Original Article

WM&R

Waste Management & Research
2014, Vol. 32(9) Supplement 48–58

DOI: 10.1177/0734242X14541168
wmr.sagepub.com
SAGE

Landfill mining in Austria: Foundations for an integrated ecological and economic assessment

Robert Hermann[1], Rupert J Baumgartner[2], Renato Sarc[1], Arne Ragossnig[3], Tanja Wolfsberger[1], Martin Eisenberger[4], Andreas Budischowsky[5] and Roland Pomberger[1]

Abstract
For the first time, basic technical and economic studies for landfill mining are being carried out in Austria on the basis of a pilot project. An important goal of these studies is the collection of elementary data as the basis for an integrated ecological and economic assessment of landfill mining projects with regard to their feasibility. For this purpose, economic, ecological, technical, organizational, as well as political and legal influencing factors are identified and extensively studied in the article. An important aspect is the mutual influence of the factors on each other, as this can significantly affect the development of an integrated assessment system. In addition to the influencing factors, the definition of the spatial and temporal system boundaries is crucial for further investigations. Among others, the quality and quantity of recovered waste materials, temporal fluctuations or developments in prices of secondary raw material and fuels attainable in the markets, and time and duration of dumping, play a crucial role. Based on the investigations, the spatial system boundary is defined in as much as all the necessary process steps, from landfill mining, preparing and sorting to providing a marketable material/product by the landfill operator, are taken into account. No general accepted definition can be made for the temporal system boundary because the different time-related influencing factors necessitate an individual project-specific determination and adaptation to the facts of the on-site landfill mining project.

Keywords
Austria, ecological assessment, economic assessment, influencing factors, landfill mining, system boundaries

Introduction

While classic mining is understood as the exploration, exploitation, extraction and preparation of primary raw materials, urban mining is defined as those activities that use the city as a potential secondary raw material source (Fricke, 2009). Raw materials gained from these activities are primarily demolition materials (construction and demolition waste, metals, plastics, etc.) from the destruction of old buildings. In contrast, landfill mining is concerned with the organized mining of landfills. The landfill is considered as a source of raw materials and the recovery of valuable materials from landfilled waste is the focus of investigations (Bockreis and Knapp, 2011; Hölzle, 2010). The waste that was deposited in the past is excavated, processed and fed into a material and/or energy recovery system. Only a non-recyclable waste fraction (i.e. stabilized biofraction) has to be deposited again. A list of known landfill mining projects can be found in, among others, Bothmann et al. (2002) and Bockreis and Knapp (2011).

The implementation of landfill mining projects greatly depends on the relationship between the capital used and different monetary and non-monetary utilization factors. Therefore clear goal- and decision-making frameworks have to be designed. The achievement of these goals can only be assessed on a case-by-case basis with appropriate ecological and economic assessment tools (Frändegård et al., 2013). Integrated cost-benefit considerations, taking into account the interaction between, e.g. costs of landfill mining, savings during closure/aftercare, revenues from the recovery of land (land recycling) and the generation of secondary raw materials or the saving of emission certificates by reducing greenhouse gas emissions have not been carried out, or not in a sufficient extent (Fricke et al., 2012). To date, for example, only individual cost and revenue items for landfill mining are available for profitability calculations and no standardized assessment tools exist for a comprehensible ecological/economic assessment of landfill mining projects (Bernhard et al., 2011; Bölte and Geiping,

[1]Montanuniversitaet Leoben, Leoben, Austria
[2]University of Graz, Graz, Austria
[3]UTC UmweltTechnik und GeoConsulting ZT GmbH, Vienna, Austria
[4]Environmental Law Consulting, Graz, Austria
[5]NUA-Abfallwirtschaft GmbH, Traiskirchen, Austria

Corresponding author:
Robert Hermann, Montanuniversitaet Leoben, Leoben, Franz Josefstraße 18, Austria.
Email: robert.hermann@unileoben.ac.at

Table 1. Global demand of individual raw materials for selected technologies of the future in tonnes (Angerer et al., 2009).

Raw material	Demand in 2006	Demand in 2030	Future technologies
Copper (Cu)	950	1700	Lead-free soft solders
	1,400,000	3,470,000	Industrial electric motors
	50	9100	RFID tags
	0	2270	High-temperature superconductivity
	9000	213,000	Electric traction motors for hybrid and fuel cell vehicles
Total	**1,410,000**	**3,696,070**	
Silver (Ag)	5100	9300	Lead-free soft solders
	1	44	Solar thermal power plants
	0	28	Displays
	210	518	Microelectronic capacitors
	30	250	Nanosilver
	1	5670	RFID tags
	0	14	Dye solar cells
Total	**5342**	**15,824**	
Aluminum (Al)	68	350,000	Double layer capacitors
	6	3900	RFID tags
	469	1760	Desalination
	85	757	Solid-state lasers
Total	**628**	**356,417**	
Iron (Fe) and steel	21,400,000	27,000,000	Bodywork of vehicles
	29,700	112,000	Desalination
	10,250,000	31,200,000	Preparation of computer tomographs
	10,800	59,450	High-performance permanent magnets
Total	**31,690,500**	**58,371,450**	

RFID: radio-frequency identification.

2011; Rettenberger, 2012b). But in order to develop assessment tools, the necessary fundamental data must be gathered, influencing factors must be examined and system boundaries must be defined. Subsequent articles will deal specifically with this issue.

Landfill mining – why?

Owing to the globally very uneven distribution of raw materials, the EU is heavily dependent on imports, which is why a (more) efficient use of secondary raw materials will become an important task in the future. In addition, the availability of naturally occurring fossil fuels, metals and minerals is not unlimited and the worldwide increase in raw material consumption causes sustained price increases on the international markets (Franke et al., 2011). For example, according to a study by the Fraunhofer Institute for Systems and Innovation Research (Angerer et al., 2009), different technologies will give a strong impetus to the demand for raw materials in the future. Table 1 shows how the annual global demand of selected raw materials will develop for specific technologies in the future.

It becomes clear that the annual demand for the listed raw materials will rise very steeply by 2030, even in very small and specific future (high-tech) technology sectors. Based on these numbers and the fact that demand will develop in a similar manner in other technology sectors (Kretschmer, 2010), the closing of material cycles and the opening of new secondary raw material sources will be a significant contribution to securing resources.

For this reason, in 2011 the European Commission (European Commission, 2011) published a statement that is included in the “Resource Efficient Europe” flagship initiative within the “Europe 2020 Strategy”. The basis for this statement is the “Raw Materials Initiative 2008” (European Commission, 2008), which developed a raw materials strategy for the European Union, which rests on three pillars. One of these pillars deals with the increase in resource efficiency and recycling in order to decrease the primary raw material consumption in the EU and reduce their dependence on imports. For example, the recycling shares of non-ferrous metals (Zn, Pb, Al and Cu) in global production of the industrialized countries in 2011 ranged from 10 to >50% (Graedel et al., 2011) (Figure 1) and therefore still offer great potential for recycling activities. In addition to the theoretical potential, the recoverability of metals is an essential factor influencing an economic assessment of landfill mining.

With this in mind, efficient use of valuable materials and energy from landfill mining projects can be an important pillar of sustainable resource management in the future (Jones et al., 2013). Especially in landfills where untreated waste was deposited in the period from 1960 to 2004, potential, economically recyclable materials were found in addition to pollutants and these can be re-used in times of scarce geogenic raw materials and fossil fuels (Bernhard et al., 2011). Mainly owing to the increased demand for secondary fuels (e.g. plastics) as a possible substitute for fossil fuels (e.g. oil, coal, natural gas), the above-mentioned trend of rising raw material prices and the globally increasing shortage or demand for certain raw materials

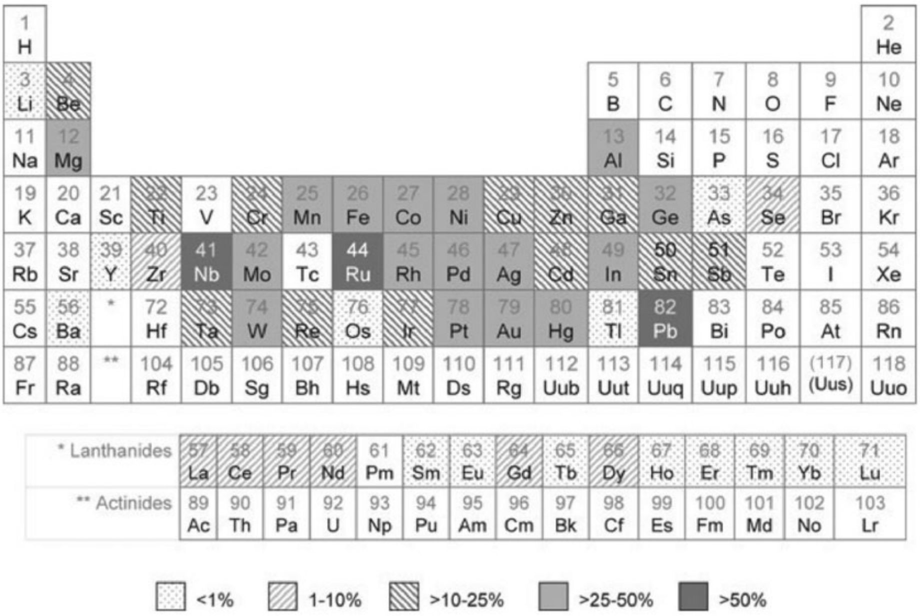

Figure 1. Recycled share for the individual metals in global production (Graedel et al., 2011).

(e.g. metals), landfills are increasingly becoming the focus of interest as possible raw material deposits for economic reasons (Krutzler et al., 2012).

Studies by Nispel (2012) showed a comparatively high potential of iron and non-ferrous metals in a municipal solid waste landfill in Germany (Hechingen county landfill), for example. 2.8 weight-% (wgt.-%) of ferrous metals and 0.6 wgt.-% of non-ferrous metals were found there. Similar values are also named by Rettenberger (2012b), where studies of two landfills resulted in an average of 1.2 wgt.-% or 3.5 wgt.-% ferrous metals. This number means a theoretical potential only; in addition the recoverability of metals is an essential factor influencing an economic assessment of landfill mining.

For German landfills, the summary of raw material potential of approximately:

- 26 million tonnes of iron scrap (318 kg per inhabitant, equals the specific consumption of 0.7 years);
- 0.85 million tonnes of copper scrap (10 kg per inhabitant, equals the specific consumption of 0.4 years);
- 0.5 million tonnes aluminum scrap (6 kg per inhabitant, equals the specific consumption of 0.4 years); and
- 0.65 million tonnes of phosphates (8 kg per inhabitant, equals the specific consumption of 5 years);

applies (Franke et al., 2010). The specific consumption data are taken from (Huy et al., 2013). The current Landfill Mining Austria project, which is described in the following section, will investigate this raw material potential for Austria.

Landfill Mining Austria – Pilot Region Styria

Since subsequent versions refer in part to the underlying data of the "Landfill Mining Austria – Pilot Region Styria" Austrian pilot project, this project will be briefly discussed here.

In the "Landfill Mining Austria – Pilot Region Styria" project, basic technical and economic knowledge about the "mining" of landfills was obtained for the first time in Austria. Owing to the geological, waste-related and environmental facts (existing variety of mechanical–biological waste treatment, incineration and landfill technologies), as well as the site-specific vicinity, Styria was defined as the "pilot project region".

Based on research results available so far, the main goal of this project is to develop an improved basis for decision-making for future landfill mining projects focussing on economic viability of the deconstruction of landfills. To get a reliable result it is important to consider the ban on landfilling of untreated waste since 2004 (in exceptional cases, 2009). In the course of this project, the technical possibilities, theoretical resource potential, quality restrictions and economically sensible types of recycling and process risks are reviewed based on theoretical and scientific foundations. An important part of the project is the identification of basic data and the development of several assessment criteria for an integrated economic and ecological evaluation of landfill mining projects in Austria.

For landfill mining, only such landfills are attractive that have a high percentage of usable recyclables, such as metals and energy resources (e.g. high calorific fractions) compared with the total amount of waste deposited at the site. This category includes landfills from the 1960s until 2004 in which household and industrial waste, as well as inert waste, were partly deposited without pretreatment. In such landfills (municipal waste/household waste landfills), large quantities of raw materials in the form of municipal waste, sludge or building material waste are sometimes stored (Gäth and Nispel, 2010). Small municipal landfills, with a landfill capacity of less than 100,000 m^3 in volume, are less suitable for landfill mining projects owing to lower deposited waste quantities and the associated lower recyclable material potential, because in these cases, cost-effective mining is usually not possible (Bernhard et al., 2011). Afterwards, only for the

Table 2. (Sub-)Categories and number of landfills in Styria (Province of Styria, 2013).

Landfill (sub-)categories	Number of sites in Styria
Excavated soil landfill	62
Landfill for inert waste	1
Demolition and construction waste landfill	48
Residual waste landfill	11
Mass waste landfill	25
Total	**147**

Table 3. Capacity distribution of mass waste landfills in Styria (Province of Styria, 2013).

Volume [in m^3]	Number of sites in Styria – operational	Number of sites in Styria – closed
<25,000	0	2
>25,000–100,000	0	5
>100,000–1,000,000	5	10
>1,000,000	2	1
Total	**7**	**18**

landfill mining, suitable landfills in Styria are extensively discussed. Therefore, out of in total 147 landfills, 81 are still in operation (2013), and the remaining 66 have been already closed. In Table 2 the classification of landfills in the appropriate landfill (sub-)categories for the Styria region (Province of Styria, 2013) is shown.

As already described, residual waste and mass waste landfills are especially suitable for the consideration of mining. As the economic efficiency of mining is largely determined by the amount of recyclable materials, the main focus of the landfill mining project is set on large mass waste landfills and landfill capacities with a minimum capacity of 100,000 m^3. Based on this, in Styria, 18 landfills are suitable for mining (see Table 3) (Province of Styria, 2013).

To get an overview of the total waste landfills in Austria, waste quantities, arranged by waste type (i.e. waste code), were collected for the period 1998–2007 based on evaluations of the landfill database by Umweltbundesamt GmbH. The 74 mass waste landfills operated in this period of time yielded in total of around 25.5 million tonnes of waste, and the 35 residual waste landfills yielded, in total, around 6.4 million tonnes. With 41%, household and bulky waste represent the greatest proportion of waste deposited in mass waste landfills, followed by excavation materials (16%), residues from mechanical–biological waste treatment and shredders (14%), as well as residues from thermal treatment of waste (11%) (Bernhard et al., 2011).

Based on this data, it was decided that the possibility for mining of mass waste landfills, and not residual waste landfills, would be examined in the project "Landfill Mining Austria". In Styria, there are currently 7 mass waste landfills in operation, while 18 are already closed and inoperative (as of 2012). It is assumed that the recyclables to be recovered will mainly be found in untreated municipal waste and similar industrial waste.

Materials and methods

In principle, the approach of a material flow analysis was used as the basis for an integrated economic/ecological assessment of landfill mining projects in sub-areas (Austrian Water and Waste Management Association, 2003). A fundamental objective was defined as the "generation of base data for an integrated economic/ecological assessment of landfill mining projects".

Based on this, the definition and accounting of landfill mining systems or landfill systems used for comparison was carried out. These include, in particular, the spatial and temporal system boundaries, the individual processes in the system, material and goods flows, as well as the definition or identification of subsystems that may be present within the system boundaries (Beckmann et al., 2012; Gohlke, 2006). Specifically, the definition of spatial and temporal system boundaries must be assigned very great importance, since this can greatly affect the outcome of a subsequent economic and environmental evaluation (Ortmann und Döberl, 2010).

In addition, for landfill mining projects, their influencing factors need to be examined and quantified in advance (van Passel et al., 2013). For this purpose, the environment of such projects was considered in detail in the first step of the investigation and all aspects that could have a relevant impact on the implementation were identified. Only a full accounting of all influencing factors ultimately guarantees a reliable assessment result.

Results and discussion

Definition of the spatial system boundary, processes, goods and materials

An examination of the spatial system boundary of a landfill mining project results in very different levels of observation. Depending on the perspective, different availability and quality of data and information are available from the landfill operators. Furthermore, spatial system boundaries affect the complexity and cost of providing the data and the level of detail with which it should be included in the calculation. Therefore, a clarification must be made concerning which processes and processing steps related to landfill mining must be considered. So, it is crucial which sorting, processing and treatment steps can be carried out by the landfill operator at the site itself, or whether external systems must be used outside the landfill site. If this is the case, additional data and information on, for example, the transport and utilization of third-party systems, is to be included in the considerations. Another aspect that must be considered in the spatial system boundaries is the refilling of excavated landfill waste that cannot be recycled and, at best after pretreatment, must be re-deposited. Depending on whether the re-deposition must be at the deconstructed landfill site itself or in an external landfill, different framework conditions must be taken into account.

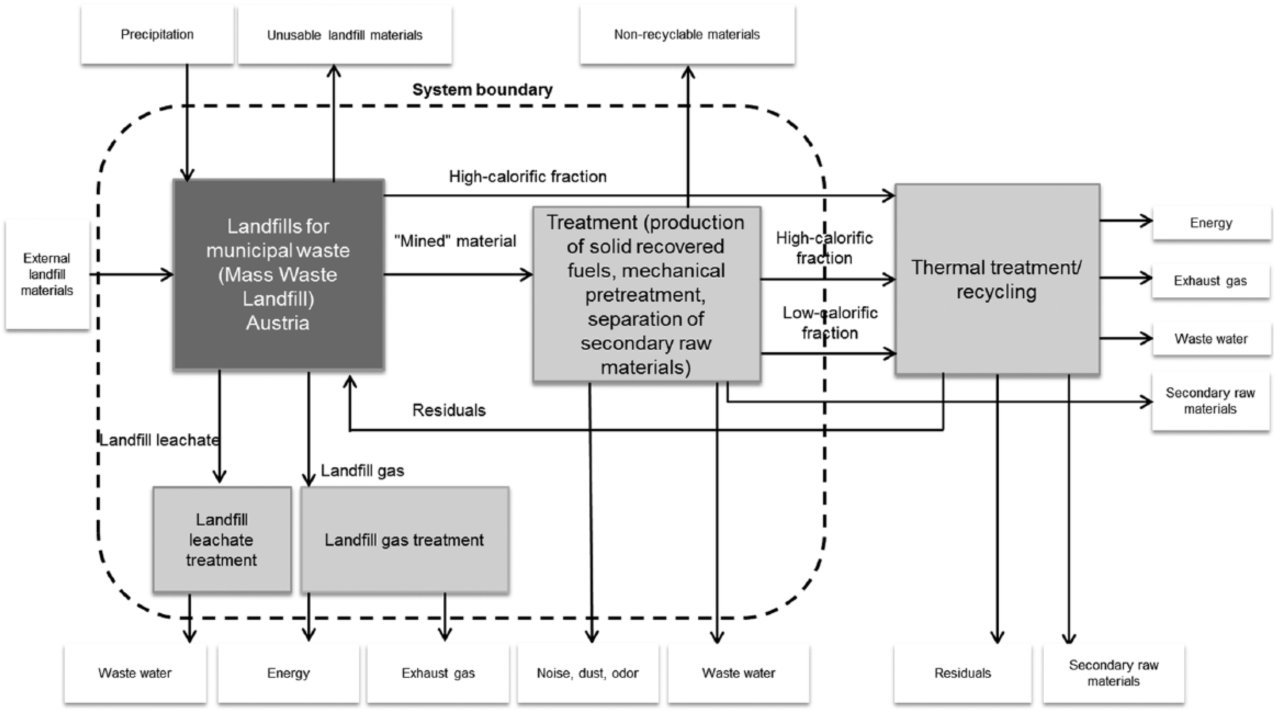

Figure 2. Spatial system boundary for landfill mining projects in Austria.

Based on the investigations, all the necessary process steps for the definition of the spatial system boundary are taken into account for the present landfill mining project in Austria that are necessary, from preparing, processing and sorting, to providing a marketable material/product by the landfill operator. It is irrelevant whether these process steps are carried out on-site or at an external location. It is important, however, that specifications on quality requirements from secondary raw materials and alternative fuel markets are available for these materials and products. For example, calorific properties and the amount of heavy metals and chlorine determine the suitability of the high-caloric fractions as substitute fuels (Nispel, 2012). Quality requirements are necessary to provide landfill operators with planning security for required process steps for manufacturing a marketable, quality-assured existing substance. Figure 2 shows the possibilities of the spatial system boundary for landfill mining projects in Austria.

The choice of the spatial system boundary for landfills in the closure/aftercare phase without landfill mining is not a challenge, in contrast to the temporal boundary, and can be seen in Figure 3.

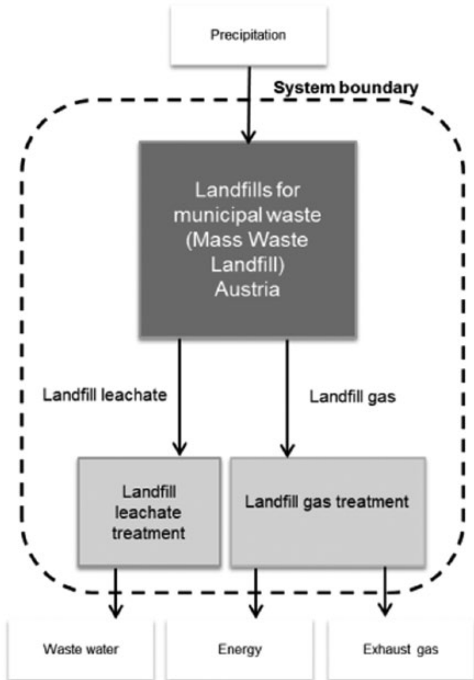

Figure 3. Spatial system boundary for landfills in the closure/aftercare.

Definition of the temporal system boundary

The definition of the temporal system boundaries in landfill mining projects and landfills greatly influences the results of a subsequent economic and environmental assessment. For this reason, different landfill phases and their duration, which are of importance for such projects, are described and defined here.

According to the Austrian Landfill Ordinance of 2008 (Federal Ministry of Agriculture, Forestry, Environment and Water 2008), the aftercare phase of a landfill begins with the indicated end of waste disposal and ends with the official finding that no aftercare action is required. This is the case when a landfill is no longer expected to be a risk for humans and the environment (Laner et al., 2011).

As a calculative basis for the assessment, 30 years are set of the financial deposit for the enforcement costs for mass waste

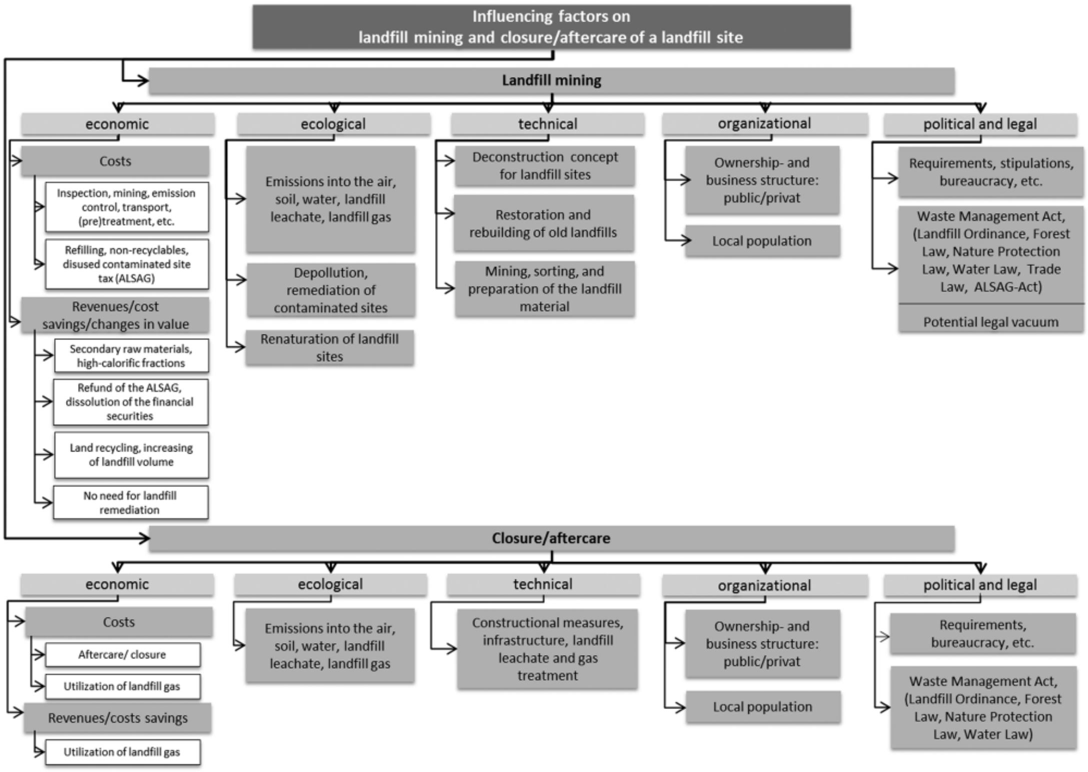

Figure 4. Comparison of influencing factors on landfill mining and closure/aftercare of landfills.
ALSAG (Altlastensanierungsgesetz): the ALSAG stipulates a landfill tax depending on the quality of waste.

and residual waste landfills in accordance with the Landfill Ordinance of 2008. If biodegradable waste, especially mixed municipal waste, was disposed of at a certain landfill, the calculative period is 40 years.

It should be noted that the actual duration of the aftercare period from the end of the deposition phase is not limited as a matter of law, but after assessing the criteria "if risk for humans and the environment is no longer to be expected for this landfill".

According to Laner and Fellner (2012), site-specific factors play a crucial role in the estimation of required landfill aftercare periods. These works resulted in aftercare periods of 30–560 years for three already-closed solid-waste household landfills depending on different aftercare concepts. The decisive factor for determining the aftercare period at solid-waste household landfills is leachate emissions. Other periods specified in the literature for reactive and already-closed household waste landfills in this context are 30–80 years (Burkhardt and Egloffstein, 2005) or 10–50 years (Stegmann et al., 2006). Based on these considerations, infinite aftercare lives must sometimes be assumed depending on the site. Since this cannot be calculated economically, a project-specific realistic follow-up period of 40 years for landfills is defined in order to enable the comparison with a landfill mining project. This approach is based on the statutory calculative approaches for determining financial securities for mass waste landfills with high amounts of non-treated municipal waste, in accordance with Appendix 8 of the Landfill Ordinance of 2008. Since deposits made before the ban of untreated waste in 2004 (in exceptional cases 2008) are considered in this project, landfill mining is considered until the year 2048 at the latest.

Described periods and landfill phases, as has already been mentioned, have a significant influence on the necessary definition of the temporal system boundary for an economic/ecological assessment of landfill mining projects. A number of time-dependent parameters must be taken into account in this context. Residues and their qualities recovered from the disposal site, which are highly dependent on the duration of deposition, play a major role. If one considers, for example, the degree of corrosion of metals present in the disposal site, it can be seen that this can strongly influence the attainable prices on the raw materials markets. Another aspect is the water content in the residue, which makes further processing more difficult and also depends on the duration of the deposition. The temporal fluctuations and developments of achievable secondary raw material and fuel prices that can be obtained on the market are directly linked to this. These decisively influence the revenues and thus directly affect the results of an economic evaluation.

Influencing factors for an integrated assessment of landfill mining projects

The result of this investigation is a list of relevant influencing factors that are structured into different groups in a later step. The classification of these groups is done in terms of economic, ecological, technical, organizational and political and legal factors, which thereby facilitates the further structured approach. Figure 4 shows a summary of different influencing factors for landfill mining projects and landfills in the aftercare or closure phase in Austria.

Economic influencing factors

Economic influencing factors are usually cost and revenue items that correlate directly with other influencing parameters and allow an assessment of the economics of landfill mining projects (Gosten, 2009). The DWA (German Association for Water, Wastewater and Waste) "Deconstructing Landfilled Waste", among others, lists following cost and revenue items:

Cost items (DWA German Association for Water, Wastewater and Waste e.V., 2012).

- Planning and approval of the mining action, including all opinions and evidence.
- Mining of the landfill surface seal and the gas collection system as well as intermediate storage of re-usable materials.
- Preparatory and accompanying measures to limit emissions and for protecting employees during waste removal.
- Preparatory measures for the proper recovery, protection and disposal of hazardous waste.
- Waste removal and loading, including rough sorting (excavator sorting) for the separation of waste and soil, as well as for separation of coarse contaminants and hazardous waste.
- Transport and disposal costs for hazardous waste, if appropriate for different systems with different types of waste.
- Transport of recyclable portions of the landfill material for further processing (sorting, treatment, etc.).
- Further processing (sorting, treatment, etc.) of the removed waste in different plants if appropriate.
- Sampling, analysis and review of all treatment products according to the assignment values.
- Market observations on the profit-oriented marketing of the marketable material (price on the raw material markets, qualities of the residues, etc.).
- Basic or intermediate cover (if raw materials are stored again).
- Removal, for example, refilling of non-recyclable waste.
- Construction of a new landfill surface seal (if non-recyclable residues are redeposited at the site).
- Emission and immission monitoring (soil, water, air).
- Mining, clean-up and marketing of cleared landfill sites.
- Compensating measures for residents and neighbors.
- Levy imposed on the landfilling of waste (ALSAG) for depositing residues from landfill mining or possibly other contributory activities in the scope of landfill mining.

Revenues/cost savings (DWA German Association for Water, Wastewater and Waste e.V., 2012).

- Revenue from the recovery of secondary raw materials and fuels (scrap iron, non-ferrous metals, high calorific fraction, etc.) depending on their qualities and prices on the raw material markets.
- Recovery of landfill space and surface – extension lifetime of landfills or new use of the recovered area – land recycling.
- Recoveries from already-paid levy imposed on the landfilling of waste (ALSAG).
- No need any more for provided financial securities (Bagin, 2012).
- No costs for monitoring any longer.
- No costs for operation of the mined landfill any more.

In addition to the listed cost and revenue items, future cost savings that can be achieved through landfill mining must also be included in the considerations. These include clean-up of landfill sites that will no longer be necessary in the future and the setting free of the provided financial securities which were given. Thus, landfill mining would, at best, render clean-up of old landfill sites superfluous, the landfill phases would be reduced and existing provisions could be dissolved.

Ecological influencing factors

Ecological factors that have a negative impact on landfill mining can be emissions into the air, soil and water that are caused by excavating the landfill, preparing the landfill material and necessary transport measures. Ecological factors with beneficial effects can be the removal of pollutants from the landfill, the renaturation of landfill space or the removal of a source of danger (e.g. hazardous landfill waste) and the clean-up of a contaminated site (Schulte, 2012).

Technical influencing factors

The fundamental ability to deconstruct a landfill site depends heavily on the technical influencing factors and primarily affects excavating, sorting (pulping, conditioning/packaging and sorting) and the preparation of landfill material (Pretz and Garth, 2012; Rettenberger, 2012a). If, for example, only part of a landfill is deconstructed by landfill mining, necessary adjustment measures of the remaining landfill must be made to make it state-of-the-art (this can even involve re-construction of the landfill).

Organizational influencing factors

Organizational influencing factors on landfill mining projects are defined as operators, owners and neighboring structures of landfill sites, which are considered in order to account for the influence of persons, groups or institutions on such projects (Milosevic and Naunovic, 2013).

Landfill owners or property owners are classified as public or private owners on the basis of the criteria listed below. Public ordering parties of landfill mining projects, in contrast to private ordering parties, are obligated to announce orders with different threshold values to the public, for example in accordance with the Federal Procurement Act of 2006 (Federal Chancellery, 2006).

Furthermore, financial security for the maintenance, closure as well as decommissioning and aftercare of landfills can be created for a public operator by a declaration of liability from a local authority or a water and waste management association. In contrast, a guarantee or declaration of liability for the financial security of the measures mentioned above (with the exception of a bank guarantee or insurance) is not permitted by private landfill operators (Federal Ministry of Agriculture, Forestry, Environment and Water, 2010).

The following landfill owner or ownership structures can be cited for Austria.

- Countries, public.
- Municipalities, public.
- Waste management associations, public.
- Private Public Partnership (PPP) models with public–private cooperation.
- Companies, private.

Another important organizational influencing factor is the neighboring structure. It decides what form a possible re-use of land recovered through landfill mining can take (land recycling). It could, for example, be used as an industrial plot, or even re-designated as a building site or agricultural land in the future.

Political and legal influencing factors

Political influencing factors can have a significant role in the success of landfill mining projects. For example, requirements for action against odor, noise and dust pollution, support measures or bureaucratic efforts to implement such projects play a major role.

The political and legal framework, especially for landfill mining taking into account the recovery of recyclable materials from landfills, currently leads to strong uncertainties at the European (Elger, 2013) and national level. In Austria, there is a dense legislative network that regulates the licensing, operation, closure and aftercare of landfills, but for landfill mining no material legislation exists yet. Waste legislation in Austria does not include administrative regulations that prevent landfill mining, i.e. mining of closed landfills, especially since the landfill is defined as a plant that is built or used for the long-term depositing of waste and thus opening closed landfills for purposes other than for clean-up of contamination is by definition not permitted. There exists no defined legal framework for landfill mining projects yet.

Mutually influencing factors

A challenge in the study of influencing factors is their influence on each other. For example, the existing legal framework affects economic considerations with regard to performing landfill mining projects in different ways.

In this context, a classification of the deposits that can be considered for landfill mining into "dumped before 1989" and "dumped after 1989" makes sense, since deposits in landfills before this defined year were not yet subject according to the conditions of the Altlastensanierungsgesetz (ALSAG) (Austrian Federal Ministry of Agriculture and Forestry, Environment and Water, 2013). If waste that was deposited before 1989 is excavated and treated during landfill mining, levy imposed on the landfilling of waste (ALSAG) taxes might need to be calculated for the treatment itself but also for the remainders resulting from the treatment of such waste. The tax law questions concerning landfill mining are very complicated and cannot be accurately estimated according to the current legal situation in Austria. An individual case study should be done depending on the concept that underlies the recovery of existing substances. Relevant questions are as follows.

- Has a levy imposed on the landfilling of waste (ALSAG) already been paid for the deposited waste?
- What amount was paid for the levy imposed on the landfilling of waste (ALSAG) (the question is whether a difference between the original and current level of tax must be paid)?
- Whether and in what form was the processed/prepared/sorted waste changed?
- Whether a final contributory activity was performed with the residues from waste treatment (e.g. dumping of waste in a landfill body, incineration of waste, production of fuel products from the waste, etc.) (Austrian Federal Ministry of Agriculture and Forestry, Environment and Water, 2013) and if so, which?

If waste is treated, for which no levy imposed on the landfilling of waste has yet been paid, and this is then taken to the landfill, it is doubtful whether there can ever be a tax-free rearrangement. In most cases, waste for which no tax was paid was deposited prior to 1989, and it is questionable whether landfills attributable to this period are permitted even when technical adjustments are made for a renewed dumping of waste, or whether it is not a completely new situation that is to be reassessed in terms of tax law. Figure 5 illustrates the described relationships.

Based on these interrelations, it can be seen that prior legal certainty is of great importance for project applicants of landfill mining projects; legal security is a prerequisite for a complete economic calculation in order to be able to make a serious economic feasibility study of a landfill mining project (Sanden und Schomerus, 2012).

Conclusions

Until today, only individual economic factors, such as cost and revenue items as well as technical specifications or requirements, are available for an integrated and traceable ecological/economic assessment of landfill mining projects, but no standardized assessment tools exist. Influencing factors, such as land recycling, re-use scenarios, price fluctuations on the secondary raw material markets, operating structures or synergies and costs

Figure 5. Legal/economic interrelation using the example of levy imposed on the landfilling of waste for landfill mining projects in Austria.

saved in aftercare, were not taken into account, or not to a sufficient degree. But in order to develop these assessment tools, the necessary foundations and influencing factors and system boundaries must be examined and system boundaries must be defined in advance. The necessary approach may be that of a materials flow and goods flow analysis.

The definition of the spatial and temporal system boundaries significantly influences both the selection of the assessment instrument and the result of the subsequent evaluation. Basically, it must be assumed that, although spatial system boundaries are defined, no generally accepted temporal system boundaries can be defined. These must be determined individually based on the project and the conditions adjusted on-site. A simple classification of the landfill with regard to, for example age, type of cover or seal, performed before landfill mining appears quite reasonable and can facilitate a definition of the system boundaries.

Basic economic, ecological, technical, organizational or political and legal factors must be taken into account for landfill mining projects. However, their interrelation necessitates an integrated and complete investigation within the defined project system boundaries.

In principle, based on the research results described in this article, there is a need for a number of different research projects in several directions. A great need exists in the area of quantification of the different influencing factors defined in this article. The aggregation of individual factors within groups (e.g. economic) and multidimentionality across the five groups of influencing factors also create some research questions that need to be clarified. Another focus in the future should be placed on the evaluation, selection, adaptation or development of appropriate integrated economic/ecological assessment tools for landfill mining projects. The validity check of these assessment tools based on real data and the review of the required quality and quantity of input data to obtain usable results constitute further research needs.

Declaration of conflicting interests

The authors declare that there is no conflict of interest.

Funding

This work was financed by the Austrian Research Promotion Agency (FFG) and part of the project "LAMIS – Landfill Mining Austria".

References

Austrian Federal Ministry of Agriculture and Forestry, Environment and Water (2013) Law for the clean-up of contaminated sites *(Altlastensanierungsgesetz = ALSAG)*.Vienna, Austria.

Austrian Water and Waste Management Association (2003) The application of material flow analysis in waste management, issued by Austrian Water and Waste Management Association *(Österreichischer Wasser- und Abfallwirtschaftsverband)*. Vienna (ÖWAV Regelblatt 514).

Angerer G, Erdmann L, Marscheider-Weidemann F, et al. (2009) Raw materials for the technologies of the future. Influence of the sector specific raw material demand in raw material intensive technologies of the future on the future raw material demand *(Rohstoffe für Zukunftstechnologien. Einfluss des branchenspezifischen Rohstoffbedarfs in rohstoffintensiven Zukunftstechnologien auf die zukünftige Rohstoffnachfrage)*, Stuttgart: Fraunhofer-IRB-Verl (ISI-Schriftenreihe "Innovationspotenziale").

Bagin W (2012) What are the costs for closed landfills – examples from the province of Böblingen *(Was kosten abgeschlossene Deponien – Beispiele aus dem Landkreis Böblingen)*. In: Kranert M (ed.) Up to date landfill technologie 2012 – strategies for landfills in the closure and aftercare phase *(Zeitgemäße Deponietechnik 2012. Strategien für Deponien in Stilllegungs- und Nachsorgephase)*. Munich: Oldenbourg Industrieverl. (Stuttgarter Berichte zur Abfallwirtschaft, 104).

Beckmann M, Scholz R and Pohl M (2012) Balancing and energetic assessement of waste treatment processes *(Bilanzierung und energetische Bewertung von Verfahren zur Abfallbehandlung)*. In: Thome K Kozmiensky and Beckmann M (ed.) Energy from Waste *(Energie aus Abfall)*. Neuruppin: TK Verlag (9), 147–189.

Bernhard A, Domenig M, Reisinger H, et al. (2011) Landfill mining, economics, ressource potential *(Deponierückbau. Wirtschaftlichkeit, Ressourcenpotenzial und Klimarelevanz)*, Vienna (Report/ Umweltbundesamt, 0378).

Bockreis A and Knapp J (2011) Landfill Mining – Landfills as a source of resources *(Landfill Mining – Deponien als Rohstoffquelle)*. In: *Österr Wasser- und Abfallw* 63(2–3): 70–75.

Bölte S and Geiping J (2011) Municipal solid waste landfills – Aftercare or deconstruction *(Siedlungsabfalldeponien – Nachsorge oder Rückbau?)*. University of Applied Science, Fachhochschule Münster. 12. Münsteraner Abfallwirtschaftstage. Münster, 15.02.2011.

Bothmann P, Doedens H, Eitner R and Engelmann B (2002) Relocation and mining of landfilled waste *(Umlagerung und Rückbau von deponierten Abfällen)*, issued by DWA German Association for Water, Wastewater and Waste e.V.- ATV-DVWK/VKS Fachausschuss 3.6 "Deponien". Hennef (ATV-DVWK-Arbeitsbericht).

Burkhardt G and Egloffstein T (2005) Assessment of after-care and follow-up costs of landfills *(Ermittlung der Nachsorge und Folgekosten von Deponien)*. In: Kranert M (ed.) Landfill recovery ordinance and solutions to landfill close-down *(Deponieverwertungsverordnung und Lösungsansätze bei der Deponiestilllegung)*, Bd. 84. München: Oldenburg [in Komm.] (Stuttgarter Berichte zur Abfallwirtschaft, Bd. 84), 77–98.

DWA German Association for Water, Wastewater and Waste e.V. (ed.) (2012) Mining of landfilled waste *(Rückbau von deponierten Abfällen)*. Hennef: DWA (DWA-Themen, T6).

Elger L (2013) Landfill Mining; a realistic contribution to resource protection *(Landfill Mining: Ein realistischer Beitrag zum Ressourcenschutz?)*. *NuR* 35(4): 257–263.

European Commission (2008) Communication from the Commission to the European Parliament. The raw materials initiative -meeting our critical needs for growth and jobs in Europe. KOM 699, 04.11.2008.

European Commission (2011) Communication from the Commission to the European Parlament, the Council, the European economic and social Committee and the Committee of the Regions, Tackling the Challenges in commodity markets and on raw materials. KOM 25, 02.02.2011.

Frändegård P, Krook J, Svensson N and Eklund M (2013) A novel approach for environmental evaluation of landfill mining. *Journal of Cleaner Production* 55: 24–34.

Franke M, Mocker M and Faulstich M (2010) Resource potential of landfill mining – A national and regional evaluation. In: ISWA World Congress. Vol. 15.

Franke M, Mocker M and Löh I (2011) Landfill Mining – Raw material potentials in landfills *(Landfill Mining – Rohstoffpotentiale in Deponien)*. In: Thomé Kozmiensky K and Goldmann D (ed.) Recycling and raw material *(Recycling und Rohstoffe)*, Vol. 4. Neuruppin: TK, 403–415.

Fricke K (2009) Urban Mining – only a buzzword (Urban Mining – nur ein Modebegriff). *Müll und Abfall* 10: 489.

Fricke K, Münnich K, Heußner C, et al. (2012) Landfill mining a contribution of waste management to resource security *(Landfill Mining ein Beitrag der Abfallwirtschaft für die Ressourcensicherung)*. In: Thomé Kozmiensky K and Goldmann D (eds) Recycling and raw materiasls *(Recycling und Rohstoffe)*. Vol. 5. Nietwerder: TK, 933–944.

Federal Chancellery (2006) Federal Procurement Act (*Bundesvergabegesetz)* 2006: Federal law on the procurement of orders *(Bundesgesetz über die Vergabe von Aufträgen)*. Vienna, Austria.

Federal Ministry of Agriculture, Forestry, Environment and Water (2008) Landfill Ordinance 2008. Vienna, Austria.

Federal Ministry of Agriculture, Forestry, Environment and Water (2010) Statutory calculative approach for determining financial securities for landfills *(Richtlinie zur Berechnung von finanziellen Sicherstellungen für Deponien)*. Federal Ministry of Agriculture, Forestry, Environment and Water. Vienna; Austria.

Gäth S and Nispel J (2010) Resource potential of selected household waste landfills in Germany (Ressourcenpotenzial von ausgewählten Hausmülldeponien in Deutschland). In: Lorber , et al. (eds.) *Proceedings of the 10th Depotech conference*, 375–380.

Gohlke O (2006) Tools for the assessment of Waste Treatment Processes *(Werkzeuge zur Bewertung von Abfallbehandlungsverfahren)*. Methoden und Ergebnisse. 1st ed. Düsseldorf: VDI.

Gosten A (2009) Investigation with regard to the positive effects of the excavation of landfills *(Untersuchungen über den Nutzen des Deponierückbaus)*. In: Thomé Kozmiensky K and Goldmann D (eds) Recycling and raw materials *(Recycling und Rohstoffe)*. Vol. 2. Neuruppin: TK, 447–468.

Graedel TE, Allwood J, Birat JP, et al. (2011) What do we know about metal recycling rates? *Journal of Industrial Ecology* 15(3): 355–366.

Hölzle I (2010) From excavation of landills to landfill mining – a synthesis of international investigations (Vom Deponierückbau bis zum landfill mining – eine Synthese internationaler Untersuchungen). In: *Österr Wasser- und Abfallw* 62(7–8): 155–161.

Huy D, Andruleit H, Babies H-G, et al. (2013) *Germany – Natural Resources Situation* 2012. Hg. v. Federal Institute for Geosciences and Natural Resources.

Jones PT, Geysen D, Tielemans Y, et al. (2013) Enhanced landfill mining in view of multiple resource recovery: a critical review. *Journal of Cleaner Production* 55: 45–55.

Kretschmer T (2010) New technologies. Core-topics of technology monitoring at INT between 1996 and 2009 *(Neue Technologien. Kernthemen des Technologiemonitorings am INT zwischen 1996 und 2009)*. Stuttgart: Fraunhofer-Verl.

Krutzler T, Reisinger H and Schindler I (2012) Resource consumption of industry in Austria. Analysis and prospect for the most important sectors and rare metals *(Ressourcenverbrauch der Industrie in Österreich. Analyse und Ausblick für die bedeutendsten Branchen und seltene Metalle)*. Wien: Umweltbundesamt (Report/Umweltbundesamt, [N.F.], 363).

Laner D and Fellner J (2012) Deriving of site-specific criteria for the ending of the need of landfill aftercare measures – case studies *(Ableitung standortspezifischer Nachsorgeentlassungskriterien: Fallstudien.)* In: Lorber K-E, Pomberger R, Adam J, et al. (eds) Waste management, Waste technology, Landfill technology and contaminated sites *(Abfallwirtschaft, Abfalltechnik, Deponietechnik und Altlasten.) proceedings of the 11th DepoTech conference*, University of Leoben. Leoben, pp.539–544.

Laner D, Fellner J and Brunner PH (2011) Site specific criteria for the assessment of the environmental soundness of landfill emissions based on the aspect of the duration of the after-care period *(Standortbezogene Kriterien zur Beurteilung der Umweltverträglichkeit von Deponieemissionen unter dem Aspekt der Nachsorgedauer (SKUDENA))*. Technical University Vienna, Institute of water quality, resource management and waste management: Vienna.

Milosevic I and Naunovic Z (2013) The application of a multi-parameter analysis in choosing the location of a new solid waste landfill in Serbia. *Waste Management & Research* 31(10): 1019–1027.

Nispel J (2012) Resource potential of houshold waste landfills on the example of the regional landfill Hechingen *(Ressourcenpotenzial von Hausmülldeponien am Beispiel der Kreismülldeponie Hechingen.)* Gießen: Univ. (Boden und Landschaft, 59).

Ortmann M and Döberl G (2010) Ecological assessement of measures for contaminated sites *(Umweltökologische Bewertung von Maßnahmen an kontaminierten Standorten. Endbericht zum Arbeitspaket 7 des Projektes "Altlastenmanagement 2010"); (Neuausrichtung der Beurteilung und Sanierung von kontaminierten Standorten)*. Vienna Umweltbundesamt (Report/Umweltbundesamt, [N.F.] 159).

Pretz T and Garth A (2012) Sorting of dumped waste *(Sortierung von abgelagerten Abfällen.)* In: Thomé Kozmiensky K and Goldmann D (eds) recycling and raw materials *(Recycling und Rohstoffe)*. Vol. 5. [Nietwerder]: TK, 946–954.

Province of Styria (2013) Department A14, "Waste Management and Sustainability" Water Management, Resources and Sustainability Unit", Summary of mass waste landfill in Styria *(Zusammenfassung der Massenabfalldeponien in der Steiermark)*. University of Leoben.

Rettenberger G (2012a) Raw material potential in landfills *(Rohstoffpotential in Deponien.)* In: Thomé Kozmiensky K and Goldmann D (eds) Recycling and Raw Materials *(Recycling und Rohstoffe)*, Vol, 5. [Nietwerder]: TK, 919–931.

Rettenberger G (2012b) Excavation of landfills – dream and reality *(Deponierückbau – Traum und Wirklichkeit*.) 16th international symposium on waster, waste water and energy, symposium on sustainable waste management *(16. Internationales Symposium Wasser, Abwasser, Energie, Symposium zur nachhaltigen Abfallwirtschaft.)* Internationales Congress Center Munich. Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V., European Water Association, International Solid Waste Association, Verband kommunaler Unternehmen Abfallwirtschaft und Stadtreinigung VKS. Munich, 07.05.2012.

Sanden J and Schomerus T (2012) Legal imlications of landfill mining. Andvances in landfill law for the sake of resource recovery (Rechtsfragen des Landfill Mining. Weiterentwicklung des Deponierechts zur Rückgewinnung von Ressourcen). *AbfallR : Zeitschrift für das Recht der Abfallwirtschaft* 11(5): 194–201.

Schulte B (2012) Excavation of landfills *(Deponierückbau – Vorstellungen des Themenbandes von DWA und VKU.)* 8. Leipziger Deponiefachtagung. Hochschule für Technik, Wirtschaft und Kultur. Leipzig, 28.02.2012.

Stegmann R, Heyer KU, Hupe K, et al. (2006) Aftercare of landfills – possible options, duration, costs and quantitative criteria for ending of the after care period *(Deponienachsorge – Handlungsoptionen, Dauer, Kosten und quantitative Kriterien für die Entlassung aus der Nachsorge)*. Hg. v. Umweltbundesamt. Hamburg.

van Passel S, Dubois M, Eyckmans J, et al. (2013) The economics of enhanced landfill mining: private and societal performance drivers. *Journal of Cleaner Production* 55: 92–102.