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Paradigms on landfill mining: From dump site scavenging to ecosystem services revitalization



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ABSTRACT

For the next century to come, one of the biggest challenges is to provide the mankind with relevant and sufficient resources. Recovery of secondary resources plays a significant role. Industrial processes developed to regain minerals for commodity production in a circular economy become ever more important in the European Union and worldwide. Landfill mining (LFM) constitutes an important technological toolset of processes that regain resources and redistribute them with an accompanying reduction of hazardous influence of environmental contamination and other threats for human health hidden in former dump sites and landfills. This review paper is devoted to LFM problems, historical development and driving paradigms of LFM from 'classical hunting for valuables' to 'perspective in ecosystem revitalization'. The main goal is to provide a description of historical experience and link it to more advanced concept of a circular economy. The challenge is to adapt the existing knowledge to make decisions in accordance with both, economic feasibility and ecosystems revitalization aspects.

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1. Introduction

The shift towards a more resource efficient circular economy is becoming increasingly important as the world is facing severe global environmental challenges and climate change effects as well as resource shortages (Rockström et al., 2009; EC 2010; Henckens et al., 2014; Walan et al., 2014; Reijnders 2014; Jin et al., 2016). In order to overcome these challenges, the European Commission has adopted a new strategy of the European economy for a sustainable use of renewable resources. According to the European Commission's 'Roadmap to a Resource Efficient Europe', wastes should be

managed as a 'resource' by 2020 rather than be seen as a 'get rid of the material' issue (EU, 2011).

Even though not directly mentioned in this roadmap, landfills are the prime candidates for resource recovery as landfills have been widely used as a final way to dispose, and store, residuals during the last decades. This waste is waiting to be picked up and utilized as a man-made resource from the past. However, as leachate and landfill gas is generated, landfills are mainly regarded as an environmental hazard. Old landfills, which generally lack modern environmental technology, are the sources of groundwater pollution due to hazardous substances leaching or long-term methane emissions contributing to the global warming. Countries having good environmental performance exhibit authorities which prefer to close these dumpsites to reduce risk and build new sanitary landfills. Nevertheless, they reject attempts to harvest resources from landfills. This is considered the old-style paradigm that says old landfilled waste should remain in the ground.

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Contrary to this, landfills should be seen as 'urban stocks' and be considered as resource reservoirs for future recovery, 'a bank account' for coming generations (Hogland, 2001; Brunner and Rechberger, 2004; Wittmer and Lichtensteiger, 2007). The current enormous volumes of dumped waste in landfills could be regarded as potential resource reservoirs for metals, high quality recycled aggregates and waste derived fuels by LFM. The state of the art of LFM is the concept of ELM which has been proposed as an improved practice of landfill mining (Jones et al., 2013). ELM has been said to integrate the valorization of historic and future waste streams as both Waste-to-Material (WtM) and Waste-to-Energy (WtE) while considering stringent ecological and social criteria (Hogland et al., 2010; Jones et al., 2013).

150,000–500,000 old and still active landfills exist throughout EU representing an estimated total volume of 30–50 Gm³ of waste (Hogland, 2002; Hogland and Kriipsalu, 2003; Van der Zee et al., 2004; Hogland et al., 2008a,b; Van Vossen and Prent, 2011). Thus, LFM should be emphasized as an approach to management of sustainable material that combines municipal waste management and material recycling. Accordingly, LFM has been adopted as a feasible technology for the ecological remediation of old landfills (Krook, 2010; Krook and Baas, 2013).

Except for the purpose of resource recovery, LFM is crucial for the remediation of landfills to prevent local emissions, to create new potential landfill volumes in existing ones and create space for new infrastructure plus produce recyclable materials (Goeschl, 2012). This new perspective of LFM is of interest from an economic point of view and in terms of mitigating climate change and reducing the pressure on scarce natural resources. EU promotes investment into waste management infrastructure. According to the EU legislation, only 10% of all wastes is planned to be landfilled by 2030 making investment in new landfills doubtful. Preferably, existing landfills should incorporate principles of LFM as the best available technology (BAT) in daily business operations. European and future targets are to abolish landfills in the way they were used in the past.

First attempts to analyse results of LFM projects and reports were performed in 90-ties of the last century and beginning of 21st century by Cossu et al. (1996), Hogland et al. (1997) and Hogland and Joseph (2008). Asian projects were reported in project type reviews by Joseph et al. (2003, 2004, 2008). Later comprehensive reviews were compiled by Krook (2010), Krook, et al. (2012) and Krook and Baas (2013), specifically environmental questions were taken in account in review by Frändegård et al. (2012).

This paper was performed on literature basis of previously done reviews, case studies, project reports and takes in account additional literature on environmental aspects linked to performance of LFM that were not considered widely in previous studies. Authors take an insight in paradigm development from classical LFM and resource recovery ideas of enhanced LFM (ELFM) towards full ecosystem services revitalization concept.

2. Brief history of LFM case studies and development of paradigms

There have been various trials of LFM projects for recovery of energy, material and space for landfills waste, including full scale and experimental research projects with the idea to later upscale the pilot studies. The numbers of such cases are summarized in Fig. 1.

The first reported landfill mining action was organized in Tel Aviv in Israel in 1953 (Shual and Hillel 1958; Joseph et al., 2004, 2008). After several decades, ideas for deriving fuel for incineration and energy recovery appeared in the United States of America (USA) (Cossu et al., 1996; Hogland 1996; US EPA 1997). Two devel-

opments took place in USA from the 50s and 80s that impacted LFM. One was elaborated for recovery of steel containers, but the second development took place in the late 1960s and early 1970s and dealt with the assessment of the technical feasibility of composting landfilled MSW in situ (Joseph et al., 2008). The project was not implemented in full scale because of technical infeasibility. However, valuable information was gained on the degradation of organic matter in a landfill and the importance of providing multi-cell structure in sanitary landfills (Joseph et al., 2008). Afterwards, six landfill mining projects in the USA (Lee and Jones 1990; Murphy 1993) reported different aspects of MSW aerobic digestion and reclamation processes. LFM has been a method of waste management and planned or implemented in many developed and developing countries (Forster, 1995; Murphy, 1993; Nelson, 1995; Hull et al., 2001). Dumps in the countries of Asia are similar and characterized by stochastically disposed heaps of open-air waste with open burning actions, stinky pools of stagnant contaminated water, scavenging by animals and poor people. Additionally, the absence of cover and primitive safety measures is disregarded (Rushbrook, 2001). In these countries improvement of infrastructure, management, monitoring for leachate, safety (fences against scavengers and control), and sustainable planning is highly needed (Joseph et al., 2003, 2004; Hogland and Joseph, 2008).

Landfill mining in Europe has been performed mostly for experimental purposes with linked ideas to perform environmental remediation with partial recovery of materials and energy (see Table 1).

In the early 1980s, New Jersey environmental officials started to talk about that 'Recycling Pays' however cost was estimated higher than expected (Morris, 1996), this discussion has topicality until nowadays nevertheless of successful source separation from the raw waste (E-Waste, 2016). Complex approaches, such as recovery of space for creating new cells for waste, can be combined with recycling of LFM waste for biogas production (Hogland and Marques, 1998). During the 1990s it was popular to construct biocells at landfills for biogas production. In Sweden, as well as in many other EU countries, former dumps mostly are capped and monitored. However, sometimes this is not an efficient solution as some of them needs to be exhumed, e.g., in Ringstorp (Hogland and Kriipsalu, 2001; Van der Zee et al., 2004). Experiments on material and energy recovery were successfully performed in Kudjape Landfill, Estonia during its remediation process through LFM (Burlakovs et al., 2013). In 2015 the same research group performed test excavations at the Torma landfill in Estonia where the first landfill according to the EU Landfill Directive was constructed (comply with the requirements of Directive 1999/31/EC on the landfill of waste; hence old dump sites usually do not comply) and analytical studies are in progress.

There is on-going dispute how the primary generated waste (municipal, construction and other waste) should be treated; and recovery through LFM, also dominantly, are closely related to recycling, energy production or both. In fact, previously landfilled material could be processed to recover materials for recycling, and combustible materials for energy. However, not all countries have the possibility to use waste for energy, which actually could limit the feasibility of LFM projects in some cases. If there is the possibility to recover fuel besides recyclables, for some countries without incineration capacity appears opportunity to recover fuels and send them to countries which can utilize them. It is a tiny fraction of the energy that is needed to make products from raw resources. For example, producing newsprint requires more than 2.5 more energy generated than by incinerating it. Glass requires 30 times more and aluminium 350 times (Morris, 2010; ZeroWaste, 2016). Recycling also reduces the energy consumption associated with extraction and the initial processing of raw resources. The recycling process typically is more energy efficient than production from new mate-

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