Environmental and socio-economic impacts of landfills

Maheshi Danthurebandara
University of Peradeniya

Steven Van Passel
University of Antwerp

Dirk Nelen
Flemish Institute for Technological Research

Yves Tielemans
Group Machiels

ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS OF LANDFILLS

Maheshi Danthurebandara[1,2]
Steven Van Passel[2,5]
Dirk Nelen[3]
Yves Tielemans[4,5]
Karel Van Acker[1,5]
[1]Department of Metallurgy and Materials Engineering, KU Leuven, Belgium
[2]Centre for Environmental Sciences, Faculty of Business Economics, UHasselt, Belgium
[3]VITO, Belgium
[4]Group Machiels, Belgium
[5]Enhanced Landfill Mining Consortium, Belgium

ABSTRACT

A modern landfill is an engineered method for depositing waste in specially constructed and protected cells on the land surface or in excavations into the land surface. Despite the fact that an increasing amount of waste is reused, recycled or energetically valorized, landfills still play an important role in waste management strategies. The degradation of wastes in the landfill results in the production of leachate and gases. These emissions are potential threats to human health and to the quality of the environment. Landfill gas consists mainly of methane and carbon dioxide, both important greenhouse gases. Landfill sites contribute 20% of the global anthropogenic methane emissions. Furthermore, it usually contains a large number of other gases at low concentrations, some of which are toxic. Leachate can migrate to groundwater or even to surface water through the flaws in the liners and this poses a serious problem as aquifers require extensive time for rehabilitation. Construction and management of landfills have ecological effects that may lead to landscape changes, loss of habitats and displacement of fauna. Socio-economic impacts of landfills include risks for public health derived from surface or groundwater contamination by leachate, the diffusion of litter into the wider environment and inadequate on-site recycling activities. Nuisances such as flies, odors, smoke and noise are frequently cited among the reasons why people do not want to reside close to landfills. Various researches conclude that landfills likely have an adverse negative impact upon housing values depending upon the actual distance from the landfill. The present paper reviews the environmental and socio-economic impacts related to landfills and presents existing modeling approaches to assess these impacts. Furthermore, this review is complemented with suggestions to minimize the environmental burden of landfills and to re-introduce the buried resources to the material cycle.

KEYWORDS

Landfill, Landfill gas, Leachate, Environmental impacts, Socio-economic impacts, Bio reactor, ELFM.

1 INTRODUCTION

Despite the fact that the EU waste hierarchy, as set by the Waste Framework Directive (2008/98/EC) establishes the preference of reuse, recycling and recovery of waste above landfilling, a significant amount of waste is still landfilled. It is a well-known fact that landfilling has environmental effects, mainly due to the long term methane emission and leachate production. Landfill gas consists mainly of methane and carbon dioxide and it can also contain a large number of other gases at low concentrations some of which are toxic[1]. The substances that are present in landfill gas are known to contribute to several environmental problems such as global warming, acidification, depletion of the quality of ecosystem as well as social issues like human health [2-7]. Leachate production is also a major concern as leachate can migrate to surface and groundwater. This is more serious than river pollution because aquifers require extensive time for rehabilitation [1]. Landfill leachate may present significant concentrations of trace metals, nutrients such as nitrate and phosphate, ammonia and chlorides. Apart from the environmental burdens, occupation and requirement of the enormous space for landfills generates the issue of land scarcity for the development of human society and eco systems. Moreover, landfills decrease the market value of the surrounding area [4, 5]. Different modeling approaches to quantify landfill emissions have been developed. Most of the models concentrate on landfill gas and leachate and a few of them address nuisances like odor, dust, noise and etc. In addition to the generation models, a few studies have been performed to model the impacts of landfills. Landfill modeling in life cycle analysis (LCA) is the most common approach.
The purpose of our research is to review the existing literature on environmental and socio-economic impacts of landfills. An attention has been given to the available modeling approaches to assess the landfill emissions and their impacts. Furthermore, this paper highlights evolving landfill concepts such as landfill bio reactors and enhanced landfill mining as to minimize the risk and environmental burdens of landfills and to re-introduce the disposed resources to the material cycle.

2 LANDFILLS AND LANDFILL EMISSIONS

A modern landfill is an engineered method for depositing waste in specially constructed and protected cells on the land surface or in excavations into the land surface. Within the landfill, biological, chemical and physical processes occur and they promote the degradation of wastes and result in the production of leachate and gases. The landfill ecosystem is quite diverse due to the heterogeneous nature of waste and the variety of landfill operating characteristics. The diversity of the ecosystem promotes stability; however the system is strongly influenced by environmental conditions such as temperature, pH, the presence of toxins, moisture content and the oxidation reduction potential. The stabilization of wastes proceeds in five sequential and distinct phases [8]:

1) Initial adjustment phase: This phase is associated with initial deposition of solid waste and accumulation of moisture within landfills. An acclimatization period is observed until sufficient moisture develops to support an active microbial community.
2) Transition phase: In the transition phase transformation from aerobic to anaerobic environment occurs.
3) Acid formation phase: The continuous hydrolysis of solid waste followed by the microbial conversion of biodegradable organic content results in the production of intermediate volatile organic acids at high concentrations throughout this phase.
4) Methane fermentation phase: Intermediate acids are consumed by methanogenic bacteria and converted into methane and carbon dioxide.

5) Maturation phase: During the final state of landfill stabilization, nutrients and available substrate become limiting, gas production dramatically drops and leachate strength stays steady at much lower concentrations.

Apart from landfill gas and leachate emission, wind-blown litter, vermin and insects are also identified as the minor emissions of the landfills. But the following discussion is limited to the landfill gas and leachate as they are the most important causes for number of environmental and socio economic impacts.

2.1 Landfill Gas

In theory the biological decomposition of one ton of municipal solid waste produces 442 m^3 of landfill gas containing 55% methane and a calorific value of 15 - 21 MJ/m^3 [9], which is approximately half that of natural gas. The major components of landfill gas are methane (CH_4) and carbon dioxide (CO_2), with a large number of other constituents at low concentrations such as ammonia, sulfide and non-methane volatile organic compounds (VOCs) [1]. Chemical and biochemical transformations within the landfill create new organic or inorganic substances; e.g. tri- and per-chlorethylene to vinylchloride; amino acids to methyl- and ethyl-mercaptans; or sulphur compounds to hydrogen sulphide (H_2S). For these reasons, inclusion of large amounts of particular types of industrial waste in a landfill can generate high quantities of other gaseous compounds. For example, a very large proportion of plasterboard (i.e. gypsum, $CaSO_4$) may cause the emission of H_2S [10]. The US EPA [11] listed 94 non-methane organic compounds found in air emissions from municipal solid waste landfills, which included benzene, toluene, chloroform, vinyl chloride, carbon tetrachloride, and 1,1,1trichloroethane. Forty-one are halogenated compounds. Toluene, xylenes, propylbenzenes, vinyl chloride, tetrachloroethylene, methanethiol and methanol have been reported from landfills that received both municipal and industrial wastes [12]. CH_4 and CO_2 are greenhouse gases which were the main focus of the 1997 Kyoto Agreement and of subsequent efforts at world-wide emission reduction. Landfill sites contribute 20% of the total global anthropogenic methane emission [13].

Landfill gas is generally controlled by installing vertical or horizontal wells within the landfill. These wells are either vented to the atmosphere or connected to a central blower system that pulls gas to a flare or treatment process. Intergovernmental Panel on Climate Change (IPCC) report that the landfill gas collection efficiencies ranging from 9-90% and estimates an average of 20% [14]. The uncaptured gas can pose an environmental threat because methane is a greenhouse gas and many of the VOCs are odorous and toxic. This issue is discussed in the other sections of this paper.

2.2 Leachate

Leachate is defined as any liquid percolating through the deposited waste and emitted from or contained within a landfill. As it percolates through the waste it picks up suspended and soluble materials that originate from, or are products of the degradation of the waste. The principal organic contents of leachate are formed during the breakdown process described above and its organic strength is normally measured in terms of biochemical oxygen demand (BOD), chemical oxygen demand (COD), or total organic carbon (TOC) [1]. The municipal solid waste leachate contains a wide variety of hazardous, toxic or carcinogenic chemical contaminants [6]. Moreover, mining wastes, sewage sludge and residual solids from air pollution control equipment contain high concentrations of trace metals, a range of acids and even radioactive material. Under the acidic conditions hazardous trace metals such as copper, cadmium, zinc and lead dissolve and travel with leachate [1].The characteristics of leachate produced are highly variable depending on the composition of the waste, precipitation rates,

site hydrology, compaction, cover design, waste age, sampling procedures and interaction of leachate with the environment and landfill design and operation.
It is important to control and manage the leachate production and discharge due to the potential threat of it to both the environment, particularly groundwater, and human health. An effective leachate collection and removal system is a prerequisite for all non-hazardous and hazardous landfill sites and it must function over the landfill's design lifetime.

3 MODELING APPROACHES TO ASSESS THE LANDFILL EMISSION AND THEIR IMPACTS

Modeling landfill emissions and their impacts already exists for several decades. Many researchers have conducted studies to evaluate the landfill emission management. Most of the studies are mainly about landfill gas and leachate and a few of them address nuisances like odor, dust and noise. This section summarizes the different modeling approaches available to evaluate and quantify the landfill emission and their environmental and socio-economic impacts.
Attempts to model landfill gas formation stem from the early '80's. The first landfill gas formation models were made to help determine the size of landfill gas recovery projects. They estimate the amount of formation and including future expectation and gas recovery. More recent models quantify methane emission. As described in the review of Oonk H. [15], modeling of methane emission generally requires modeling of methane generation, measuring landfill gas recovery and assuming some methane oxidation. The emission equals the gas generation minus the gas recovery minus the gas oxidation.
According to Oonk, the major issue when modeling methane emissions is the modeling of the methane or landfill gas formation. Most of the models are based on a first order decay model (a first order decay models have one half-time of biodegradation) or a multi-phase model (multi-phase models consider 3 fractions: fast, moderate and slow degradation of waste, each with their own half-time of biodegradation). Modeling oxidation has received less attention: in most cases 10% of the methane flux through the top layer simply is assumed to be oxidized. Nevertheless, more recent models are being developed for the evaluation of methane oxidation as well. The most widely applied generation models are the IPCC model, the TNO model, GasSim Lite, Landgem, the Afvalzorg-model, the French E-PRTR-model and the Finnish E-PRTR-model [15]. The IPCC model is intended to give guidance to national authorities in the quantification of methane emissions from all landfills in a country. But the model itself can also be used for individual landfills. The choices exist between a first order decay model and a multi-phase model. The IPCC model accommodates for 4 different climate regions [16]. TNO is the first model in which model parameters were based on real data of landfill gas generation in a larger group of landfills. Both a first order and a multi-phase model were made, that describe landfill gas generation as a function of amount of waste deposited from different origin ([17, 18]. GasSim Lite quantifies all landfill gas problems of a landfill, ranging from methane emissions, effects of utilization of landfill gas on local air quality to landfill gas migration via the subsoil to adjacent buildings [15]. Landgem is a first order decay model, with separate default values for the rate constant of biodegradation for conventional and arid regions [19]. The Afvalzorg model itself is a multi-phase model and is intended to give a more realistic prognosis of methane generation at landfills with little or no household waste deposited. The French E-PRTR-model is a simplified first order decay model and the Finnish E-PRTR-model is a multi-phase model with model parameters for different climatic regions [15]. In addition to these models, three dimensional models have been developed for transport and reaction of gaseous mixtures in a landfill [20-24].

Successful prediction of the amount of landfill leachate generated and its composition is a highly complex and difficult task. As discussed in previous sections, the amount of leachate generated is primarily a function of water availability, waste characteristics and landfill surface conditions. Similar to landfill gas, numerous leachate generation and transport models have been developed. These models can be classified into two types: (1) models that emphasized only the quantity of leachate generated; and (2) models that combined both quantity and composition [25]. Among these models that can estimate the volume of leachate generated from a landfill, the Water Balance Method (WBM) is the most commonly used [25-27]. The WBM simply states that water infiltrating through the landfill cover and past the depth influenced by evapotranspiration will eventually emanate from the landfill as leachate. This is valid after the solid waste reaches absorptive capacity for holding water, which may take several years. Although this method is theoretically correct and simple, a great degree of uncertainty is associated with estimating its variables [28]. Demetracopoulos, Sehayek et al. [29] built up a mathematical model for the generation and transport of solute contaminants through a solid waste landfill. A three dimensional mathematical model has been developed by Demirekler, Rowe et al. [30] to estimate the quality and quantity of the leachate produced. The model takes the effects of changing hydraulic conductivity with overburden pressure and time dependent landfill development into consideration. Laner, Fellner et al.[31] suggested a methodology to estimate future emission levels, mainly leachate, for a closed municipal solid waste landfill. The approach is based on an assessment of the state of the landfill including detailed analysis of landfill monitoring data, investigations of the landfill waste and an evaluation of engineered landfill facilities.

Apart from these gas and leachate generation models, many modeling approaches have been developed for assessing the environmental and socio economic impact of the landfills. Landfill modeling in life cycle analysis (LCA) is the most common approach. Obersteiner, Binner et al. [32] introduce and discuss the different approaches concerning time horizon and life cycle inventory data for landfills in Central Europe. Damgaard, Manfredi et al. [3] performed an economic and environmental evaluation of landfill leachate and gas technologies by using waste LCA model EASEWASTE. A methodology to estimate future emission rates and evaluate the response of the affected environment based on the current state of the landfill and its surroundings has been introduced by Laner, Fellner et al. [31]. They present a modeling approach to evaluate residual environmental impacts in view of different post closure management strategies. In addition to that numerous LCA studies have been conducted to compare the environmental impact of landfills with that of other waste treatment technologies [33-35]. Furthermore, Úbeda, Ferrer et al.[36] developed a Gaussian dispersion model to evaluate the odor impact from a landfill area. Apart from environmental modeling a few studies report for economic models of landfills. Similar to the environmental modeling, landfilling has been compared with the other waste management systems from an economic point of view [7, 37]. Some studies have been performed to assess the social impacts of landfills. Assessing the impact of landfills on residential property values is an example [4, 5, 38].

4 ENVIRONMENTAL IMPACT OF LANDFILLS

As with any waste management activity, landfilling is also a potential threat to the quality of the environment due to its gaseous and leachate emissions as well as wind-blown litter and dust. There are also substantial environmental effects associated with waste transport and collection. In this section the environmental effects of landfilling are discussed, making use of the results of above mentioned modeling approaches towards landfill emission and their impacts. Three major categories of environmental impacts are considered: (1) Landfill construction (2) Landfill gas (3) Leachate.

4.1 Impact of landfill construction

Site selection of waste management facilities can be a major issue as all infrastructural projects have the capacity to damage the ecology of the site on which they are developed, causing landscape changes, loss of habitats and displacement of fauna. Such impacts are generally site specific and need to be assessed on a case by case basis [1, 39-41].

The soils on selected sites tend to suffer from high levels of disturbances and their chemical and physical properties differ from those of the surrounding areas due to the general removal of topsoil as well as specific process related changes. Soil is an important resource which supports a variety of ecological, economic and cultural functions. The factors like porosity, density, water holding capacity and aggregate strength that operates the soil quality are best developed in the top soil fraction, subsoil being more poorly developed and having a lower ability to support plant growth. This quality can be disturbed during the construction activities. The movements of heavy machinery can lead to excessive compaction of topsoil and subsoil, and in deeper soil this may only be reversible over relatively longer time periods. There is a considerable impact on flora and fauna during the construction phase of landfills due to the removal of existing vegetation. But this damage could be recovered after the closing phase of the landfills. The studies have shown that landfills are capable of supporting a rich and varied fauna including exotic species during the operational and closing phase of landfills [42].

4.2 Impact of landfill gas

The environmental impact of gaseous emission from landfills, which are of global or regional significance, can be mainly grouped as contribution to the greenhouse effect and damage to the eco system. Apart from that, risk of explosion and odor problem due to some trace gases can also be identified as significant impacts.

As described in earlier sections of this paper, CO_2 and CH_4 are the primary constituents of environmental importance in landfill gas. They act as greenhouse gases of global significance, with CH_4 being the most active but CO_2 being produced in the greatest quantities [2]. The LCA modeling performed by Damgaard, Manfredi et al. [3] shows that landfills are main contributors for global warming and photochemical and stratospheric ozone formation. According to Clarke [43], O'Neill [44] and Wellburn [45], CH_4 reacts with hydroxyl radicals and oxygen in the atmosphere to generate CO_2 within a period of days to a few years, thereby losing some of their greenhouse gas potential. Small amounts of methane are also consumed after absorption by soil [46]. Nevertheless, control of these emissions at the source is necessary from an environmental protection viewpoint and to address the obligations under the Kyoto protocol.

Gaseous pollutants have significant effects on plants, animals and entire eco systems. The lateral migration of gas through soil beyond landfill boundaries causes the displacement of oxygen from soil. This results in a decline in soil faunal populations and burrowing animals and causes vegetation dieback. Mainly the vegetation around the landfill and the newly planted vegetation on a closed landfill can be damaged due to the suppression of air around the roots by migrated landfill gas [1]. The acidic gaseous constituents contribute to the phenomenon of acid rains and its secondary effects on the acidification of soils and ecosystems. Ammonia is a major acidic constituent which can be found in the landfill gas. It is a secondary acidifying agent following its atmospheric oxidation to nitric acid. It has effects on plants, causing a loss of stomatal control, a reduction in photosynthesis, enzyme inhibition, changes in synthetic pathways and depressed growth and yield. Hydrogen sulfide is also having a considerable impact on ecosystem. It is an extremely biotoxic gas, effective at a few parts per billion in mammals. Plants are far less sensitive to direct toxicity effects but have a threshold of 1µg/g [45, 47]. The most severe impact on plants is inhibition and destruction of root growth and vegetation cover due to the anaerobic soil conditions created by high concentration of sulfides which laterally seepage from landfill sites. VOCs play a significant role in formation of ground level ozone. High concentrations of ground level ozone tend to inhibit the photosynthesis, reduce growth and depress the agricultural yields [48, 49].

Gendebien, Pauwels et al.[50] say that the lateral migration of gas through soil has been the cause of a number of hazardous explosions as methane is inflammable and explosive when it mix with sufficient amount of air. Moreover, an unpleasant odor can be caused by the series of trace elements present in the landfill gas especially organic fatty acids from the acid phase and H_2S and other sulfur containing compounds. These impacts are discussed further in this paper under the section of socio- economic impacts of landfills.

4.3 Impact of leachate

The leachate production decreases very slowly and some parameters might be of environmental relevance for many decades to centuries. The main constituents of landfill leachate are dissolved methane, fatty acids, sulfate, nitrate, nitrite, phosphates, calcium, sodium, chloride, magnesium, potassium and trace metals like chromium, manganese, iron, nickel, copper, zinc, cadmium, mercury and lead. Leachate can migrate through the soil to groundwater or even to surface water due to the absence of proper liner system or damages of the liners and this results a serious problem as aquifers require extensive time periods for rehabilitation. Moreover, soil can retain the constituents of the leachate like metals and nutrients and can cause adverse impacts on the eco system.

The metals retained by the soil uptake by plants and thereby provide a key route for entry of metals into the food chain. Deposition of trace metals in the plants can affect crop growth and productivity and also pose a greater threat to animal health. Those metals such as lead, zinc and cadmium show differential mobility through the vegetation and invertebrate trophic levels and must be assessed by case by case basis [1]. Uptake by plants is affected by soil pH and salinity and also cadmium and lead uptake is enhanced by the chloride complexation of the metals present in the leachate [51]. Eutrophication is the most extensive threat when the leachate is mixed with the surface water with higher concentrations of nitrate and phosphates [52]. Eutrophic conditions invariably cause excessive production of planktonic algae and cyanobacteria in the open sectors of the lakes. This excessive production of algae results adverse impacts on fish species in the lake by limiting the light penetration into the lake. Ammonia generated from leachate within landfills will migrate through the soil horizons where it is progressively nitrified to nitrite and nitrate and cause eutrophication problem. A number of chemicals can disrupt the reproductive behavior in a range of species by acting as oestrogen mimics. Dempsey and Costello [53] found the landfill leachate as a potential source for these substances.

Above mentioned metals can be present in the leachate either in large or small concentrations depending on the waste categories deposed in the landfills. Mercury is one of the best studied contaminant. It is one of the most toxic metals within the food chain, being readily absorbed by animals, fish and shellfish. Landfills are potential mercury emitters to the eco system due to the disposal of batteries and paint residues in the landfills. Alloway [51] revealed that the chromide to chromate conversion in the landfills is environmentally significant as chromate is more toxic to plants than chromide.

5 THE HEALTH AND SOCIAL IMPACTS OF LANDFILLS

Apart from the environmental impacts, landfills are sources for several socio-economic impacts like public health issues due to the exposure to landfill gas and to the ground and surface water contaminated by landfill leachate. Although modern landfill sites are well designed to reduce emissions, the emissions from landfills continue to give rise to concerns about the health effects of living and working near these sites, both new and old. The exposure to contaminants and emissions can be via direct contact, inhalation or ingestion of contaminated food and water. Drinking water contamination has been identified as the source of exposure to harmful substances in many studies [54-56]. Those studies revealed that congenital malformations, birth weight, prematurity and child growth and cancers have a significant impact on landfill emissions. In a multi- site study of residents of New York State, a 12% increased risk of congenital malformations in children born to families within one mile of hazardous waste sites were reported [57]. Fielder, Poon-King et al.[58] and Vrijheid, Dolk et al. [59] also found an increased risk of congenital malformations in populations live near landfill sites. A multi-site European study called EUROHAZCON discovered a 33% increase in non- chromosomal birth defects among the residents living within 3 km of the 21 hazardous waste landfill sites studied [60]. This conclusion was confirmed by the study conducted by Elliott, Briggs et al.[61]. A number of studies revealed that there is a higher risk of developing cancer among the people near landfill sites and the elevated risks were observed for cancers of the stomach, liver and intrahepatic bile ducts and trachea, bronchus, lung, cervix and prostate [62, 63]

In addition to the health issues, landfills create considerable impacts on land value, land degradation and land availability. Various researches conclude that landfills likely have an adverse negative impact upon housing values depending upon the actual distance from the landfill [4, 5, 38]. Potential hazards such as flies, odor, smoke, noise and threat to water supplies are cited as reasons why the public do not want to reside close to the landfills. Reichert, Small et al. [38] revealed that 40% of participants to their survey reported odor and unattractiveness as the most severe nuisance while 35 % reported about the toxic water runoff and methane gas emission. Their study concluded that landfills have a negative impact of 5.5-7.3% of market value depending on the distance to landfills. Akinjare, Ayedun et al.[5] found that all residential property values increased with the distance away from landfill sites at an average of 6%. Ready [4] performed a meta-analysis that included all available hedonic price studies of the impact of landfills on nearby property values. It showed that landfills that accept high volumes of waste (500 tons per day or more) depresses the value of an adjacent property by 12.9% while a low volume landfill depresses this value only by 2.5%. Furthermore, occupation and requirement of the enormous space for landfills contribute to land scarcity for the development of human society and eco systems.

6 EVOLVING LANDFILL CONCEPTS

Despite the landfilling has become the final option of the waste hierarchy defined by the EU waste directive (2008/98/EC), it is still expected to be applied in several cases because of the growing amount of solid wastes and a lack of suitable techniques to treat all kinds of wastes. But it is very clear that the landfill concept should evolve to minimize the potential risks and environmental burden of landfills and on the other hand to re-introduce the buried resources to the material cycle. One approach is engineered bioreactor landfills in which a controlled degradation is allowed in order to guarantee the long term stability of the landfill [64]. Another approach is the concept of enhanced landfill mining (ELFM) that reduces the emission and potential hazard of landfills and valorize the resources contained in it. Several studies have been conducted on ELFM both in environmental and economic point of view [65-68].

6.1 Landfill as a reactor

Waste decomposing period of a MSW landfill is estimated as over fifty years. There is considerable interest in techniques for shortening this time because it has the potential of reducing overall costs and risks. One method is considering a landfill as a bio-reactor in which the degradation processes is provocatively accelerated [1]. A bioreactor landfill is a sanitary landfill site that uses enhanced microbiological processes to transform and stabilize the readily and moderately decomposable organic waste constituents within 5 to 8 years of bioreactor process implementation [64] . According to Warith's study, the bioreactor landfill significantly increases the extent of organic waste decomposition, conversion rates and process effectiveness over those occur within the traditional landfill sites. The environmental performance measurement parameters (landfill gas composition and generation rate, and leachate constituent concentrations) remain at steady levels. A bioreactor landfill site requires effective operation of liquid addition and management. Other than that waste shredding, pH adjustment, nutrient addition and balance, waste pre-disposal and post-disposal conditioning, and temperature management may also serve to optimize the bioreactor process. The advantages of bio reactor landfills are: enhancement the landfill gas generation rates, reduction of environmental impact, production of end product that does not need land filling, overall reduction of land filling cost, reduction of leachate treatment operational cost, reduction in post-closure care, maintenance and overall reduction of contaminating life span of the landfill due to a decrease in contaminant concentrations during the operating period of the bioreactor landfills.

6.2 Enhanced landfill mining (ELFM)

The previous sections of this paper highlighted that landfills have related implications such as long term methane emissions, local pollution concerns, settling issues and limitation on urban development. Landfill mining consisting of excavation, processing, treatment and/or recycling of deposited materials has been suggested as a strategy to address such problems [67]. ELFM includes the combined valorization of the historic waste streams as both materials and energy. As mentioned in the review of Krook, Svensson et al. [67] massive amounts of important materials such as metals have accumulated in landfills. On a global level, the amount of copper situated in such deposits (393 million metric tons) has been estimated as comparable in size to the present stock in use within the technosphere (330 milion metric tons). The same study revealed that apart from metals, the amount of potential waste fuel situated in municipal waste landfills is enough to cover the district heating demand in the country for 10 years. Apart from old landfills, ELFM is also applicable to new landfills by considering them as temporary storages. In that approach landfills become future mines for materials which could not be recycled with existing technologies or show a clear potential to be recycled in a more effective way in near future [69, 70]. Recently, Van Passel, Dubois et al.[66] address the economics of ELFM both from private point of view as well as from a societal perspective. Their analysis shows that there is a substantial economic potential for ELFM projects on the wider regional level. Furthermore, the feasibility of ELFM is studied by synthesizing the research on the Closing the Circle project, the first ELFM project targeting the 18 million metric ton landfill in Houthalen-Helchteren in the East of Belgium [71]. They highlighted the worldwide potential of ELFM in terms of climate gains, materials and energy utilization, job creation and land reclamation. Nevertheless, for ELFM to reach its full potential, developing standardized frameworks for evaluating critical factors for environmental and economic performance is necessary. Moreover, strategic policy decisions and tailored support systems, including combined incentives for material recycling, energy utilization and nature restoration, are also required [67, 71].

7 CONCLUSIONS

Landfills mainly emit gas and contaminated water as well as wind-blown litter and dust. Landfills are potential threat to the quality of the environment, although the full extent of this threat has not always been scientifically validated. The main potential impacts are due to landfill gas and leachate. Both are highly complex mixtures and vary from site to site and with waste composition and age of the landfill. It is clear that enough attention has been given to modeling of landfill emission in order to quantify the landfill gas and leachate production. But on the other hand, studies that model the impacts of landfill emission are scarce. A few LCA studies have been performed to compare landfilling with other waste management technologies but by our knowledge an integrated assessment of the impacts of landfills has not been addressed yet. Nevertheless, available literature highlights that the landfills create significant impacts on global warming, eco system, ground and surface water, human health, land value and land availability. In order to minimize the potential risk and environmental burden of landfills and on the other hand to re-introduce the buried resources to the material cycle the landfill concepts should be made operational in the future. Further development of the concepts of landfill bioreactors and enhanced landfill mining can be seen as a promising approach to reduce the environmental impact and the negative socio-economic impacts.

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