009); Resource classification; Resource policy

1 Introduction

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 resources', e.g. via the recycling of waste (e.g. EC, 2011). Moreover, by recovering materials from obsolete stocks and flows, the need for final sinks, such as landfills, will decrease, or at least not increase along with growing waste quantities (Kral and Brunner, 2014). In addition, the secondary production of metals, for instance, is considerably less energy intensive than primary production, leading to reduced greenhouse gas emissions (UNEP, 2013). 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., Submitted-b). While the exploration of geogenic 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 vital to provide a methodological framework for the classification of anthropogenic materials. In this paper first the parallels and differences between anthropogenic and geogenic resource assessment are analysed. Understanding the heterogeneity of anthropogenic resources will help to systematically classify them under UNFC-2009. Therefore, in a second step, we investigate how different types of anthropogenic resources could fit into UNFC-2009 by comparing the recovery of anthropogenic materials from 1) an old landfill, 2) waste electrical and electronic equipment (WEEE) and 3) wind turbines in a qualitative discussion. Finally, potentials and challenges for the integration of anthropogenic resources into UNFC-2009 are presented.

2 Geogenic vs. anthropogenic resources

Evaluating anthropogenic resources requires a somewhat different approach compared to geogenic deposits. Factors, which directly or indirectly influence the classification process, differ or have at least different priorities and implications. There are seven key aspects to be considered when mining anthropogenic material stocks and flows:

(1) **Human influence** on deposit formation: Production, consumption & disposal embedded in a specific system (e.g. laws)
(2) **Diverse and scattered sources** of anthropogenic materials (e.g. e-waste vs. old landfill)
(3) **Many diverse recoverable fractions** within one anthropogenic mining project
(4) **Time** of genesis shorter
(5) **High uncertainties** (legal and technological framework, quality of the materials)
(6) Anticipating future obsolete stocks and waste flows **by investigating in-use stocks**
(7) **Often positive externalities** (e.g. removing source of pollution, greenhouse gas emission savings)

Of utmost importance is the human influence (1) on the creation of anthropogenic deposits, whereas the genesis of geogenic resource deposits and also renewable primary energies entirely depends on natural conditions and processes. The formation of anthropogenic material deposits depends on various aspects of production, consumption and disposal occurring in a system, which is defined by, amongst others, the cultural, economic, and legal context, resulting in very diverse and scattered sources of anthropogenic materials (2). Manufacturers determine the design of products that have to be disposed of later on, e.g. obsolete personal computers. On the one hand they are subject to the influence of consumers and their buying patterns, and on the other hand they are regulated via laws and policies, for instance on integrated waste management, eco-design or design for recycling (e.g. McCann and Wittmann, 2015; Oswald, 2013). Consumers do not only put pressure on producers through their buying behaviour, but do also play a key role when it comes to waste disposal. For instance, their awareness about source separation of wastes or their timing of discard decisions potentially increases (or deceases) the quantity, quality and grade of minable materials, which is obviously not possible for a natural ore deposit. In this context also profit-seeking recyclers play a central role, being subject on the one hand to laws and policies and on the other hand to commodity markets. Those recycling companies are usually much smaller compared to internationally operating mining companies in the primary sector, and lack therefore political power and influence.

It is inherent to human cultures that they are constantly developing. Therefore parameter values and system conditions are not static, but likely to change over time. Old landfills, for instance, are witnesses of changing production, consumption and disposal behaviors as well as changing waste management laws and policies over a certain period of time (Bockreis and Knapp, 2011; Gäth and Nispel, 2012; Hölzle, 2010). Technological changes on both on the production and on the disposal side are amongst the most powerful forces. On the one hand they influence the demand and prices for certain raw materials and on the other hand they potentially improve technical feasibility of recycling due to decreasing costs.

In the primary sector each mine has commonly only few main products and some by-products, such as selenium in copper mines, which, however, are usually not reported (Weber, 2013; Winterstetter et al., 2015b). In an anthropogenic mine there are many diverse fractions to be recovered within one project. Within a landfill mining project, for instance, usually a soil-like fraction is recovered, together with ferrous and non-ferrous metals and a combustible fraction. Also the regained land sale or new landfill capacity together with avoided costs for the landfill's aftercare contributes to the economic performance. Revenues for selling all those raw materials and secondary products have to be evaluated as one single project, while markets for each fraction might be very different (3).

While geogenic resources have built up over geologic periods of time, i.e. millions of years, the genesis of anthropogenic stocks occurs over shorter time spans (4) and is subject to various transforming dynamics, such as changing waste legislation, implying high uncertainties (5) for the planning of mining activities. Uncertainties also stem from a potentially changing legal environment or technological developments and sometimes from concerns over qualities of the recovered materials (e.g. fines from landfill mining). While extraction technologies for geogenic resources tend to be well established, the utilization of new technology or existing technology to new materials is associated with high uncertainties for anthropogenic resources (e.g. Bosmans et al., 2012). For some end-of-life materials, such as rare earth elements in permanent magnets, extraction or processing technologies are not available at all or have only been tested at laboratory scale (e.g. Angerer et al., 2009; Schüler et al., 2011).

While mining companies are mainly interested in the commercially recoverable share of the resources, i.e. the reserves, many anthropogenic material deposits are currently likely to be classified as "potentially commercial" (resource). The distinction for anthropogenic resources between non-resources and resources is relevant to support decisions on specific treatments or storage for potential future extraction (6), provided that there are reasonable prospects for future economic extraction. Information on the future mining potential of in-use materials can be useful to manufacturers to increase their products' recyclability and thereby improve future resource availability.

Unlike geogenic resources, anthropogenic deposits often must be assessed not only under aspects of resource recovery, but also in view alternative waste treatment and disposal costs (7). In the mining industry non-monetary effects are mainly considered in order to show potential threats to the economic performance of a project in the form of looming additional costs, such as uncertainty concerning the administration, interpretation and enforcement of existing regulations, new environmental regulations, regulatory duplication and inconsistencies, uncertainty concerning native land claims and protected areas, infrastructure, socioeconomic agreements, political stability, labor issues, geological database, and security (McMahon and Cervantes, 2011). For anthropogenic deposits, in contrast, those non-monetary effects tend to generate additional benefits and should therefore be monetized and included in the evaluation, for instance the value of eliminating sources of pollution or saved greenhouse gas emissions (e.g. Hermann et al., 2014; Hogland et al., 2010; Van Passel et al., 2013).

3 Show cases: E-waste vs. an old landfill vs. in-use wind turbines

Details on the following case studies can be found in Winterstetter et al. (Submitted-a) and Winterstetter et al. (2015a).

3.1 Waste Flow: E-Waste

Treating waste flows, such as waste electrical and electronic equipment (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. Under the extended producer responsibility (EPR) producers have to finance the take back of WEEE from consumers, guarantee their safe disposal and fulfill the set recycling targets (European Commission, 2012). So here the question arises 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 as well as the share of usable materials and potential hazardous substances. The technical and project feasibility of mining WEEE is chiefly determined by the set-up of the collection and recycling system. A considerable number of stakeholders is hereby involved with different responsibilities, such as legislators, producers, retailers, consumers, recyclers and municipalities (e.g. Huisman et al., 2008). Aside from collection, the recycling chain for WEEE consists of further succeeding steps, namely sorting, dismantling, pre-processing, and end-processing, which includes refining and disposal. A wide range of different treatment technologies are available, which can (potentially) address the specific needs of each product group (e.g. Dalrymple et al., 2007). 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. Under UNFC-2009 only confined projects can be classified. Therefore, spatial and temporal system boundaries have to be determined for waste flows (UNECE, 2010).

3.2 Obsolete stock: Old landfill

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 deposited waste is left untouched. If the landfill represents a threat to the environment, e.g. to groundwater, or if new landfill space is urgently needed, 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 factors 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 (e.g. Bockreis and Knapp, 2011). A public entity, on the other hand, is more interested in long-term societal and environmental effects (Graedel et al., 2012), such as the elimination of a source of local soil and water pollution, the avoidance of long-term landfill emissions, or the creation of new jobs (e.g.Van Passel et al., 2013; Winterstetter et al., 2015a).

3.3 In-Use Stock: Nd in wind turbines

In-use stocks of NdFeB materials in wind turbines are currently not available for mining, but will become waste flows in future. Most probably the recycling of wind turbines will be regulated by laws soon, similar to the EU WEEE directive, based on the producer responsibility principle (Cherrington et al., 2012), meaning that permanent magnets and / or Nd materials will have to be extracted from wind turbines **(push situation)**. So, non-monetary effects, such as avoided environmental burden or positive societal externalities (e.g. supply security) can be internalized. To classify potential future mining projects of in-use stocks mainly **system variables** are considered. Generating in-depth knowledge on a deposit's resource potential has priority over the following socioeconomic evaluation, which is obviously linked to high uncertainties, due to not (yet) existing commercially proven technologies and thus precise knowledge on the share of potentially extractable and usable materials. 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 (Gattringer, 2012). Uncertainties stem from producers' information and data, from the emergence of rare earth elements (REE) alternatives, from raw material and energy market dynamics as well as from governmental renewable energy policies (Schüler et al., 2011). Uncertainties arise also from the technical feasibility of recycling permanent magnets, since manufacturers typically do not publish reports or data on their individual recycling processes (Sonich-Mullin, 2012). Therefore, information on recovery efficiencies, investment and operating costs can practically not be found. The choice of specific methods and technologies for removing permanent magnets from wind turbines, and processing and separating REE from the magnets, influences the final amount of recovered materials, such as iron, boron and REE (Nd, Dy, Pr etc) or entire permanent magnets, as well as investment and operating costs (Binnemans et al., 2013). Similar as in the case of 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.

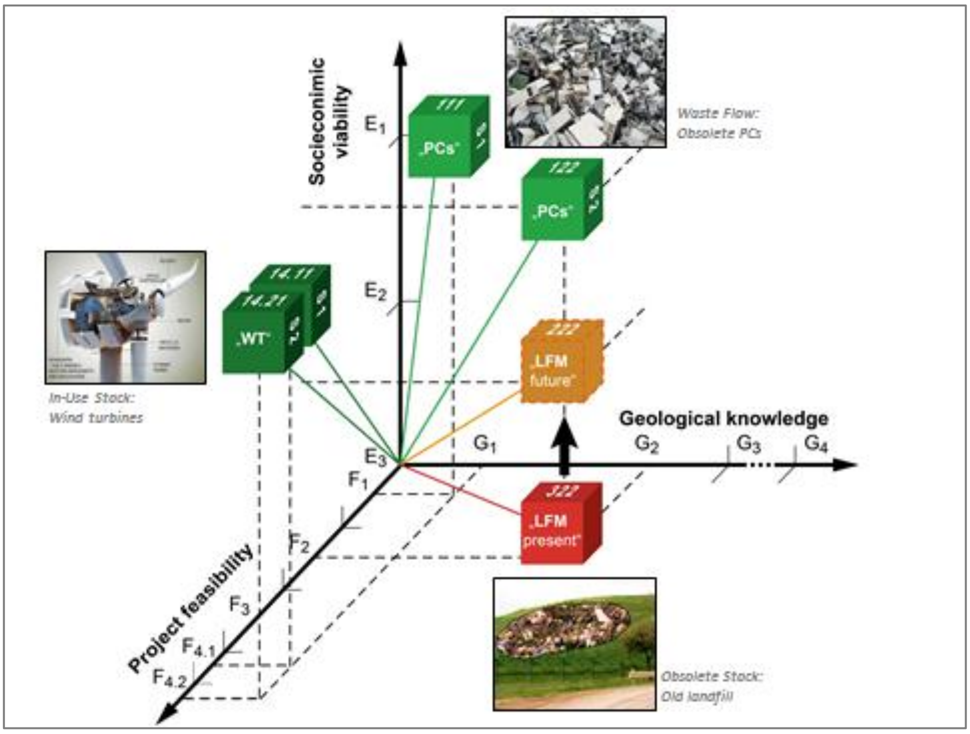

Figure 1: The applicability of UNFC-2009 is illustrated by classifying an old landfill, obsolete PCs and in-use wind turbines (reproduced from Winterstetter et al., Submitted-a).

Figure 1 shows the exemplary classification of three different types of anthropogenic material deposits, i.e. an old landfill, obsolete personal computers and in-use wind turbines, within the three dimensions of UNFC-2009, comprising "Geological Knowledge", Project Feasibility" and "Socioeconomic Viability". Those extraction projects yield different evaluation results and therefore end up with different classifications under UNFC-2009 (Winterstetter et al., Submitted-a).

4 Challenges and potentials for the classification under UNFC-2009

As discussed in Winterstetter et al. (Submitted-b),the incorporation of anthropogenic resources into UNFC-2009 seems like a coherent and consequent next step towards a comprehensive picture of available and potentially minable geogenic and anthropogenic raw materials. In order to make potential resource extraction projects comparable for interested parties, transparency and consistency are of utmost importance. To prevent the emergence of non-transparent and rather subjective practices, similar to the ones existing in the mining industry, where evaluations are made by a team of experts around a "competent person", it is important to create precise guidelines to evaluate anthropogenic resources in order to fit them into UNFC-2009. A methodological framework, including common definitions, might help to enhance the knowledge base on the resource potential present in the anthroposphere, by standardizing the data collection processes, facilitating cross-border communication between involved stakeholders (e.g. for e-waste records), and to finally harmonize practices, standards and guidelines for a comprehensive and sustainable recovery of materials from wastes.

Due to the heterogeneous nature of anthropogenic resources, their classification has several specific characteristics, which can best be accounted for by UNFC-2009, for being the most general and advanced resource classification framework. For instance, the classification of anthropogenic in-use stocks would be impossible under frameworks, designed primarily for public reporting purposes, such as the CRIRSCO template, but requires a broader approach, as offered by UNFC-2009. To classify currently non-extractable quantities due to, for instance, site constraints, technology limitations or other constraints, the UNFC-2009 category E3F4G1-4 (“additional quantities in place”) can be used (UNECE 2014, UNECE 2010). However, we consider, that for evaluating the hypothetical mining of a certain in-use stock under current conditions, it is justified to use the E-axis’ full range (E1 – E3) for the final classification, and not exclusively “E3”. Information on the projected economic performance of mining anthropogenic materials, which are currently in-use, is highly relevant to facilitate decision-making for political and private business stakeholders. To indicate the in-use stock’s current unavailability for mining, “F4” is granted by default on the F-axis, with F4.1 – F4.2 displaying the maturity of extraction and processing technologies.

As for parts of anthropogenic materials, extraction is not (yet) economically viable, the systematic integration of non-monetary effects will be of high priority, to create (additional) financial incentives in pull situations or to outperform the minimum legal requirements in push situations. Social and environmental externalities (e.g. eliminating sources of pollution, greenhouse gas emission savings) tend to generate additional benefits and should therefore be monetized and included in the evaluation. For this purpose various existing concepts of non-market valuation can be useful. Non-marketed assets, such as environmental quality, can be valued by using stated preference studies (i.e. willingness-to-pay estimates), while the depletion of natural assets might be considered via the good’s respective market price. However, what non-monetary effects to finally include in the evaluation will depend also on the specific perspective of the stakeholder interested in performing a certain mining project (private vs. public).

A decisive advantage of UNFC-2009 over the two-dimensional systems (like most of the codes from the CRIRSCO family), is the additional third axis, displaying a mining project’s “technical feasibility and field project status”. The two-dimensional systems only account for the knowledge on composition of a deposit and the economics of a mining project. This might produce a distorted picture, especially where technologies for extraction or processing do not exist yet or are immature and therefore expensive. From a two-dimensional system, one would only get the information, that the project is “uneconomic”, while the F-axis under UNFC-2009 offers a more nuanced view by potentially showing the development status of technologies applied in the project.

Another major challenge is the evaluation and classification of dynamic waste flows. Under UNFC-2009 only defined projects can be evaluated and classified (UNECE, 2010). Therefore, for a constantly renewing waste flow, such as obsolete PCs, system boundaries must be arbitrarily chosen, e.g. on a spatial and / or temporal level. Alternatively, an entirely new way of integrating them under UNFC-2009 needs to be established. Moreover, as there are many diverse recoverable fractions within one anthropogenic mining project, they all have to be evaluated as one single range of raw materials and secondary products.

5 Conclusion & Outlook

All in all, this paper shows that, on principle, UNFC-2009 is applicable to different types of anthropogenic resources. Different settings of anthropogenic resource classification were illustrated by comparing mining anthropogenic materials from an old landfill (obsolete stock), from WEEE (waste flow) and from wind turbines (in-use stock) in a qualitative discussion. Understanding the heterogeneity of anthropogenic resources will help to systematically classify them under UNFC-2009. The integration of geogenic and anthropogenic resources into one single framework, will allow for quantitative resource assessments in consideration of the raw materials present in natural deposits as well as raw materials present in society. On this basis, complete and comprehensive assessments of raw material supply can be made. Also, criticality considerations can be extended by including anthropogenic material stocks. Although the groundwork has been laid for landfill mining and some other selected waste streams, further case studies addressing various settings of mining anthropogenic resources are needed to gain an overview of material resource availability in society.

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