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Framework for the evaluation of anthropogenic resources: A landfill mining case study – Resource or reserve?

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ABSTRACT

The goal of this study is to apply the natural resource classification framework UNFC-2009 to a landfill-mining project to identify the landfilled materials as potential anthropogenic 'resources' (reasonable prospects for eventual economic extraction in the foreseeable future) or 'reserves' (current economic extraction possible), and to reveal critical factors for the classification of the project. Based on data from a landfill-mining project in Belgium, the focus of the evaluation was set on technological options and economics, with a material flow analysis quantifying relevant material and energy flows and a discounted cash flow analysis including Monte Carlo simulations, exploring the project's socioeconomic viability. Four scenarios have been investigated, representing different alternatives for the combustible waste fraction's thermal treatment (gas-plasma technology vs. incineration) and for specific stakeholder interests (public vs. private perspective). The net present values were found to be negative for all four scenarios, implying that none of the project's variations is currently economically viable. The main drivers of the economic performance are parameters related to the thermal treatment of the combustible waste fraction as well as to the sales of recovered metals. Based on required future price increases for non-ferrous metals or electricity to make the project economically viable, the scenarios resulted in different final resource classifications. Although the applicability of UNFC-2009 to landfill mining has been proven successfully, further research is needed to define generally suitable criteria for categorizing various kinds of anthropogenic resources under UNFC-2009. This will allow for fair comparisons between naturally occurring and anthropogenic resource deposits.

1. Introduction

While the exploration and subsequent evaluation of primary resource deposits is a well-established discipline, the knowledge on anthropogenic resource stocks and their availability for reuse and recycling is very limited. To forecast supply coverage of specific raw materials, studies often compare the total amount of anthropogenic resources to only that geological stock estimated to be economically extractable, i.e. the reserves. This is, however, an asymmetrical comparison, as there are materials also in the anthroposphere that are not even hypothetically extractable. Various authors, such as Johansson et al. (2013), Weber (2013) or Wallsten et al. (2013) have advocated for establishing a link between mining virgin materials and mining anthropogenic resources. Furthermore, there have been concrete attempts to map anthropogenic resources in classification codes for natural resources, amongst others by Lederer et al. (2014) and Mueller et al. (2014). The integration of anthropogenic resources into the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) (UNECE, 2004, 2013) would facilitate comparisons between countries' total natural and anthropogenic inventories and hence lead to better estimates of total world stocks.

The commodity-specific specifications for solid minerals under UNFC-2009 (CRIRSCO, 2013) define mineral resources as "concentration of naturally occurring materials in or on the Earth's crust

Abbreviations: DCF, discounted cash flow analysis; ELFM, enhanced landfill mining; GP, gas-plasma technology; INC, incineration; IW, industrial waste; LCA, life cycle assessment; LFG, landfill gas; LFM, landfill mining; MFA, material flow analysis; MSW, municipal solid waste; NFM, non-ferrous metals; NPV, net present value; PV, present value; RDF, refused-derived fuel.

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[1] http://iwr.tuwien.ac.at/anthropogenic-resources/home.html.

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with reasonable prospects for eventual economic extraction, either currently or at some point in the future". Mineral reserves are resources that are "known to be economically feasible for extraction under present conditions". Modifying factors (legal, market, economic, technological etc.) determine the permanently evolving boundaries between 'resources' and 'reserves'.

Whether this concept can be applied to anthropogenic deposits in a similar way to distinguish 'resources' from 'reserves', will be attempted in a first case study on landfill mining: mining of waste deposits, compared to other resource recovery undertakings, exhibits the most similarities with traditional mining projects. Moreover, in the EU there is a considerable potential of between 150,000 and 500,000 historic landfills, which could deliver a significant stream of secondary materials and energy, justifying the exploration and subsequent evaluation of landfill mining projects (Jones et al., 2013; Krook et al., 2012). The first report of a landfill-mining project dates back to 1953 in Israel, aiming to excavate the waste of an old landfill and process it for use as a soil amendment (Savage et al., 1993). This project stayed the single documentation of landfill mining until the 1980s. Most of the following early landfill-mining projects were primarily motivated by local pollution issues or increase of landfill capacities (Bockreis and Knapp, 2011; Hogland et al., 2004) rather than by recovering landfilled materials as secondary resources. Until today landfill mining focusing chiefly on resource recovery has not been commercialized on a large scale. This is mainly due to the fact that factors modifying the socioeconomic viability of landfill-mining projects differ for each site and are often linked to high uncertainties (Hogland et al., 2010; Kaartinen et al., 2013). Therefore, similar to a conventional mine, each landfill needs to be investigated on a case-by-case basis, ideally following a standardized procedure.

The goal of this study is to apply the universal primary resource classification framework UNFC-2009 to a landfill-mining project in order to categorize the landfilled materials either as anthropogenic 'resources' or 'reserves' and to identify critical factors for the resource classification of the project. Therefore, an operative evaluation procedure has been developed and applied to a case study on enhanced landfill mining (ELFM) (ELFM, 2013; Jones et al., 2013). Four scenarios have been investigated, representing different technological alternatives for the combustible waste fraction's thermal treatment (gas-plasma technology vs. incineration) and for specific stakeholder interests (public vs. private perspective). Material flow analysis (MFA) is used to quantify the extractable and potentially usable share of the landfill's resource potential. Subsequently, the economic viability of mining the identified extractable raw materials is explored from different stakeholders' perspectives, based on a discounted cash flow (DCF) analysis, including an uncertainty and sensitivity analysis by using Monte Carlo simulations. Finally, the classification of the four scenarios is attempted under UNFC-2009.

2. Materials and methods

2.1. Conceptual evaluation framework

To identify the landfill's resource potential, being economically feasible for extraction under present conditions ('reserves') or in the foreseeable future ('resources'), three basic dimensions need to be considered: first, the knowledge about the composition and size of the resource stock, second, the technical feasibility of extraction in terms of quantity and quality, and third, the socioeconomic viability based on a financial evaluation including also not directly monetized effects, the so-called "modifying factors", such as environmental, social, legal or market aspects (CRIRSCO, 2013). These three dimensions are reflected in the generic principle-based

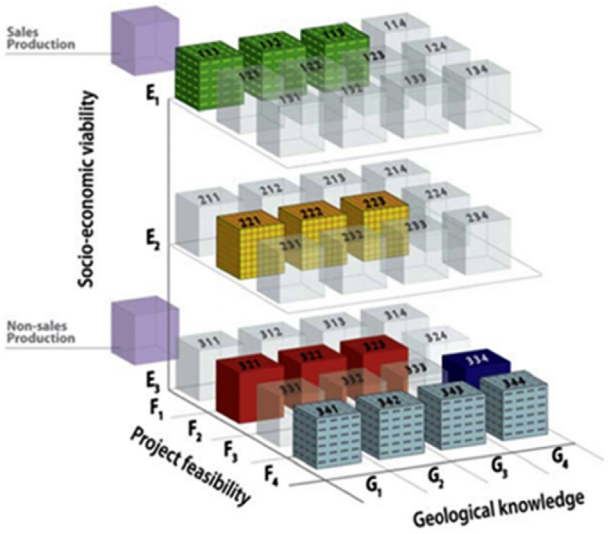

Fig. 1. United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) (UNECE, 2013). 1st digit (E) – "Socio-economic viability"; 2nd digit (F) – "Field project status and technical feasibility"; 3rd digit (G) – "Knowledge on geological composition". Reproduced courtesy of the United Nations Economic Commission for Europe.

UNFC-2009 classification system, which can either be directly applied or used as a bridging tool to harmonize, for instance, existing different national resource codes. Like in the two-dimensional systems based on USGS (1980), there are axes describing "socioeconomic viability" (E) and "knowledge on geological composition" (G), but UNFC-2009 includes an additional third axis relating to the "field project status and technical feasibility" (F). These criteria are each subdivided into categories and sub-categories, which are then combined in the form of classes or sub-classes, creating a three-dimensional system by using a numerical coding scheme (UNECE, 2013) (see Fig. 1). Detailed explanations and definitions of the single categories F1–4, E1–3 and G1–4 can be found in Annex 1 of UNECE (2013).

In concrete terms, UNFC-2009 is applied to the case study on enhanced landfill mining (ELFM) by first developing four alternative scenarios, representing different technological options for the combustible waste fraction's thermal treatment (gas-plasma technology vs. incineration) and for specific stakeholder interests (public vs. private perspective). To classify a natural resource deposit before starting actual mining activities, the stages "prospection", "exploration" and "evaluation" have to be run through (Torries, 1998). In Table 1 those four phases are linked to the goals of a landfill-mining project and then mapped each to the respective UNFC axis considered as suitable. Material flow analysis (MFA) (Brunner and Rechberger, 2004) is a suitable tool for the first two phases in order to identify and later characterize relevant anthropogenic stocks and flows (Lederer et al., 2014; Wallsten et al., 2013). Skipping the prospection phase in this study, MFA first quantifies the landfill's total resource potential, and then the extractable and potentially usable share of materials as a basis for the following economic analysis. The socioeconomic viability of mining the identified extractable raw materials is explored, based on a discounted cash flow (DCF) analysis. At first, only direct costs and revenues, representing a private investor's micro perspective are included, while in a second step, non-monetary modifying factors that might significantly impact the project's economic viability are evaluated in a public entity's macro view. Specifically, greenhouse gas (GHG) emissions of the landfill-mining project are compared to a "Do-Nothing" scenario. Additionally, the impact of extended landfill aftercare obligations is investigated, and a conservative discount