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Cost-benefit analysis of copper recovery in remediation projects: A case study from Sweden

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HIGHLIGHTS

- Copper recycling has a low economic potential and associated with high uncertainties.
- Recycling of copper combined with a local disposal of the waste is the best option.
- The production of a safe and reusable residue improves the economic potential.
- The quality of recovered metals has to be investigated to assure their value.
- Investments in the process equipment have to be made as a separate project.

GRAPHICAL ABSTRACT

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ABSTRACT

Contamination resulting from past industrial activity is a problem throughout the world and many sites are severely contaminated by metals. Advances in research in recent years have resulted in the development of technologies for recovering metal from metal-rich materials within the framework of remediation projects. Using cost-benefit analysis (CBA), and explicitly taking uncertainties into account, this paper evaluates the potential social profitability of copper recovery as part of four remediation alternatives at a Swedish site. One alternative involves delivery of copper-rich ash to a metal production company for refining. The other three alternatives involve metal leaching from materials and sale of the resulting metal sludge for its further processing at a metal production company using metallurgical methods. All the alternatives are evaluated relative to the conventional excavation and disposal method. Metal recovery from the ash, metal sludge sale, and disposal of the contaminated soil and the ash residue at the local landfill site, was found to be the best remediation alternative. However, given the present conditions, its economic potential is low relative to the conventional excavation and disposal method but higher than direct disposal of the copper-rich ash for refining. Volatile copper prices, the high cost of processing equipment, the highly uncertain cost of the metal leaching and washing process, coupled with the substantial project risks, contribute most to the uncertainties in the CBA results for the alternatives involving metal leaching prior to refining. However, investment in processing equipment within the framework of a long-term investment project, production of safe, reusable soil residue, and higher copper prices on the metal market, can make metal recovery technology socially profitable.

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1. Introduction

Extensive industrialization aimed at reorganizing an agrarian society has resulted in overexploitation of natural resources, exhaustion of the capability of ecosystems to cope with growing volumes of waste, and worldwide contamination of soil, air, groundwater, surface water and sediments. These emerging degradation processes have led to scientists and policy-makers recognizing the issue and bringing forward a number of high-impact reports and policy documents aimed at promoting responsible use of finite and rapidly depleting natural resources, e.g. the Brundtland Report (WCED, 1987), Millennium Ecosystem Assessment (MEA, 2005), and the outcome document of the United Nations Conference on Sustainable Development, entitled "The Future We Want" (UN, 2012). Furthermore, the worldwide environmental movement launched in the 1980s has resulted in the enforcement of international and national environmental laws aimed at safeguarding human health and the environment.

The new era of information technology, coupled with advanced industrial technologies and economic globalization, have taken industrialized society to another economic level, leading to the closure of old industrial sites that are often contaminated with embedded organic and inorganic pollutants. To facilitate a sustainable land use transition, underused areas in cities and the urban surroundings in developed (and developing) countries require site investigations and management of the risks to human health and the environment posed by contaminants (RESCUE, 2005; CABERNET, 2006; REVIT, 2007; HOMBRE, 2013; Norrman et al., 2016). By balancing environmental, sociocultural and economic aspects, and taking uncertainties explicitly into account, sustainability appraisal of remediation alternatives for risk mitigation is an important form of decision support, enabling decision-makers to make transparent and explainable decisions (Harbottle et al., 2008; Alvarez-Guerra et al., 2009; Rosén et al., 2009; SuRF-UK, 2010, 2011; Linkov and Moberg, 2011; Brinkhoff, 2011; Sparrevik et al., 2012; Smith and Kerrison, 2013; Beames et al., 2014; Rosén et al., 2015). In this type of appraisal, the economic aspect can be addressed by means of a cost-benefit analysis (CBA) in order to assess the social profitability of the planned remedial action (Rosén et al., 2008; Söderqvist et al., 2015).

In Western Europe, there are >2.5 million potentially contaminated sites (Panagos et al., 2013). Approximately 85,000 of these sites are located in Sweden (Swedish EPA, 2017). According to the national inventories of contaminated sites, there are approximately 1,300 sites that pose a very high risk to human health or the environment, and 13,000 sites that pose a significant risk (ibid.). To date, approximately 100 of these 1,300 most severely contaminated sites have been remediated (Rosén et al., 2014). The level of innovation for remediation technologies in Sweden, however, is low (Swedish EPA, 2013). Contaminated materials are usually excavated and sent for landfill because of time constraints, low disposal fees and reliability concerns with regard to alternative remediation methods (SGI, 2012). To underpin the conventional excavation and disposal remediation method, and to make use of the valuable metals embedded in the excavated materials, advances in research in recent years have resulted in innovative metal recovery technology (Karlfeldt Fedje et al., 2013, 2015). This *ex-situ* off-site technology enables efficient extraction of metals from contaminated soil and their concentration into metal sludge. Furthermore, excavated peat and bark deposits (contaminated by copper as a result of industrial activity) can also be treated efficiently following incineration (Karlfeldt Fedje et al., 2013). Developed metal recovery technology can thus turn the contamination problem into a valuable metal product in conjunction with site remediation. However, this method has only been studied on the laboratory scale. Full-scale studies of metal recovery during site remediation are not well developed or commonly used neither in Sweden nor internationally (Berggren Kleja and Ohlsson, 2013).

The EU's demand for certain metals far outstrips its own production, making manufacturing industry in the EU heavily reliant on metal imports. Between 2000 and 2008, EU domestic refinery production of copper (supply) only met 62.5% of the refined usage (demand) of this metal (Ecorys, 2011). Copper is the second most expensive non-ferrous metal on the metal market. Copper prices are very unstable and vary significantly over relatively short time horizons (Fig. 1).

Mining and processing of metal ores are the most common activities in metal production. However, these activities often lead to environmental degradation, i.e. depletion of natural resources, soil contamination with trace elements, waste generation, extensive emissions into the air and acid deposition (Dudka and Adriano, 1997). Production of copper, zinc and lead has the largest environmental impact (ibid.). For example, over 99.5% of the material mined to produce virgin copper is referred to as waste, which is often not properly managed, forming toxic tailings and leading to degradation of the environment (Bridge, 2004). Furthermore, the world's natural metal reserves suitable for financially viable production of virgin metals are limited. Following the trends in population growth and consumption rates, copper reserves available for mining could be exhausted by 2050 (Brown, 2006).

In contrast to the EU, more metals (including copper) are produced in Sweden from mines than from recycling (Johansson et al., 2014). Metal recovery and recycling from secondary raw materials, i.e. industrial waste, manufacturing scrap and end-of-life products, is not yet a replacement but is an increasingly important complement to primary production of metals through mining and metal ore processing. In particular, one-third of the copper traded on the global metal market is recycled from secondary raw materials (Ecorys, 2011). The metal sludge produced from metal-rich materials deriving from remediation projects may serve as important input for the refinery production of valuable metals (Karlfeldt Fedje et al., 2013, 2015; Elander, 2014). To the best of the authors' knowledge, there are no studies in the academic literature that assess the social profitability of metal recovery in conjunction with site remediation, or its economic competitiveness relative to conventional excavation and disposal methods. The application of the methods for economic assessment of metal recovery in a number of international remediation projects, as well as the subsequent economic results, and their optimization, are believed to provide a good basis for drawing some general conclusions with regard to which policy instruments can be used to valorise metal recycling as part of site remediation on the national and international level.

The main purpose of this study is to perform a CBA of copper recovery from contaminated materials within the framework of remediation projects in order to evaluate the potential social profitability of metal recovery technology. Based on the results of the study, an evaluation is made to determine under which conditions copper recovery may be beneficial, taking into account both project-specific (internal) and external project effects. This study presents a CBA of copper recovery at the Köpmannebro remediation site in Sweden. The study site, the metal recovery technology, and the studied remediation alternatives are presented in Sections 2, 3 and 4. The methods used in this research are described in Section 5. The economic assessment results are

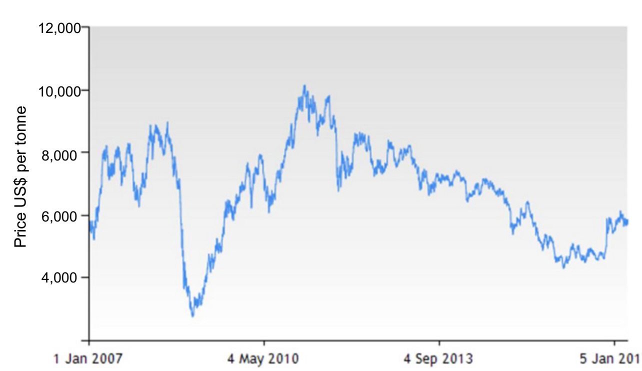

Fig. 1. Graph showing the dynamics of copper prices over the past ten years. Source: London Metal Exchange.