geosciences

MDPI

Review

Landfill Impacts on the Environment—Review

Magdalena Daria Vaverková [1,2]

[1] Department of Applied and Landscape Ecology, Faculty of AgriSciences, Zemědělská 1, Mendel University in Brno, 613 00 Brno, Czech Republic; magda.vaverkova@uake.cz

[2] Faculty of Civil and Environmental Engineering, Nowoursynowska 159, Warsaw University of Life Sciences—SGGW, 02 776 Warsaw, Poland

Received: 11 June 2019; Accepted: 29 September 2019; Published: 3 October 2019

check for updates

Abstract: Waste management (WM) is a demanding undertaking in all countries, with important implications for human health, environmental preservation, sustainability and circular economy. The method of sanitary landfilling for final disposal of waste remains a generally accepted and used method but the available scientific evidence on the waste-related environmental and health effects is not conclusive. Comparative studies of various WM methods (landfilling, incineration, composting etc.) show that among the municipal solid waste (MSW) treatment and disposal technological options, sanitary landfilling or open dumping is popular in most countries because of the relative low cost and low-technical requirement. The European Union (EU) Directive on waste landfills has introduced specific goals for reducing the volume of disposed waste and very strict requirements for landfilling and landfill sites. Evaluation of the impact of landfills on the environment is a crucial topic in the literature and has received increased attention recently, given growing environmental concerns. The main goal of this survey was to conduct a comprehensive assessment of possible impacts of MSW landfills on the environment. The main conclusion of the overall assessment of the literature is that the disposal of MSW in landfills entails a number of environmental risks but with respect to the current situation and rich style of living adopted in industrially developed countries, the idea of WM systems functioning without landfilling—at least in the foreseeable future within one generation—seems to be somewhat unreal. The results also provided important information of landfills as a source of environmental risk. Results of this research may have an important impact on landfill management and the disposal of waste. From the literature review, it is evident that even if high levels of waste avoidance, reuse and recycling are achieved, some waste materials will always need to be forwarded for disposal.

Keywords: final disposal of waste; landfill; sustainability; environment impact

1. Introduction

The continually growing industrial production and trade in many countries worldwide in the last decennia has accompanied a rapid increase of the production of municipal and industrial waste [1–4]. In the second half of the 1990s, the annual volume of waste production ranged between (300–800) kg per capita in developed countries and less than 200 kg per capita in other countries [5,6]. The global waste will nearly double to 2.2 billion annual tones by 2025 and almost all the cities in the world are struggling to meet their waste reduction targets [7]. Landfills and/or open dumpsites were the common practice for municipal solid waste (MSW) disposal all over the world for example, in the U.S.A., 52.6% of MSW was discarded in landfills [8], in Brazil 59.1% [9], in The Kingdom of Saudi Arabia (KSA) 85% [10], in Malaysia 94.5% [11], in China 79% [12], in Venezuela: sanitary landfills 32%, controlled disposal 43% and non-controlled disposals or open dumps 24% [13], in Mexico: sanitary landfills 65%, in uncontrolled and open dumps 30% [14] and in Thailand 27% [15].

The method of landfilling for final disposal of MSW remains a generally accepted and used method thanks to its economic advantages [16–18]. Landfilling is defined as the disposal, compression and embankment fill of waste at appropriate sites Landfill for the moment is easy, adjustable with lower cost than the rest of disposal methods and stands alone as the only all waste material disposal method. Although the disposal of MSW in landfills has decreased, landfills are likely to remain an important part of integrated solid waste management systems all over the word. Comparative studies of various waste management (WM) methods (landfilling, incineration, composting etc.) show that among the MSW treatment and disposal technological options, sanitary landfilling or open dumping is popular in most countries because of the relative low cost and low-technical requirement [16–18].

The European Union (EU) Directive on waste landfills has introduced specific goals for reducing the volume of disposed waste and very strict requirements for landfilling and landfilling sites [19,20]. Regardless of this directive, the situation in Europe is not homogeneous. For example, Switzerland, Germany, the Netherlands, Sweden, Austria, Denmark and Belgium report landfilling below 5% of waste produced [21]. In new member countries, candidate countries and on islands, landfilling is still the prevailing technology of WM. For example, the representation of landfilled waste in Poland is 37%, 38% in Slovakia and 64% in Bulgaria, while in the Czech Republic (CR) it reaches 50% [22].

The hypothesis is that the landfills can be a source of environmental pollution and risk. The main aims of this review were to: (i) summarize the most recent scientific information on waste disposal options, (ii) present the direct and indirect impact of WM activities on the environment based on literature research.

The principal sources of emissions from landfill sites are as follows: the waste materials as they are brought onto site; emissions from transport; waste blown by the wind; dust generated from the landfill surface; landfill gas generated; leachate produced. The literature search was carried out online databases and included studies and reviews of impacts of WM methods in particular MSW landfills on the environment. In total, 116 references were selected for inclusion in this study; these satisfied the principal criterion for the study that the reported data must come from clearly defined sources and must be accurate. Results of this research may have an important impact on landfill management and the disposal of waste.

2. Waste Production in the European Union

The mass of waste produced in the world as well as in EU countries has been growing considerably for many decades. As mentioned above, the most practical solution for WM in a majority of EU countries remains landfilling due to technical, economic and legal reasons (Table 1) [21,23,24].

Table 1. Municipal solid waste generated in 1995 and 2016 (Kg/capita) adopted from [25] and share of landfill disposal (%) adopted from [26].

Country	1995	2016	2017	Waste Treatment—Landfill, 2016 (Share of Landfill Disposal)
Austria	480	552	570	3%
Belgium	446	414	409	1%
Bulgaria	531	404	416	64%
Cyprus	595	592	637	81%
Czech Republic	312	339	344	50%
Denmark	521	777	781	1%
Estonia	370	327	390	12%
Finland	437	504	510	3%
France	476	510	513	22%
Germany	623	625	633	1%

Table 1. *Cont.*

Country	1995	2016	2017	Waste Treatment—Landfill, 2016 (Share of Landfill Disposal)
Greece	331	498	-	82%
Hungary	377	380	385	51%
Ireland *	430	615	-	22%
Italy	468	436	489	28%
Latvia	184	367	438	72%
Lithuania	542	422	455	31%
Luxemburg	587	614	607	17%
Malta	387	584	604	92%
Netherlands	509	518	513	1%
Poland	284	307	315	37%
Portugal *	351	483	487	49%
Romania	254	228	272	80%
Slovakia	294	344	378	66%
Slovenia **	469	434	471	24%
Spain	365	443	462	57%
Sweden	386	442	452	1%
United Kingdom *	501	476	-	28%

* Data from 2014; ** Data from 2015.

Disposal in landfills are considered an effective method for WM [27]; however, there are many reasons why landfilling appears as the least rational method of WM. Waste can be landfilled only for limited time and the period of landfill reclamation may last up to hundreds of years [28]. Biogas and leachates can seriously impact the environment [21,28–30]. In addition, MSW is disposed on landfills without any sorting in numerous countries. Moreover, for the majority of landfills worldwide, unfavorable odor and air pollution bring about serious sanitary problems and are the main causes for the "not in my backyard (NIMBY)" syndrome for the nearby communities [31]. WM has recorded significant development and its regulation imposed by legislation (e.g., setting of goals for recycling and permitted amount of landfilled biologically degradable waste) curbs the rate of landfill extension now. Evaluation of the impact of landfills on the environment (Figure 1) is a crucial topic in the literature and has received increased attention recently, given growing environmental concerns.

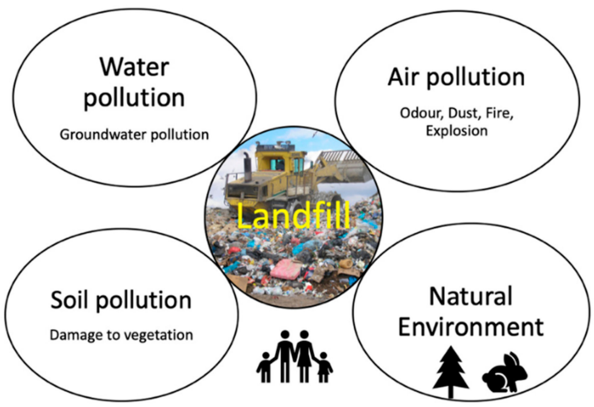

Figure 1. Potential impact of landfills on the environment.

3. Landfill as a Potential Source of Pollution

The need for the collection and sanitary disposal of MSW was not recognized until recently. Fifty years ago, throughout the world, most MSW was disposed of in open dumps or tips. In 1959, the American Society of Civil Engineers (ASCE) defined "sanitary landfilling" as a controlled operation in which MSW is deposited in defined layers, each layer being compacted and covered with soil before depositing the next layer [32].

The fundamental difference between a dump and a landfill is that in a dump there is no attempt to separate the waste from the underlying soil or rock strata and where the hole extends to below the groundwater level, waste is dumped directly into the groundwater [32]. In contrast, a sanitary landfill is an engineered structure consisting of bottom liners, leachate collection and removal systems, and final covers (Figure 2). Landfills are designed both to store and to treat wastes. Much of the potential risk from MSW landfill results from the migration of contaminated leachate and landfill gas therefore the environmental impacts of the many landfills existing throughout the world cannot be ignored. Major emissions (leachates and biogas) are considerably affected by biological processes occurring in them. If the MSW is disposed on the landfill with no pre-treatment, emissions develop during the landfill operation period, which are produced even after the landfill will have been closed [33–35]. According to Białowiec (2011) these emissions produce on average circa 150 (range of 70–300) m^3 of biogas per 103 kg of municipal waste (related to dry matter weight) and about 5 m^3. $ha^{-1}.d^{-1}$ of severely contaminated leachates, depending on waste composition, climatic conditions etc. [28]. The values approximately correspond to heavily compacted landfills in central Europe with annual total precipitation amounts ranging from (550−750) mm. The produced biogas has to be collected and incinerated or it can be used as a source of energy. The produced leachates have to be collected and treated [28].

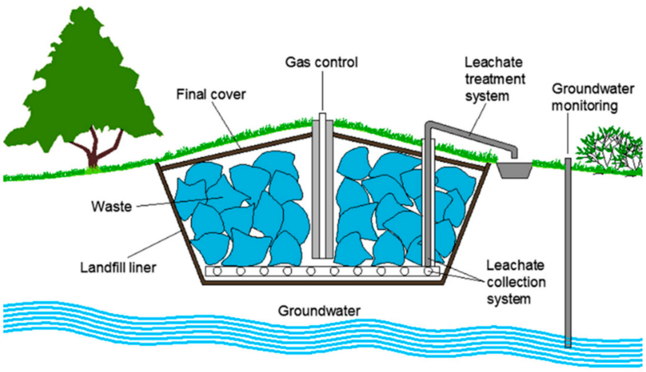

Figure 2. Sanitary landfill.

3.1. Landfill Gas

One of the products of biological processes occurring in MSW landfills is biogas or landfill gas (LFG) [35]. Biogas is a product of the decomposition of biologically decomposable organic matter [36]. The rate of biogas production and its composition change during the landfill lifetime. Landfill gas production (Figure 3) is based on the composite model of bacterial waste decomposition and on the model of long-term behavior of landfill gas from old waste repositories [37].

LFG obtained from the MSW develops during anaerobic decomposition of organic matter. MSW contains about (150–250) kg of organic carbon per ton of waste, microorganisms in which transform it into landfill gas during anaerobic processes. The generated LFG with (40–60%) methane has an average heating value of 17,765 kJ/N m^3. With the energy conversion efficiency being 34%, the produced electric energy is approximately 2.5 kW h/N m^3 [38]. Considering the presence of methane and carbon dioxide within the LFG, the total amount of greenhouse gases (GHE) in the landfill life can be estimated at about 1.37 E+09 kg of equivalent carbon dioxide [39].

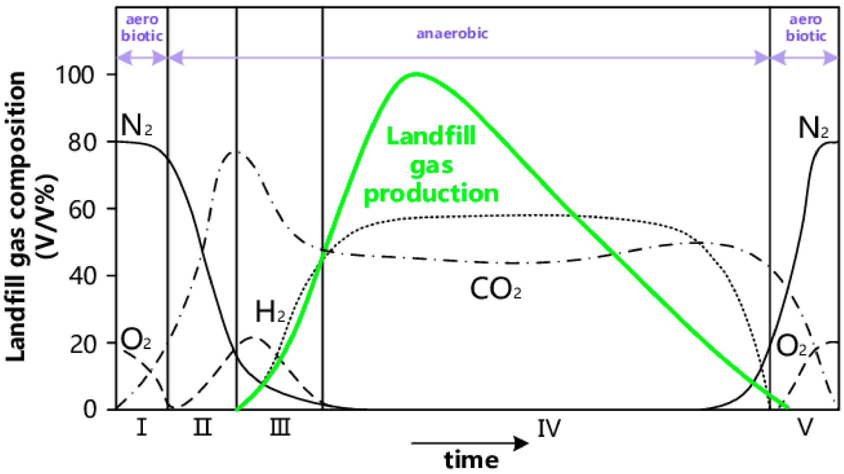

Figure 3. Composition of each stage of landfill degradation [34].

Main factors affecting the amount of LFG are as follows: waste composition, moisture content, temperature, landfill age etc. LFG generation starts one to two years after waste disposal into the landfill and continues for (15–25) years [40–42]. Moreover, according to Directive 31/1999/CE: "LFG shall be collected from all landfills receiving biodegradable waste and the LFG must be treated and used. If the collected LFG cannot be used to produce energy, it must be incinerated".

3.2. Landfill Leachates

Rain has a major influence in the formation of leachates. Precipitation percolates through the deposited waste and binds to dissolved and non-dissolved waste constituents by means of several physical and chemical reactions. Groundwater tributaries, surface runoff and biological decomposition also participate in the formation of leachates. Liquid fractions in the waste combined with soil cover moisture content take part in the formation of leachates as well.

Moisture can be eliminated from the landfill by the consumption of water in LFG formation by means of water vapor evaporated in LFG or by means of leachate removed through drainage system.

Thus, the discharge of leachates is closely related to rainfalls, surface runoff and infiltration of groundwater soaking up the landfill. The method of landfilling (water-proof covers, requirements for insulation layers such as clay (mineral cohesive soil), geotextiles (GCL) and/or plastic materials) is crucial for checking the amount of water reaching the upper layers of the landfill, and hence, for mitigation of pollution risk. The production of leachates is also greatly affected by climatic conditions since they influence the input of precipitation into the landfill and losses due to evaporation. Moreover, the production of leachates depends on the character of disposed waste, namely on water content and on the degree of compaction of upper landfill layers [43].

Technology applied as routine on landfills established in Europe in the 20th century was technology of leachate treatment based on the "dilute and disperse" system. Landfills were usually not properly sealed and the leachates produced were leaking into the wider surroundings where they mixed with groundwater in which they were dispersed. Such facilities for dilution and dispersion are no more built nowadays; however, the existing ones have left old environmental burdens all over Europe in the form of landfills, which may represent a risk of contamination, particularly in areas with high groundwater table [44–46].

3.2.1. Composition of Leachates

Many studies have proven that landfill leachate is a significant source of pollutants as a consequence of the leaching of hazardous substances [21,43,47,48]. Leachates contain four main components: nutrients (namely nitrogen), volatile organic compounds, heavy metals (HM) and toxic organic compounds [48–50]. Nitrogen in the form of NH_3 was identified as one of priority substances to be eliminated for the mitigation of leachate toxicity [51–53].

There are many factors affecting the quality of leachates, e.g., landfill age, seasonal weather fluctuations, total precipitation amount, waste type and its composition [54]. Composition of leachates significantly changes especially in dependence on landfill age. There are three types of leachates defined according to landfill age (Table 2). Concentration of organic compounds (COD) in leachates decreases with the increasing age of the landfill, while the concentration of NH_3 increases.

Table 2. Classification of landfill leachates ([9,55,56] adapted by Vaverková).

Parameter	Low-Age Landfill	Mid-Age Landfill	Old Landfill
Landfill age (years)	<1	1–5	>5
pH	<6.5	6.5–7.5	>7.5
COD (g O_2.dm^{-3})	>15	3.0–15	<3.0
BOD_5/COD	0.5–1	0.1–0.5	<0.1
TOC/COD	<0.3	0.3–0.5	>0.5
NH_3-N (mg.dm^{-3})	<400	400	>400
Heavy metals (mg.dm^{-3})	>2.0	<2.0	<2.0

Concentration of organic compounds (COD), Biochemical oxygen demand (BOD), Total organic carbon (TOC).

3.2.2. Toxicity of Landfill Leachates

Leachates represent complex mixtures of substances including dissolved organic matter, inorganic macro-components, HM and a wide range of xenobiotic organic compounds. A great amount of these substances occurring in landfill leachates is hazardous and toxic to human health and the environment. Moreover, chemicals can bioaccumulate in organisms and be passed along the food chain, eventually reaching humans [48].

The assessment of risks from landfill leachates is traditionally based on the evaluation of individual chemical substances by means of chemical analysis. Although the approach is important, it features some limitations. First, some chemical contaminants may occur in the leachates that are below the detection limits of chemical analysis and their detection can be difficult due to the limitations of analytical techniques. For the regime of continual chemical sampling, changes caused by regular refluxes may be necessary; however, this system is rather costly and labor force intensive.

Furthermore, these chemical techniques do not allow prediction of the effects of pollutants on recipients (ecosystems). Eco-toxicological studies of the responses of model biological organisms exposed to the effects of toxic substances can provide important information complementing the standard chemical analyses [46]. Unlike the chemical analysis, the biological test of toxicity can include biological effects of all present compounds as well as their biological availability [46,47]. The chemical analysis by itself provides only limited information about the environmental fate of complex refluxes of leachates [46]. Thus, eco-toxicological tests can provide the necessary link between the traditional chemical analysis and comprehensive field studies with using biological organisms in controlled (defined) environmental conditions [57,58].

Cameron [59] published one of the first studies on the toxicity of leachates. In this study, they highlighted shortcomings of traditional chemical testing and used a recently developed test with the salmoniform fish of rainbow trout (*Oncorhynchus mykiss*), setting up standard methodology for the evaluation of biological toxicity of leachates. The authors identified main constituents of leachate toxicity (non-ionized ammonia, tannins and copper) on the model fish species. NH_3 can have negative toxic effect on the environment. It was demonstrated that NH_3 is highly toxic for aquatic organisms both acutely and chronically. This statement was confirmed in previous studies demonstrating that NH_3 is a primary cause to the toxicity of leachates from MSW landfills [59,60]. In addition,

NH_3 is released from leachates by means of volatilization (Henry's constant is 32.2 $Pa.m^{-3}.mol^{-1}$ at 20/25 °C) and increased concentrations of NH_3 in the atmosphere may have adverse impacts on vegetation [59–61]. Comparative toxicological studies also revealed mutagenic properties of these leachates. Helma et al. [62] demonstrated that the genotoxic potential of leachates MSW landfills is higher than that of wastewater from the manufacture of cellulose, industrial wastewater, contaminated surface and ground waters or even of drinking water and bathing water samples.

The above-described properties of leachates from landfills clearly point out the necessity of introducing high-quality strategy in the management of landfill leachates (collection, re-circulation and final treatment prior to discharge into the environment) as a final strategy for the management of pollutants [63].

3.2.3. Landfill Leachate Treatment Technologies

There is considerable scientific literature on the collection, storage and suitable treatment of landfill leachates. A range of technologies are available for the treatment of landfill leachate, aimed at achieving the standards established by legislation. Typically, the leachate treatment can be carried out through: (1) biological processes (activated sludge, aerobic and anaerobic stabilization lagoons and biological filters); (2) physical-chemical processes (flotation, coagulation/flocculation, adsorption, chemical precipitation, air stripping, pH adjustment, chemical oxidation, ion exchange, electrochemical treatment); (3) membrane filtration (microfiltration, ultrafiltration, nanofiltration and reverse osmosis), (4) advanced oxidative treatments (ozonization) and (4) natural systems (wetlands) [9,63–66].

3.3. Landfill Fires—A Source of Pollution

Landfill fires are unexpectedly common [67,68]; however, the environmental aspects of landfill fires have been given little attention within the research community. In 2004–2010, there were 840 fire events recorded in U.S., which resulted in the subsequent loss of material and machinery as well as of human health damages [69]. More than 60 landfill fires were recently recorded in Poland and the authorities announced that many of them are likely to have had been set up on purpose in order to devour illegal waste imported from other countries. These incidents show that landfill fires are controllable only with difficulties and have a great impact on the environment. Published reports on the impact of landfill fires on the environment due to the emission of toxic substances are few (Table 3).

Table 3. The impact of a landfill fire on environment. MSW: municipal solid waste.

Type of Landfill	Landfill Location	Year	Environment	References
MSW, industrial and construction waste	Western Norway	2003	Landfill leachates	[70]
MSW	Tagarades, Greece	2006	Landfill surrounding area/soil and vegetation samples	[71,72]
Landfill's shredded tire drainage layer	Iowa City, United States	2012	Air	[73,74]
MSW	Niger Delta, Southern Nigeria	2013	Air	[75]
MSW	Iqaluit, Northern Canada	2014	Air	[76]
MSW, electronic waste and bulky waste	Araraquara city, Brazil	2015	Soil, dust, leachate and well water	[77]
Tire landfill	Seseña, Toledo, Spain	2016	Air/soil	[78,79]
MSW	Talagante, Chile	2016	Air	[69]

Landfill fires can significantly harm the environment due to emissions of toxins into the atmosphere, soil and water. Risk factors depend on the type of burning waste, on the geographical location of the landfill and on the type of fire [69]. In general, these fires occur at low temperatures and under anoxic conditions. Hydrocarbons, chlorinated materials and pesticides produce a variety of toxic gases in such conditions, which may contain dioxins/furans [79], polynuclear aromatic hydrocarbons, respirable particulates (PM) [80] and HM [81] as well as other harmful compounds [78]. Smoke produced during the landfill fire may contain hazardous toxic gases such as CO, H_2S, CH_4 etc. and carcinogenic substances such as dioxins.

Emitted bad odors and smoke bother the neighborhood and may put into danger even human health, especially among vulnerable populations such as the elderly, children, pregnant women and/or people with pre-existing chronic respiratory conditions [81–86].

4. The Future of Landfills

In the hierarchy of WM, Europe increasingly moves from landfilling towards recycling and reuse [87,88]. The directive in force since 1999 comprises requirements for the reduction of waste amounts disposed in landfills. Since 2016, member countries are not allowed to landfill more than 35% of biodegradable MSW landfilled in 1995. Some countries managed to achieve these goals four years later. The main objective of the WM strategy is to prevent waste formation. If prevention is not possible, then the waste should be reused or recycled. If even this is impossible, the waste should be used to generate energy thereof (thermo-valorization). Waste should be disposed in landfills only if no other possibilities of its management exist.

Regardless of what preventive measures, reuse or recycling can be realized by the society, landfills will always play a role in the WM system. Furthermore, globally, and even in EU countries, landfill rates are still high; meanwhile, waste prevention and recycling rates are too low [89–94]. Many authors agreed that waste reducing, reusing and recycling (3R) behaviors have been a widely accepted WM strategy [89–94]. However, sufficient capacity for recycling and reuse of all types of waste will not be economically acceptable under all conditions. In the pursuit of greater prevention, investment into recycling and reuse of wastes that to disappear in the future would be economically disadvantageous. Moreover, the amount of waste fluctuates throughout the year. Sometimes, the amount of waste determined for recycling, reuse or incineration exceeds the capacity. Not all types of waste can be recycled or incinerated. For some of them, landfill is the only choice and in case that the recycling facility or incinerator are out of operation due to maintenance, repair or breakdown, the waste should not remain in residential areas. This shows that some types of waste have to be disposed in landfills even when recycling and reuse are in place [95]. In the sound system of WM, these landfills serve as 'security networks'. Landfills should be established by using sustainable methods so that they do not represent an environmental burden for future generations.

Insulation of landfills by means of impermeable membranes becomes a European standard. The insulation stops all processes in the landfill. These membranes have a lifetime of up to 50 years and can even sustain up to 500 years. However, they inevitably fail at a certain time moment, and if they are disrupted, the emission generating processes will start again. Hence, the potential emissions are postponed for future generations (Figure 1). In many countries, after-care landfill management is governed by legislation and it must be ensured in general for at least 30–60 years after landfill closure. Some countries require the after-care as long as the relevant authority of state administration considers necessary. After-case is apparently required for a time-period longer than one generation. A safe solution would be more sustainable. It follows that a society that strives for long-term sustainable development needs long-term sustainable landfills.

There are no internationally recognized definitions of sustainable landfilling (Figure 4). When it comes to landfills, discussions about sustainability frequently use terms such as stability, completion, end technologies and threat to the environment [96,97]. Scharff et al. [98] presented the following selection of definitions:

The Solid Waste Association of North America (SWANA) sub-committee for stability: landfill is "functionally stable" as long as the waste matter does not represent threat to human health and the environment after its closure. This condition must be assessed with respect to the quality and amount of leachates, gas production and composition, cover, slope gradient, slope and design of insulation, site geology and hydrogeology, climate, potential recipients, exposure of ecosystems and humans to landfill impacts, and with respect to other factors considered as relevant for specific localities.

Anglo-Welsh agency for environment protection: completion is defined as a condition when the landfill is physically, chemically and biologically stabilized to such extent that its undisturbed contents are likely not presenting any risk of environment pollution to landfill surroundings. After the landfill closure, neither active pollution controls are required within after-care (e.g., leachate and gas management) nor any monitoring systems.

Technical University Hamburg (TUH): the stage of after-care can be terminated in the moment when the potential of the development of emissions is so low that actual emissions do not harm the environment.

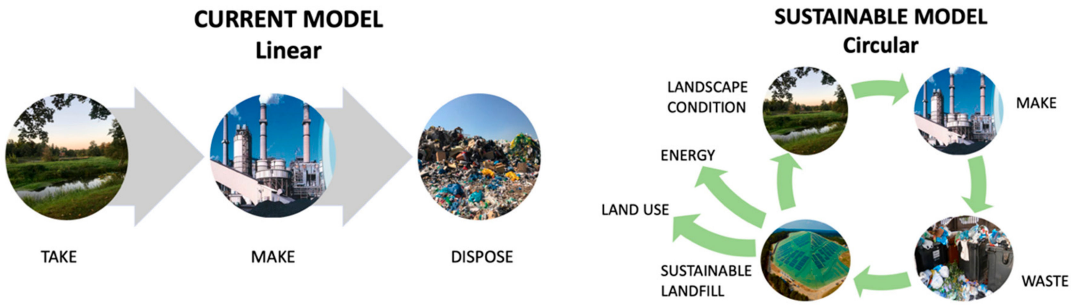

Figure 4. Current and future model of landfilling.

Although various definitions have slightly different reading, it appears that there is a general agreement that sustainable landfill or landfill in which after-care termination is considered safe is such a landfill that will reach a condition within a limited time-period when its undisturbed content will no more represent any threat to human health or the environment. This is the moment (often referred to as completion) in which the after-care of landfill can be terminated. It is important to realize that this condition is in basic agreement with the intention of EU waste legislation. Annex II to the Landfill Directive requires neither insulation nor after-care in landfills of inert waste and defines inert waste in a similar way as not representing and threat to human health or the environment [98]. A question remains to be asked whether inert waste actually does not represent a risk for human health and the environment because research in this field is scarce.

Advantages of Waste Landfilling

The most frequent threats following out from the operation of landfills have been described above. Now, the time has come to take into account arguments advocating advantages of limited disposal of waste in landfills. Especially in the long-term time horizon, landfilling can transform the troublesome share of waste flow into the short-term gas generation and provide long-term carbon supply. Moreover, the after-care of landfills can also promote renovation of brownfields, which may finally lead to new opportunities for betterment of landscape condition and of the environment.

Options of WM are not interchangeable. Diverse strategies available for solid WM are generally considered as the hierarchy of opportunities for sustainability with the reduction of waste amount at the source being the best option and landfilling the worst. However, alternative removal of waste is currently subject of criticism by both environmentalists and landfill operators and suppliers.

Although the possibility of 'zero waste' is discussed frequently [92,99], according to Song [100] transforming currently over-consuming activities into zero waste is still challenging.

Efficient introduction of recycling into practice at a reasonable price is difficult since it would require effective separation of individual waste fractions both at the source and after collection. Separation of organic matter from waste, either biologically degradable or combustible is considered a significant source of various pathogens. Composting, as the most valuable method for recycling of biologically degradable waste, inevitably also generates bioaerosols impairs the health of workers and inhabitants near large composting facilities [101–103]. Incineration is the main alternative of landfilling but brings a number of related problems. It represents a very costly technology needed for the solution of all possible risks, namely emissions into the air [104–106]. It is also a subject of criticism in relation to possible hazardous emissions [107], non-removal of pathogenic substances, non-provision of HM immobilization and also in relation to yet other shortcomings of WM economy. In addition, the perception of risks by the public considerably exceeds actual risks. Ash material from municipal waste incinerators can be disposed in landfills after or without pre-treatment but the risk of inhaling ash from the source in landfills has been assessed as insignificant.

Landfilling brings the lowest own costs. Its secondary impacts (hygienic, social and environmental—calculated on an economic basis) are traditionally referred to as significant. However, their expression in numbers is questionable and any considerations again do not take into account the new available technologies [28].

It should be emphasized that 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 landfill mining. 150,000–500,000 old and still active landfills exist throughout EU representing an estimated total volume of 30–50 Gm^3 of waste. Landfills should be seen as 'urban stocks' and be considered as resource reservoirs for future recovery, 'a bank account' for coming generations [108].

5. Landfill Mining

Landfill mining (LFM) has become very current topic. LFM has been proposed as an innovative strategy to mitigate environmental risks associated with landfills, to recover secondary raw materials and energy from the deposited waste and to enable high-valued land uses at the site [109]. Landfills are mined to obtain materials for use as raw materials (e.g., metals) or as energy resources (e.g., plastics) [110]. Moreover, the concept of LFM is designed to close the material loops towards a circular economy (CE), recovering landfill waste [111]. However, according to the latest literature, there are many problems associated with LFM. According to Hölzle [111], LFM operations required on average 103 MJ diesel (≙2.4 kg) and 1.9 MJ electricity per ton excavated waste, producing 12 kg of CO_2 equivalent. Transportation proved to be the sub-process with the largest energy consumption by far, producing 58% of total emissions, followed by processing (27%). Laner at al., [109] has pointed out that our understanding about the climate impact of LFM is limited to a few case-specific assessments [112–114]. While some of them conclude that LFM would lead to reduced climate impacts compared to business-as-usual [112,114], others have found that such projects would instead result in net contributions to global warming (GW) [113,115]. Laner at al. [116] pointed out that the economy of LFM is very important. Several case study assessments on the economy of LFM exist, a broader understanding of the driving factors is still lacking. It has been suggested [116] that 80% of the generated LFM scenarios show negative results. Therefore, the development of a treatment plant that enables maximum resource recovery and environmentally and economically reliable remains one of the technological challenges for further development of LFM. For LFM to reach its full potential, strategic policy decisions and tailored support systems, including combined incentives for material recycling, energy utilization and nature restoration are required.

6. Conclusions

On the basis of the above discussion, it can be concluded that in many countries, landfilling remains a dominant method of municipal Waste Management. Landfills continue to be one of the main methods of waste disposal despite their relatively high potential to pollute the environment. Therefore, regular landfill monitoring is required to identify and define landfill hazards for the environment. This literature research shows the necessity of identifying knowledge gaps and establishing bases for developing a more holistic framework of landfill risk analysis.

Thus far, however, with respect to the current situation and rich style of living adopted in industrially developed countries, the idea of waste management systems functioning without landfilling—at least in the foreseeable future within one generation—seems to be somewhat utopian.

From the literature review, it is evident that even if high levels of waste avoidance, reuse and recycling are achieved, some waste materials will always need to be forwarded for disposal. Therefore, the concept of sustainable landfill should be implemented. A truly sustainable landfill is one in which the waste materials are safely assimilated into the surrounding environment.

The framework of this study that obtain from a comprehensive literature review can be used as a systematic approach for evaluation of landfill impacts on the environment for all stakeholders involved in the landfill industry.

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

Abbreviations

(ASCE)	American Society of Civil Engineers
(BOD)	Biochemical oxygen demand
(CE)	Circular economy
(COD)	Concentration of organic compounds
(CR)	Czech Republic
(EU)	European Union
(GCL)	Geotextiles
(GW)	Global warming
(GHE)	Greenhouse gases
(HM)	Heavy metals
(LFG)	Landfill gas
(LFM)	Landfill mining
(MSW)	Municipal solid waste
(NIMBY)	Not in my backyard
(ASCE)	Society of Civil Engineers
(SWANA)	Solid Waste Association of North America
(TUH)	Technical University Hamburg
(KSA)	The Kingdom of Saudi Arabia
(TOC)	Total organic carbon
(WM)	Waste management

References

1. Vaverková, M.D.; Adamcová, D. Long-Term Temperature Monitoring of a Municipal Solid Waste Landfill. *Pol. J. Environ. Stud.* **2015**, *24*, 1373–1378. [CrossRef]
2. Adamović, V.M.; Antanasijević, D.Z.; Ćosović, A.R.; Ristić, M.Đ.; Pocajt, V.V. An artificial neural network approach for the estimation of the primary production of energy from municipal solid waste and its application to the Balkan countries. *Waste Manag.* **2018**, *78*, 955–968. [CrossRef]
3. Alobaid, F.; Al-Maliki, W.A.K.; Lanz, T.; Haaf, M.; Brachthäuser, A.; Epple, B.; Zorbach, I. Dynamic simulation of a municipal solid waste incinerator. *Energy* **2018**, *149*, 230–249. [CrossRef]
4. Chen, Y.C.H. Evaluating greenhouse gas emissions and energy recovery from municipal and industrial solid waste using waste-to-energy technology. *J. Clean. Prod.* **2018**, *192*, 262–269. [CrossRef]
5. Eurostat. *Waste Database Municipal Waste*; Eurostat: Brussel, Belgium, 2016.
6. Ercolano, S.; Gaeta, G.L.L.; Ghinoi, S.; Silvestri, F. Kuznets curve in municipal solid waste production: An empirical analysis based on municipal-level panel data from the Lombardy region (Italy). *Ecol. Indic.* **2018**, *93*, 397–403. [CrossRef]
7. Chan, J.K.H. The ethics of working with wicked urban waste problems: The case of Singapore's Semakau Landfill. Landsc. *Urban Plan.* **2016**, *154*, 123–131. [CrossRef]

8. Sun, W.; Wang, X.; DeCarolis, J.F.; Barlaz, M.A. Evaluation of optimal model parameters for prediction of methane generation from selected U.S. landfills. *Waste Manag.* **2019**, *91*, 120–127. [CrossRef] [PubMed]
9. Costa, A.M.; de Souza Marotta Alfaia, R.G.; Campos, J.C. Landfill leachate treatment in Brazil—An overview. *J. Environ. Manag.* **2019**, *232*, 110–116. [CrossRef]
10. Ouda, O.K.M.; Raza, S.A.; Nizami, A.S.; Rehan, M.; Al-Waked, R.; Korres, N.E. Waste to energy potential: A case study of Saudi Arabia. *Renew. Sustain. Energy Rev.* **2016**, *61*, 328–340. [CrossRef]
11. Tan, S.T.; Lee, C.T.; Hashim, H.; Ho, W.S.; Lim, J.S. Optimal process network for municipal solid waste management in Iskandar Malaysia. *J. Clean. Prod.* **2014**, *71*, 48–58. [CrossRef]
12. Havukainen, J.; Zhan, M.; Dong, J.; Liikanen, M.; Deviatkin, I.; Li, X.; Horttanainen, M. Environmental impact assessment of municipal solid waste management incorporating mechanical treatment of waste and incineration in Hangzhou, China. *J. Clean. Prod.* **2017**, *141*, 453–461. [CrossRef]
13. Balda, M.C.; Furubayashi, T.; Nakata, T. Integration of WTE technologies into the electrical system for low-carbon growth in Venezuela. *Renew. Energy* **2016**, *86*, 1247–1255. [CrossRef]
14. Güereca, L.P.; Torres, N.; Juárez-López, C.R. The co-processing of municipal waste in a cement kiln in Mexico. A life-cycle assessment approach. *J. Clean. Prod.* **2015**, *107*, 741–748. [CrossRef]
15. Wichai-utcha, N.; Chavalparit, O. 3Rs Policy and plastic waste management in Thailand. *J. Mater. Cycles Waste Manag.* **2019**, *21*, 10–22. [CrossRef]
16. Gonzalez-Valencia, R.; Magana-Rodriguez, F.; Cristóbal, J.; Thalasso, F. Hotspot detection and spatial distribution of methane emissions from landfills by a surface probe method. *Waste Manag* **2016**, *55*, 299–305. [CrossRef] [PubMed]
17. Jovanov, D.; Vujić, B.; Vujić, G. Optimization of the monitoring of landfill gas and leachate in closed methanogenic landfills. *J. Environ. Manag.* **2018**, *216*, 32–40. [CrossRef] [PubMed]
18. Feng, S.J.; Chen, Z.W.; Chen, H.X.; Zheng, Q.T.; Liu, R. Slope stability of landfills considering leachate recirculation using vertical wells. *Eng. Geol.* **2018**, *241*, 76–85. [CrossRef]
19. European Parliament. Decision No 1386/2013/EU of the European parliament and of the Council of 20 November 2013 on a general union environment action Programme to 2020 'living well, within the limits of our planet'. *Off. J. Eur. Union* **2013**, *354*, 171–200.
20. Peri, G.; Ferrante, P.; La Gennusa, M.; Pianello, C.; Rizzo, G. Greening MSW management systems by saving footprint: The contribution of the waste transportation. *J. Environ. Manag.* **2019**, *219*, 74–83. [CrossRef] [PubMed]
21. Brennan, R.B.; Healy, M.G.; Morrison, L.; Hynes, S.; Norton, D.C.; Clifford, E. Management of landfill leachate: The legacy of European Union Directives. *Waste Manag.* **2016**, *55*, 355–363. [CrossRef]
22. EPA. *Biodegradable Waste Diversion from Landfill*; EPA: Washington, DC, USA, 2015.
23. Karak, T.; Bhagat, R.M.; Bhattacharyya, P. Municipal solid waste generation, composition, and management: The world scenario. *Crit. Rev. Environ. Sci. Technol.* **2012**, *42*, 1509–1630. [CrossRef]
24. Vaverková, M.D.; Elbl, J.; Radziemska, M.; Kintl, A.; Baláková, L.; Adamcová, D.; Bartoň, S.; Hladký, J.; Kynický, J.; Brtnický, M. Environmental risk assessment and consequences of municipal waste disposal. *Chemosphere* **2018**, *208*, 569–578. [CrossRef] [PubMed]
25. Castillo-Giménez, J.; Montañés, A.; Picazo-Tadeo, A.J. Performance and convergence in municipal waste treatment in the European Union. *Waste Menag.* **2019**, *85*, 222–231. [CrossRef] [PubMed]
26. European Parliament. *EU WM: Infographic with Facts and Figures*; European Parliament: Strasbourg, France, 2018.
27. Chakravarty, P.; Kumar, M. Floral Species in Pollution Remediation and Augmentation of Micrometeorological Conditions and Microclimate an Integrated Approach. In *Phytomanagement Polluted Sites*; Elsevier: Amsterdam, The Netherlands, 2019. [CrossRef]
28. Białowiec, A. Some Aspects of Environmental Impact of Waste Dumps. In *Contemporary Problems of Management and Environmental Protection*; University of Warmia and Mazury in Olsztyn: Olsztyn, Poland, 2011.
29. Koda, E.; Miszkowska, A.; Sieczka, A. Levels of organic pollution indicators in groundwater at the old landfill and WM site. *Appl. Sci.* **2017**, *7*, 638. [CrossRef]
30. Koda, E.; Pachuta, K.; Osinski, P. Potential of plant applications in the initial stage of the landfill reclamation process. *Pol. J. Environ. Stud.* **2013**, *22*, 1731–1739.

31. Weng, Y.C.; Fujiwara, T.; Houng, H.J.; Sun, C.H.; Li, W.Y.; Kuo, Y.W. Management of landfill reclamation with regard to biodiversity preservation, global warming mitigation and landfill mining: Experiences from the Asia–Pacific region. *J. Clean. Prod.* **2015**, *104*, 364–373. [CrossRef]
32. Vallero, D.A.; Blight, G. The Municipal Landfill. In *Waste*, 2nd ed.; Academic Press: Cambridge, MA, USA, 2019. [CrossRef]
33. Laner, D.; Crest, M.; Scharff, H.; Morris, J.W.F.; Barlaz, M.A. A review of approaches for the long-term management of municipal solid waste landfills. *Waste Manag.* **2012**, *32*, 498–512. [CrossRef]
34. Ziyang, L.; Luochun, W.; Nanwen, Y.; Youcai, Z. Martial recycling from renewable landfill and associated risks: A review. *Chemosphere* **2015**, *131*, 91–103. [CrossRef]
35. Shen, S.; Chen, Y.; Zhan, L.; Xie, H.; Bouazza, A.; He, F.; Zuo, X. Methane hotspot localization and visualization at a large-scale Xi'an landfill in China: Effective tool for landfill gas management. *J. Environ. Manag.* **2018**, *225*, 232–241. [CrossRef]
36. Rada, E.C.; Ragazzi, M.; Stefani, P.; Schiavon, M.; Torretta, V. Modelling the Potential Biogas Productivity Range from a MSW Landfill for Its Sustainable Exploitation. *Sustainability* **2015**, *7*, 482–495. [CrossRef]
37. Zhao, C.; Zhang, Y.; Xie, D. The Multi-energy High precision Data Processor Based on AD7606. *IOP Conf. Ser. Earth Environ. Sci.* **2017**, *94*, 012138. [CrossRef]
38. Zappini, G.; Cocca, P.; Rossi, D. Performance analysis of energy recovery in an Italian municipal solid waste landfill. *Energy* **2010**, *35*, 5063–5069. [CrossRef]
39. Lombardi, L.; Carnevale, E.; Corti, A. Greenhouse effect reduction and energy recovery from waste landfill. *Energy* **2006**, *31*, 3208–3219. [CrossRef]
40. Tchobanoglous, G.; Kreith, F. *Handbook of Solid WM*; McGraw-Hill: New York, NY, USA, 2002.
41. Scheutz, C.; Kjeldsen, P. Guidelines for landfill gas emission monitoring using the tracer gas dispersion method. *Waste Manag.* **2019**, *85*, 351–360. [CrossRef] [PubMed]
42. Thomasen, T.B.; Scheutz, C.; Kjeldsen, P. Treatment of landfill gas with low methane content by biocover systems. *Waste Manag.* **2019**, *84*, 29–37. [CrossRef] [PubMed]
43. Da Costa, F.M.; Daflon, S.D.A.; Bila, D.M.; da Fonseca, F.V.; Campos, J.C. Evaluation of the biodegradability and toxicity of landfill leachates after pretreatment using advanced oxidative processes. *Waste Manag.* **2018**, *76*, 606–613. [CrossRef] [PubMed]
44. Regadío, M.; Ruiz, A.I.; de Soto, I.S.; Rastrero, M.R.; Sánchez, N.; Gismera, M.J.; Sevilla, M.T.; da Silva, P.; Procopio, J.R.; Cuevas, J. Pollution profiles and physicochemical parameters in old uncontrolled landfills. *Waste Manag.* **2012**, *32*, 482–497. [CrossRef] [PubMed]
45. O'Shea, F.T.; Cundy, A.B.; Spencer, K.L. The contaminant legacy from historic coastal landfills and their potential as sources of diffuse pollution. *Mar. Pollut. Bull.* **2018**, *128*, 446–455. [CrossRef] [PubMed]
46. Rezapour, S.; Samadi, A.; Kalavrouziotis, I.K.; Ghaemian, N. Impact of the uncontrolled leakage of leachate from a municipal solid waste landfill on soil in a cultivated-calcareous environment. *Waste Manag.* **2018**, *82*, 51–61. [CrossRef]
47. Melnyk, A.; Kuklinska, K.; Wolska, L. Chemical pollution and toxicity of water samples from stream receiving leachate from controlled municipal solid waste (MSW) landfill. *Environ. Res.* **2014**, *135*, 253–261. [CrossRef] [PubMed]
48. Budi, S.; Suliasih, B.A.; Othman, M.S.; Heng, L.Z.; Surif, S. Toxicity identification evaluation of landfill leachate using fish, prawn and seed plant. *Waste Manag.* **2016**, *55*, 231–237. [CrossRef] [PubMed]
49. Moody, C.M.; Townsend, T.G. A comparison of landfill leachates based on waste composition. *Waste Manag.* **2017**, *63*, 267–274. [CrossRef] [PubMed]
50. Arunbabu, V.; Indu, K.S.; Ramasamy, E.V. Leachate pollution index as an effective tool in determining the phytotoxicity of municipal solid waste leachate. *Waste Manag.* **2017**, *68*, 329–336. [CrossRef]
51. Paskuliakova, A.; McGowan, T.; Tonry, S.; Touzet, N. Microalgal bioremediation of nitrogenous compounds in landfill leachate—The importance of micronutrient balance in the treatment of leachates of variable composition. *Algal Res.* **2018**, *32*, 162–171. [CrossRef]
52. Singh, S.K.; Tang, W.Z. Statistical analysis of optimum Fenton oxidation conditions for landfill leachate treatment. *Waste Manag.* **2013**, *33*, 81–88. [CrossRef]
53. Xiong, J.; Zheng, Y.; Yang, X.; Dai, X.; Zhou, T.; He, J.; Luo, X. Recovery of NH3-N from mature leachate via negative pressure steam-stripping pretreatment and its benefits on MBR systems: A pilot scale study. *J. Clean. Prod.* **2018**, *203*, 918–925. [CrossRef]

54. Koda, E.; Zakowicz, S. Physical and hydraulic properties of the MSW for water balance of the landfill. In Proceedings of the 3rd International Congress on Environmental Geotechnics, Lisbon, Portugal, 7–11 September 1998; pp. 217–222.
55. Yao, P. Perspectives on technology for landfill leachate treatment. *Arab. J. Chem.* **2017**, *10*, S2567–S2574. [CrossRef]
56. Wang, B.; Shen, Y. Performance of an anaerobic baffled reactor (ABR) as a hydrolysis-acidogenesis unit in treating landfill leachate mixed with municipal sewage. *Water Sci. Technol.* **2000**, *42*, 115–121. [CrossRef]
57. Vaverková, M.D.; Zloch, J.; Adamcová, D.; Radziemska, M.; Vyhnánek, T.; Trojan, V.; Winkler, J.; Đorđević, B.; Elbl, J.; Brtnický, M. Landfill Leachate Effects on Germination and Seedling Growth of Hemp Cultivars (*Cannabis sativa* L.). *Waste Biomass Valorization* **2019**. [CrossRef]
58. Vaverková, M.D.; Adamcová, D. Can vegetation indicate municipal solid waste landfill impact on the environment? *Pol. J. Environ. Stud.* **2014**, *23*, 501–509.
59. Cameron, R.D.; Koch, F.A. Toxicity of landfill leachates. *Water Pollut. Control* **1980**, *52*, 760–769.
60. US EPA. *Ambient Water Quality Criteria for Ammonia (Saltwater) 440/5-88-004*; US Environmental Protection Agency, Criteria and Standards Division: Washington, DC, USA, 1989.
61. US EPA. *Ambient Water Quality Criteria for Ammonia 440/5-85-001*; US Environmental Protection Agency, Criteria and Standards Division: Washington, DC, USA, 1984.
62. Helma, A.; Mersch-Sundermann, V.; Houk, V.S.; Glasbrenner, U.; Klein, C.; Wenquing, L.; Kassie, F.; Schulte-Hermann, R.; Knasmuller, S. Comparative evaluation of four acterial assays for the detection of genotoxic effects in the dissolved water phases of aqueous matrices. *Environ. Sci. Technol.* **1996**, *30*, 897–907. [CrossRef]
63. Duggan, J. The potential for landfill leachate treatment using willows in the UK—A critical review. *Resour. Conserv. Recycl.* **2005**, *45*, 97–113. [CrossRef]
64. Renou, S.; Givaudan, J.G.; Poulain, S.; Dirassouyan, F.; Moulin, P. Landfill leachate treatment: Review and opportunity. *J. Hazard. Mater.* **2008**, *150*, 468–493. [CrossRef]
65. Raghab, S.M.; El Meguid, A.M.A.; Hegazi, H.A. Treatment of leachate from municipal solid waste landfill. *HBCR J.* **2013**, *9*, 187–192. [CrossRef]
66. Kamaruddin, M.A.; Yusoff, M.S.; Rui, L.M.; Isa, A.M.; Zawawi, M.H.; Alrozi, R. An overview of municipal solid WM and landfill leachate treatment: Malaysia and Asian perspectives. *Environ. Sci. Pollut. Res.* **2017**, *24*, 26988. [CrossRef]
67. Powell, J.T.; Pons, J.C.; Chertow, M. Waste informatics: Establishing characteristics of contemporary U.S. landfill quantities and practices. *Environ. Sci. Technol.* **2016**, *50*, 10877–10884. [CrossRef]
68. Chavan, D.; Lakshmikanthan, P.; Mondal, P.; Kumar, S.; Kumar, R. Determination of ignition temperature of municipal solid waste for understanding surface and sub-surface landfill fire. *Waste Manage.* **2019**, *97*, 123–130. [CrossRef]
69. Raúl, G.E.; Morales, S.; Toro, R.; Luis, A.; Morales, M.A.; Leiva, G. Landfill fire and airborne aerosols in a large city: Lessons learned and future needs Air Qual. *Atmos. Health* **2018**, *11*, 111–121.
70. Øygard, J.K.; Måge, A.; Gjengedal, E.; Svane, T. Effect of an uncontrolled fire and the subsequent fire fight on the chemical composition of landfill leachate. *Waste Manag.* **2005**, *25*, 712–718. [CrossRef]
71. Vassiliadou, I.; Papadopoulos, A.; Costopoulou, D.; Vasiliadou, S.; Christoforou, S.; Leondiadis, L. Dioxin contamination after an accidental fire in the municipal landfill of Tagarades, Thessaloniki, Greece. *Chemosphere* **2009**, *74*, 879–884. [CrossRef] [PubMed]
72. Chrysikou, L.; Gemenetzis, P.; Kouras, A.; Manoli, E.; Terzi, E.; Samara, C. Distribution of persistent organic pollutants, polycyclic aromatic hydrocarbons and trace elements in soil and vegetation following a large scale landfill fire in northern Greece. *Environ. Int.* **2008**, *34*, 210–225. [CrossRef] [PubMed]
73. Downard, J.; Singh, A.; Bullard, R.; Jayarathne, T.; Rathnayake, C.M.; Simmons, D.L.; Wels, B.R.; Spak, S.N.; Peters, T.; Beardsley, D.; et al. Uncontrolled combustion of shredded tires in a landfill—Part 1: Characterization of gaseous and particulate emissions. *Atmos. Environ.* **2015**, *104*, 195–204. [CrossRef] [PubMed]
74. Singh, A.; Spak, S.N.; Stone, E.A.; Downard, J.; Bullard, R.L.; Pooley, M.; Kostle, P.A.; Mainprize, M.W.; Wichman, M.D.; Peters, T.M.; et al. Uncontrolled combustion of shredded tires in a landfill—Part 2: Population exposure, public health response, and an air quality index for urban fires. *Atmos. Environ.* **2015**, *104*, 273–283. [CrossRef] [PubMed]

75. Rim-Rukeh, A. An Assessment of the Contribution of Municipal Solid Waste Dump Sites Fire to Atmospheric Pollution. *Open J. Air Pollut.* **2014**, *3*, 53–60. [CrossRef]
76. Weichenthal, S.; Van Rijswijk, D.; Kulka, R.; You, H.; Van Ryswyk, K.; Willey, J.; Dugandzic, R.; Sutcliffe, R.; Moulton, J.; Baike, M.; et al. The impact of a landfill fire on ambient air quality in the north: A case study in Iqaluit, Canada. *Environ. Res.* **2015**, *142*, 46–50. [CrossRef] [PubMed]
77. Cristale, J.; Belé, T.G.A.; Lacorte, S.; Rodrigues de Marchi, M.R.R. Occurrence of flame retardants in landfills: A case study in Brazil. *Environ. Res.* **2019**, *168*, 420–427. [CrossRef]
78. Nadal, M.; Rovira, J.; Díaz-Ferrero, J.; Schuhmacher, M.; Domingo, J.L. Human exposure to environmental pollutants after a tire landfill fire in Spain: Health risks. *Environ. Int.* **2016**, *97*, 37–44. [CrossRef]
79. Escobar-Arnanz, J.; Mekni, S.; Blanco, G.; Eljarrat, E.; Barceló, D.; Ramos, L. Characterization of organic aromatic compounds in soils affected by an uncontrolled tire landfill fire through the use of comprehensive two-dimensional gas chromatography–time-of-flight mass spectrometry. *J. Chromatogr. A* **2018**, *1536*, 163–175. [CrossRef]
80. Purser, D.A.; Maynard, R.L.; Wakefield, J.C. *Toxicology, Survival and Health Hazards of Combustion Products*; The Royal Society of Chemistry: London, UK, 2015. [CrossRef]
81. Rovira, J.; Dominguez-Morueco, N.; Nadal, M.; Schuhmacher, M.; Domingo, J.L. Temporal trend in the levels of polycyclic aromatic hydrocarbons emitted in a big tire landfill fire in Spain: Risk assessment for human health. *J. Environ. Sci. Heal. A.* **2018**, *53*, 222–229. [CrossRef]
82. Kumar, S.; Aggarwal, S.G.; Gupta, P.K.; Kawamura, K. Investigation of the tracers for plastic-enriched waste burning aerosols. *Atmos. Environ.* **2015**, *108*, 49–58. [CrossRef]
83. Sahariah, B.; Goswami, L.; Farooqui, I.U.; Raul, P.; Bhattacharyya, P.; Bhattacharya, S.S. Solubility, hydrogeochemical impact, and health assessment of toxic metals in municipal wastes of two differently populated cities. *J. Geochem. Explor.* **2015**, *157*, 100–109. [CrossRef]
84. Rao, M.N.; Sultana, R.; Kota, S.H. Municipal solid waste. In *Solid and Hazardous WM*; Elsevier: Amsterdam, The Netherlands, 2017; pp. 3–120.
85. Krzyzanowski, M.; Cohen, A. Update of WHO air quality guidelines. *Air Qual. Atmos. Health* **2008**, *1*, 7–13. [CrossRef]
86. Giusti, L. A review of WM practices and their impact on human health. *Waste Manag.* **2009**, *29*, 2227–2239. [CrossRef] [PubMed]
87. Dhabbah, A.M. Ways of analysis of fire effluents and assessment of toxic hazards. *J. Anal. Sci. Methods Instrum.* **2015**, *5*, 1–12. [CrossRef]
88. Stoeva, K.; Alriksson, S. Influence of recycling programmes on waste separation behavior. *Waste Manag.* **2017**, *68*, 732–741. [CrossRef] [PubMed]
89. Hipel, J.; Ma, K.W.; Hanson, M.L.; Cai, X.; Liu, Y. An analysis of influencing factors on municipal solid waste source-separated collection behavior in Guilin, China by using the theory of planned behavior. *Sustain. Cities Soc.* **2018**, *37*, 36–343. [CrossRef]
90. Pandey, R.U.; Surjan, A.; Kapshe, M. Exploring linkages between sustainable consumption and prevailing green practices in reuse and recycling of household waste: Case of Bhopal city in India. *J. Clean. Prod.* **2018**, *173*, 49–59. [CrossRef]
91. Matsuda, T.; Hirai, Y.; Asari, M.; Yano, J.; Miura, T.; Ii, R.; Sakai, S. Monitoring environmental burden reduction from household waste prevention. *Waste Manag.* **2018**, *71*, 2–9. [CrossRef]
92. Pietzsch, N.; Ribeiro, J.D.L.; Medeiros, J.F. Benefits, challenges and critical factors of success for zero waste: A systematic literature review. *Waste Manag.* **2017**, *67*, 324–353. [CrossRef]
93. Samadder, S.R.; Prabhakar, R.; Khan, D.; Kishan, D.; Chauhan, M.S. Analysis of the contaminants released from municipal solid waste landfill site: A case study. *Sci. Total Environ.* **2017**, *580*, 593–601. [CrossRef] [PubMed]
94. Zaman, A.U. A comprehensive study of the environmental and economic benefits of resource recovery from global WM systems. *J. Clean. Prod.* **2016**, *124*, 41–50. [CrossRef]
95. Westlake, K. Sustainable Landfill—Possibility or Pipe-Dream? *Waste Manag. Res.* **1997**, *15*, 453–461. [CrossRef]
96. Townsend, T.G.; Powell, J.; Jain, P.; Xu, Q.; Tolaymat, T.; Reinhart, D. Planning for Sustainable Landfilling Practices. Sustainable Practices for Landfill Design and Operation. In *Sustainable Practices for Landfill Design and Operation*; Springer: New York, NY, USA, 2015; pp. 35–51. [CrossRef]

97. Meegoda, J.N.; Soliman, A.; Hettiaratchi, P.A.; Agbakpe, M. Resource Mining for a Bioreactor Landfill. *Curr. Environ. Eng.* **2019**, *6*, 17–34. [CrossRef]
98. Scharff, H.; Kok, B.; Krom, A.H. The role of sustainable landfill in future WM systems. In Proceedings of the Eleventh International WM and Landfill Symposium, Cagliari, Italy, 1–5 October 2007.
99. Huber-Humer, M.; Lechner, P. Sustainable landfilling or sustainable society without landfilling? *Waste Manag.* **2011**, *31*, 1427–1428. [CrossRef] [PubMed]
100. Song, O.; Li, J.; Zeng, X. Minimizing the increasing solid waste through zero waste strategy. *J. Clean. Prod.* **2015**, *104*, 199–210. [CrossRef]
101. Taha, M.P.M.; Drew, G.H.; Longhurst, P.J.; Smith, R.; Pollard, S.J.T. Bioaerosol releases from compost facilities: Evaluating passive and active source terms at a green waste facility for improved risk assessments. *Atmos. Environ.* **2006**, *40*, 159–1169. [CrossRef]
102. Pearson, C.; Littlewood, E.; Douglas, P.; Robertson, S.; Gant, T.W.; Hansell, A.L. Exposures and health outcomes in relation to bioaerosol emissions from composting facilities: A systematic review of occupational and community studies. *J. Toxicol. Environ. Health Part B* **2015**, *18*, 43–69. [CrossRef]
103. Robertson, S.; Douglas, P.; Jarvis, D.; Marczylo, E. Bioaerosol exposure from composting facilities and health outcomes in workers and in the community: A systematic review update. *Int. J. Hyg. Environ. Health* **2019**, *222*, 364–386. [CrossRef]
104. Ounoughene, G.; Chivas-Joly, C.; Longuet, C.; Le Bihan, O.; Lopez-Cuesta, J.M.; Coq, L.L. Evaluation of nanosilica emission in polydimethylsiloxane composite during incineration. *J. Hazard. Mater.* **2019**, *371*, 415–422. [CrossRef]
105. Feng, Y.; Jiang, X.; Chen, D. The emission of fluorine gas during incineration of fluoroborate residue. *J. Hazard. Mater.* **2016**, *308*, 91–96. [CrossRef] [PubMed]
106. Jones, A.M.; Harrison, R.M. Emission of ultrafine particles from the incineration of municipal solid waste: A review. *Atmos. Environ.* **2016**, *140*, 519–528. [CrossRef]
107. Hsu, W.T.; Liu, M.C.; Hung, P.C.; Chang, S.H.; Chang, M.B. PAH emissions from coal combustion and waste incineration. *J. Hazard. Mater.* **2016**, *3018*, 32–40. [CrossRef] [PubMed]
108. Burlakovs, J.; Kriipsalu, M.; Klavins, M.; Bhatnagar, A.; Vincevica-Gaile, Y.; Stenis, J.; Jani, Z.; Mykhaylenko, V.; Denafas, G.; Turkadze, T.; et al. Paradigms on landfill mining: From dump site scavenging to ecosystem services revitalization. *Resour. Conserv. Recycl.* **2017**, *123*, 73–84. [CrossRef]
109. Laner, D.; Cencic, O.; Svensson, N.; Krook, J. Quantitative Analysis of Critical Factors for the Climate Impact of Landfill Mining. *Environ. Sci. Technol.* **2016**, *50*, 6882–6891. [CrossRef] [PubMed]
110. Mönkäre, T.; Palmroth, M.R.T.; Sormunen, K.; Rintala, J. Scaling up the treatment of the fine fraction from landfill mining: Mass balance and cost structure. *Waste Manag.* **2019**, *15*, 464–471. [CrossRef]
111. Hölzle, I. Contaminant patterns in soils from landfill mining. *Waste Manag.* **2019**, *83*, 151–160. [CrossRef] [PubMed]
112. Danthurebandara, M.; Van Passel, S.; Van Acker, K. Environmental and economic assessment of 'open waste dump' mining in Sri Lanka. *Resour. Conserv. Recycl.* **2015**, *102*, 67–79. [CrossRef]
113. Danthurebandara, M.; Van Passel, S.; Vanderreydt, I.; Van Acker, K. Assessment of environmental and economic feasibility of Enhanced Landfill Mining. *Waste Manag.* **2015**, *45*, 434–447. [CrossRef]
114. Frändegård, P.; Krook, J.; Svensson, N.E.; Eklund, M. Resource and Climate Implications of Landfill Mining. *J. Ind. Ecol.* **2013**, *17*, 742–755. [CrossRef]
115. Winterstetter, A.; Laner, D.; Rechberger, H.; Fellner, J. Framework for the evaluation of anthropogenic resources: A landfill mining case study—Resource or reserve? *Resour. Conserv. Recycl.* **2015**, *96*, 19–30. [CrossRef]
116. Laner, D.; Esguerra, J.L.; Krook, J.; Horttanainen, M.; Kriipsalu, M.; Rosendal, R.M.; Stanisavljević, N. Systematic assessment of critical factors for the economic performance of landfill mining in Europe: What drives the economy of landfill mining? *Waste Manag.* **2019**, *15*, 674–686. [CrossRef] [PubMed]