Waste management: relevance to environmental sustainability

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Abstract: Waste generation and its management present universal challenges related to negative impacts on the environment. Municipal solid waste generation in large quantities on daily basis constitutes serious environmental problems. This paper presents a review of extant literature in the management of municipal waste across a range of countries alongside waste management hierarchy that guide legislations and policies for developed and developing countries. This paper assesses the environmental consequences emanating from the influence of either the presence or absence of contaminants-based diverse management options for municipal solid waste; thereby facilitating policy makers and waste management companies informed choice(s) for the management of municipal waste sustainably. The outcome from the evaluation of environmental effect reveals that incineration; the most common waste-to-energy implementation for municipal solid waste is accompanied with the emission of greenhouse gases, Nitrogen oxides, ammonia, sulphur dioxide contributing to climate change and air acidification. Environmental concern is a critical indicator for determining the best appropriate waste management option(s). The need to encourage the increasing recycling of municipal solid waste to facilitate a global sustainable environment as well as boosting the circular economy and green cities is recommended.

Keywords: waste management; municipal solid waste; environmental sustainability; waste management hierarchy; pollution.

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1 Introduction

Waste management is a fundamental issue across the continents with varying degree of challenges such as increasing volume of waste and environmental consequence. These challenges are however more pressing, peculiar and prominent in developing countries due to incomplete institutional arrangements and poor handling of waste. Waste management can be characterised on the basis of aspects ranging from practices, strategies, goals, control, monitoring and regulation of the production, financial and marketing aspects, to environmental assessments of various treatments, evaluation and policy. These aspects can be used in a holistic approach to mitigating challenges emanating from waste, its management and various treatments. The primary focus of literature on waste management has been on instituting equilibrium between the dual objectives of conserving natural resources and ensuring environmental protection (Gharfalkar et al., 2015).

''Sustainable development encompasses the reduction of polluting emissions and the establishment of sustainable waste management practices'' (Coelho and Lange, 2018). The UN Sustainable Development Goal 6.3 targets to achieve environmentally sound management of all waste, particularly hazardous waste either chemical or biological hazardous waste. Sustainable waste management is one of the most important global environmental agendas in the 21st century (Zaman and Swapan, 2016). Sustainable waste management is considered a precondition to mitigating environmental challenges across the globe. The management of waste sustainably aims at environmental quality, which is a prerequisite for per-capita well-being over a period of time (Abila and Jussi, 2013). Massaruto (2007) writes, for instance, that "European waste policies have mostly resulted from environmental considerations; they have aimed at reducing emissions, controlling waste shipments, avoiding illegal dumping or export to standard countries". Also findings from Abila (2018) study on households' perception of financial incentives in endorsing sustainable waste management in Nigeria revealed that the most important driver for household willingness to recycle waste is its detrimental environmental impacts.

Municipal solid waste as well as its management presents varying degree of concerns for waste management. The management of municipal solid waste is one of the priority issues regarding the protection of the environment and conservation of natural resources.

Municipal solid waste is one of the main components of pollution as it contaminates the ground as well as surface water and increases air pollutants, leading to miserable living conditions for people (Sanjeevi and Shabudeen, 2015). Aside its environmental concern, the continuous and increasing generation of MSW is at alarming rate as well as its diversity in composition. According to the projection of (World Bank, 2018) with rapid population growth and urbanisation, municipal solid waste production will rise to 2.2 billion tonnes by 2025. The composition of MSW differs over time and from country to country, due to difference in lifestyle, consumption pattern and waste management practices (Margallo et al., 2015).

The increasing concern on environmental sustainability in current years has led to the development of strategies to reduce waste, improve waste recovery, resource recycling of waste and diversion of waste from landfills for a sustainable living environment (Mmereki, 2018). Albeit, the European regulation proposed waste reduction, recycling and re-use and finally waste incineration and landfilling as fundamental principles to waste management (Margallo et al., 2014). The environmental concerns emanating from unsustain waste disposal and management approaches are evitable consequence when sustainable options are fully put to practice. A shift to a green environment is paramount as it secures the ecosystem while maintaining a green economy and social equity among present and future generations; and depends on the promotion of recycling, particularly if it enables reducing environmental impacts from raw material extraction and materials processing (Ferrao et al., 2014).The evaluation of environmental sustainability of waste treatment approaches, systems and processes is critical, given the growing global importance of environmental concerns (Rada et al., 2014).

Generally, municipal waste management strategies focus on environmental, health, aesthetic, land-use, resource and economic concerns (Marshall and Farahbakhsh, 2013). Since 1990, the main focus has shifted to environmental apprehension, particularly in relation to climate change (Habib et al., 2013). One of the most important anthropogenic sources of greenhouse gases (GHGs) is improper disposal and treatment of municipal waste (Tian et al., 2013), though considerable improvements are being made in some countries. It is pertinent to determine the reason waste management is focusing more on environmental sustainability rather than economic and societal sustainability. This paper aims to evaluate the environmental consequences resulting from the influence of either the presence or absence of contaminants for different management strategies for municipal solid waste. This paper presents a comprehensive review of municipal solid waste management for different countries and considers waste management hierarchy for developed and developing countries. It further presents an explicit view to aid decision makers in their understanding on the informed choice of sustainable options for the management of municipal waste.

2 Literature review

2.1 Municipal waste management in different countries

The management of waste systems in Poland has been built on the basis of the Communal Cleanliness and Order Maintenance Act of 13 September 1996. According to the amendment act of 1 July 2011 the organisation of waste is the responsibility of the municipalities, which tackle all activities affecting local communities (Mesjasz-Lech,

2014). Similarly, in Kolkata, a metropolitan city and capital of the state of West Bengal in eastern India, the management of municipal solid waste is the responsibility of the Kolkata municipal corporation. Here, processes involved in the management of municipal solid waste include primary collection of waste from households and streets, dumping at collection points, transportation to disposal sites, and disposal (Hazra and Goel, 2009). In the UK, landfill is the most common technique of municipal waste management, accounting for 49% of municipal solid waste disposal in 2009 (Al-Salem et al., 2014). In Spain, the town of Castellon de la Plana bases household collection on the selective selection of glass, paper, cardboard and packaging at material banks and street-side collection of all other waste (Bovea et al., 2010). In Hanoi, the capital of Vietnam and its second largest city, municipal solid waste is collected without sorting and deposited directly in landfills (Thanh et al., 2015). In Limbe municipality in Cameroon, waste is moved from generation points and deposited into municipal waste bins, which are later collected, transported and finally disposed of in open dumps (Manga et al., 2008). The most common municipal solid waste disposal and management approaches in Nigeria are open dumping, landfill, open burning; incineration is seldom used (Abila and Kantola, 2017). Municipal solid waste in Guadalajara, Mexico, is separated and recycled by mostly unregulated groups known as scavengers, while collection and transportation is the sole responsibility of the municipality; waste disposal strategy is based upon the burying of 98% of municipal waste (Berneche, 2003). Waste separation and recycling is not efficiently conducted in China, and incineration is limited as compared to landfill, which is the predominant technique for the management of municipal solid waste (Zhang et al., 2010).

> "However, two major ministries are involved in municipal solid waste management, as stipulated in the law. The first is the Ministry of Construction (MOC), which supervises and administers the cleaning, collection, storage, transportation, and final disposal of municipal solid waste. The second is the Ministry of Environmental Protection (MOEP), which administers and monitors the collection, treatment, and final disposal of hazardous waste, waste trade, and secondary pollution generated by the construction and operation of municipal solid waste treatment and disposal facilities." (Chen et al., 2010)

In some developed countries such as Finland, the sorting, storage and deposition of municipal waste at central waste bins are the primary duties of consumers, while collection, transportation and treatment are the responsibility of municipal authorities (European Environment Agency, 2013). Currently, in integrated solid waste management, an effective and comprehensive programme is applied. Management of municipal solid waste in Greece is in contrast to the European Union's policy on waste: in a case where a high number of open dump sites (reduced from over 5,500 in 1990 to 1,260 in 2004) constitute the most negative element and the percentage of useful material recovered is low (Erkut et al., 2008). In Phuket, an island province in the south of Thailand collected and transported municipal solid waste undergoes secondary segregation at treatment and disposal centres rather than undergoing primary segregation at source (Liamsanguan and Gheewala, 2008). Solid waste management in Singapore has conventionally been handled by the Ministry of Environment. Solid waste incineration has top priority over other waste disposal methods (Bai and Sutanto, 2002). Similarly, in France incineration still remains (and can be expected to remain) the main waste treatment option for municipal solid waste (Beylot and Villeneuve, 2013). In Botswana,

60% of the waste is disposed by indiscriminate dumping, 38% by landfill and 1% is by open burning and recycling (Mmereki, 2018).

2.2 Waste management hierarchy

2.2.1 Waste management hierarchy in developed countries

"The waste hierarchy generally lays down a priority order of what constitutes the best overall environmental option in waste legislation and policy, while departing from such a hierarchy may be necessary for specific waste streams when justified for reasons of, inter alia, technical feasibility, economic viability and environmental protection" (Cucchiella et al., 2014). The waste management hierarchy depicts the prioritised strategies in the management of waste. Developed nations such as those in Europe and Japan tend to implement a hierarchical approach to solid waste management, including final waste disposal options (Dijkgraaf and Vollebergh, 2004). These differently prioritised strategies focus on environmental protection. Environmental concerns have been considered ever-increasing significance in the municipal solid waste decision-making process (Batool and Chuadhry, 2009). In essence, the aim of waste policies is to promote the use of natural resources and ensure waste does not pose a health or environmental hazard (Ministry of Environment, 2013; Brunner and Rechberger, 2015).

The application of the waste management hierarchy is voluntary for European member states, albeit with the expectation of adoption into national waste management laws (Williams, 2015). Each Member State has its own pre-determined goals for waste management. For instance, in the case of Swiss waste management policy, preferences include prevention of waste at source, reduction of pollutants both in production processes and finished goods, reduction of waste by improving recovery, and improvement of the environmental compatibility of remaining waste (Joos et al., 1999).

Figure 1 European Union waste management hierarchy (see online version for colours)

Source: European Commission (2015a)

European Union waste management hierarchy

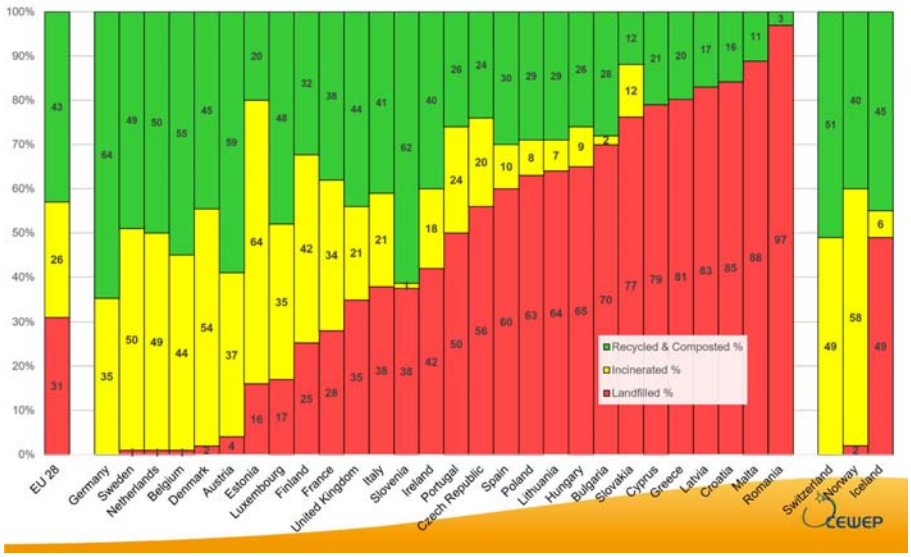
Aside waste prevention, reduction, re-use and recycling, other management of municipal solid waste still links to major environmental concerns (Moy et al., 2008). The EU waste hierarchy prioritises waste reduction and volume reduction both at primary and at secondary sources.

- *Prevention:* waste prevention, also known as waste reduction, applies to both manufacturers and waste generators. At the manufacturers' end, such a policy can be termed 'primary-source prevention', and in relation to waste generators 'secondary-source prevention'. The use of this strategy at the manufacturers' end helps minimise the production of heavy packaging materials, while for waste generators it can promote the purchasing of reusable products (USEPA, 2015a). Prevention is the highest priority in waste policy in several regions (Gentil et al., 2011).
- *Re-use:* this is defined as the further use of products, materials or substances for the end to which they were conceived (Nehrenheim, 2014). Re-use happens at the point of waste generation at the manufacturer's end. Preventing waste through re-use is often related to ideas of stewardship, conservation and preservation.
- *Recycling:* this is the process of sorting, collecting, preparing, reprocessing and remanufacturing used, re-used, or unused materials into new or original forms (Mohee et al., 2015). This ensures conservation of energy and materials, and mitigates pollution and emission of green-house gases. Recycling makes a considerable contribution to environmental benefit, proving that source separation will be more and more important in dealing with municipal solid waste in future (Song et al., 2013).
- *Recovery:* this is the recovery of energy in the form of heat, electricity and fuel from non-recyclable materials through the application of various processes including combustion, pyrolisation, gasification and anaerobic digestion (USEPA, 2015b). Energy recovery from waste is one viable alternative source of energy.
- *Disposal:* This involves the transfer of waste to landfill. This is the most common waste management strategy, though the least preferred and most unsustainable. According to the waste management hierarchy, landfill is the least preferable option and should be limited to the necessary minimum. Where waste needs to be landfilled, it must be sent to landfills which comply with the requirements of Directive 1999/31/EC on the landfill of waste (European Commission, 2015b).

2.2.2 Waste management hierarchy in developing countries

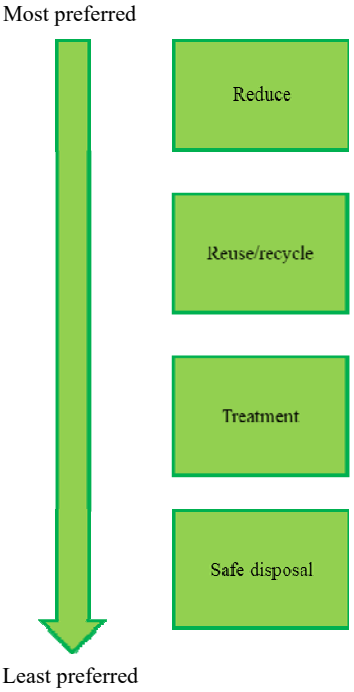
Waste management hierarchy is a widespread element of national and regional policy and is often considered the most fundamental premise of contemporary management practice for municipal solid waste (Jibril et al., 2012).

Figure 2 Graph of municipal waste treatment in Europe in 2013 (see online version for colours)



Source: Confederation of European waste-to-energy plants (CEWEP, 2015)

Figure 3 Waste management hierarchy in Botswana (see online version for colours)



Source: Mmereki (2018)

In developing countries there seems to be the absence of a consensual adopted or stipulated waste management hierarchy in regions. Thus waste management hierarchy is often country specific rather than regional with little or no disparity among countries and or between regions. Comparatively, developing countries waste management hierarchy works towards similar goals as the developed countries. In Mozambican documentation the definition of Waste hierarchy is not clear as per the priority order between prevention, reduction, reusing, recycling and other forms of recovery or disposal. Waste hierarchy does not seem to be relevant because the preferred option is considered to be the one that uses the best available technologies at sustainable cost (Ferrari et al., 2016). The core legal framework for waste management in Botswana is the Botswana waste management strategy which stated waste hierarchy as a solution towards sustainable waste management in the country with disposal being the least preferred disposal option, and re-use, recycling etc. being the highest priorities (Mmereki, 2018). Nevertheless, the waste management hierarchy operates inversely in practice; landfill is still the most used option (Mmereki, 2018). Invariably there seems to be gap in the actualisation of waste management hierarchy in theory to its application in practise.

3 Emissions emanating from municipal solid waste disposal and management

Climate change is rapidly and currently manifesting its effects of global warming and melting ice across the globe. The increasing production and quantity of waste contributing to anthropogenic sources of GHG emissions is one of the vital and huge drivers. In many nations, the main emissions of anthropogenic source of methane are from landfills (Couth et al., 2011), particularly from developing nations. Globally, about 50% of methane emissions from solid waste disposal options are emitted from ten countries (Barton et al., 2008), of which annually about 10–19% of global emissions are generating from landfills (Chen et al., 2008). Cherubini et al., 2008; analysed scenarios from urban waste management and they revealed that landfilling is the most polluting option at the global scale since it generates many different emissions such as methane, H2S hydrogen chloride, nitrogen, and phosphorus inorganic compounds; and it appears that pollution problems cannot be mitigated by any of investigated options ranging from landfills, anaerobic digestion and incineration. Dioxins have been emitted from incineration plants and conventionally been highlighted as one of the most significant sources of toxic emissions and heavy metals (Nzihou et al., 2012). Considering composting, emissions of ammonia alongside volatile sulphur compounds of hydrogen sulphide, methyl mercaptan, dimethyl sulphide, carbon disulphide, dimethyl disulphide, methane, nitrous oxide and volatile organic compounds (VOC) are components of this waste management option (Moreno et al., 2014; Maulini-Duran et al., 2014).

4 Environmental effects associated with municipal solid waste management

Environmental effects arising from the management approaches for municipal solid waste can either be positive or negative. These negative and positive environmental effects are outcomes or consequences from impacts or influence of either the presence or absence of

contaminants that unfold over a period of time. Negative effects result in declines both in human health and in the health of other living organisms. “The perils associated with inappropriate solid waste disposal, and associated environmental health impacts, should therefore be of utmost concern to waste management experts” (Ayomoh et al., 2008).

Table 1 Environmental effects of municipal solid waste management

Environmental effect	*Contaminant*	*Municipal solid waste management technique*	*Source*
Air pollution	Gas emissions such as methane	Landfill	Aljaradin and Persson (2012), Vrijheid (2000), Dijkgraaf and Vollebergh (2004)
Explosion hazards	Gas emissions such as methane and hydrogen	Landfill	Aljaradin and Persson (2012)
Water pollution	Leachates with high content of carbon and ammonium	Landfill	Aljaradin and Persson (2012), Vrijheid (2000), Dijkgraaf and Vollebergh (2004) and Kirkeby et al. (2007).
Nuisance odour	Fungi and bacteria bioaerosols	Landfill composting	Ulfik and Nowak (2014).
Soil pollution	Heavy metals such as lead, cadmium, mercury, copper, iron and zinc	Landfill	Ulfik and Nowak (2014), Anikwe and Nwobodo (2002), Vrijheid (2000) and Dijkgraaf and Vollebergh (2004)
Global warming	Gas emissions such as methane, nitrous oxide, carbon dioxide, nitrogen oxides	Backyard burning, landfill, incineration, anaerobic digestion	USEPA (2015b), Kirkeby et al. (2007, 2006) and Banar et al. (2009)
Ozone layer depletion	Ethylene, nitrogen oxides	Backyard burning, landfill	USEPA(2015b) and Kirkeby et al. (2007).
Air acidification	Sulphur dioxide, nitrogen oxides, ammonia, nitrous oxide	Backyard burning, landfill, incineration, composting	USEPA (2015b), Kirkeby et al.(2007) and Banar et al. (2009)
Eutrophication	Nitrate, nitrogen, phosphorus	Landfill and composting	Kirkeby et al. (2007) and Banar et al. (2009)

Table 1 Environmental effects of municipal solid waste management (continued)

Environmental effect	*Contaminant*	*Municipal solid waste management technique*	*Source*
Smog formation	Nitrogen oxides	Backyard burning	USEPA (2015b)
Conservation of natural resources, reduces pollution, reduces the toxicity of waste, reduces greenhouse gas emissions and helps sustain the environment for future generation.	_	Reduction	Jibril et al. (2012) and USEPA (2018)
Reduces the quantity of waste directly disposed of to landfill, ensures the conservation of virgin materials and eliminates chances of emissions.	_	Recycling	Abila (2018), Cherubini et al. (2008) and Emery et al. (2007)
Minimises the amount of waste that will need to be recycled or sent to landfills and incinerators, prevents pollution, reduces greenhouse gas emissions and helps sustain the environment for future generation.	_	Reuse	Cooper and Gutowski (2017) and USEPA (2018)

Landfill, the most conventional means of waste treatment, is the least desirable option because of the many possible adverse impacts it can present. The most serious of these is the production and release into the air of methane, a powerful greenhouse gas 25 times more potent than carbon dioxide (European Commission, 2010). GHG from waste management contribute immensely to climate change, and these emissions have been recognised as an important environmental issue in the waste sector (Menikpura et al., 2013). Apart from its global warming potential, methane also contributes to depleting the ozone layer (Johari et al., 2012).

Comparably, the climatic benefits of waste prevention and recycling far outweigh the benefits from any waste-treatment technology such as anaerobic digestion, waste to energy (WtE), pyrolysis, gasification, or even energy recovered during the process (Couth and Trois, 2012). One of the most important measures to inform decision-making on the most sustainable options for municipal waste management is the evaluation of environmental impacts (Al-Salem et al., 2014).

Table 1 highlights adverse environmental effects associated with different municipal solid waste management techniques and contaminants.

5 Conclusions

Global sustainable management of waste is worth the effort it requires, considering its short- and long-term effects on the environment. Re-use and recycling strategies may be the best environmentally-friendly options for municipal waste management so as to ensure environmental sustainability. According to Cherubini et al. (2008) “recycling is a rewarding practice requiring least environmental support”. It limits the quantity of waste

diverted to landfill, reduces the depletion of natural resources, improves energy efficiency and eliminates chances of emissions.

Environmental consequences are one of the most critical indexes for determining the best waste management options. Considering the consequences of inappropriate waste management, environmental evaluation is very important to inform decision-making. The outcome from the evaluation of environmental effects reveals that the management treatment options for energy recovery from municipal solid waste is accompanied with the release of certain gases contributing to climate change and acidic rain.

The sustainable management of municipal waste translates into a sustainable environment which guarantees sustainable development for present and future generations. However, sustainability in terms of waste management and environment requires a global effort. Environmental concerns demand prompt solutions to ensure the stability of the natural world and human existence.

This study is relevant to policy makers and waste management companies in guiding their choice(s) of management for municipal solid waste management.

It is paramount for extended producers to develop green manufacturing production all through the production phase thereby utilising materials or substances that are composed mainly for recycling possibilities.

The role and participation of stakeholders at each phase of waste management is a prelude to the attainment of a sustainable waste management.

Increasing generation of waste can barely be reduced substantially as population growth and industrialisation are driving forces; it is imperative to consider, emphasise, and conform to increasing recycling as an outstanding management option for municipal solid waste besides environmental gains but for the boosting of a circular economy and green cities.

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References

Abila, B. (2018) 'Households' perception of financial incentives in endorsing sustainable waste recycling in Nigeria', *Recycling*, Vol. 3, No. 2, p.28.

Abila, B. and Kantola, J. (2013) 'Municipal waste management problems in Nigeria: evolving knowledge management solution', *International Journal of Environmental, Ecological, Geological and Mining Engineering*, Vol. 7, No. 6, pp.172–177.

Abila, B. and Kantola, J. (2017) 'Proposed solutions in municipal solid-waste management', *International Journal of Environment and Waste Managemen*t, Vol. 19, No. 4, pp.297–317.

Aljaradin, M. and Persson, K.M. (2012) 'Environmental impact of municipal solid waste landfills in semi-arid climates. Case study: Jordan', *The Open Waste Management Journal*, Vol. 5, No. 1, pp.28–39.

Al-Salem, S.M., Evangelisti, S. and Lettieri, P. (2014) 'Life cycle assessment of alternative technologies for municipal solid waste and plastic solid waste management in the Greater London area', *Chemical Engineering Journal*, Vol. 244, pp.391–402.

Anikwe, M.A.N. and Nwobodo, K.C.A. (2002) 'Long term effect of municipal waste disposal on soil properties and productivity of sites used for urban agriculture in Abakaliki, Nigeria', *Bioresource Technology*, Vol. 83, No. 3, pp.241–250.

Ayomoh, M.K.O., Okeb, S.A., Adedeji W.O. and Charles-Owaba, O.E. (2008) 'An approach to tackling the environmental and health impacts of municipal solid waste disposal in developing countries', *Journal of Environmental Management*, Vol. 88, No. 1, pp.108–114.

Bai, R. and Sutanto, M. (2002) 'The practice and challenges of solid waste management in Singapore', *Waste Management*, Vol. 22, No. 5, pp.557–567.

Banar, M., Cokaygil, Z. and Ozkan, A. (2009) 'Life cycle assessment of solid waste management options for Eskisehir, Turkey', *Waste Management*, Vol. 29, No. 1, pp.54–62.

Barton, J.R., Issaias, I. and Stentiford E.I. (2008) 'Carbon – making the right choice for waste management in developing countries', *Waste management*, Vol. 28, No. 4, pp.690–698.

Batool, S.A. and Chuadhry, M.N. (2009) 'The impact of municipal solid waste treatment methods on greenhouse gas emissions in Lahore, Pakistan', *Waste Management*, Vol. 29, No. 1, pp.63–69.

Berneche, G. (2003) 'The environmental impact of municipal waste management: the case of Guadalajara metro area', *Resources, Conservation and Recycling*, Vol. 39, No. 3, pp.223–237.

Beylot, A. and Villeneuve, J. (2013) 'Environmental impacts of residual municipal solid waste incineration: a comparison of 110 French incinerators using a life cycle approach', *Waste Management*, Vol. 33, No. 12, pp.2781–2788.

Bovea, M.D., Ibanez-Fores, V., Gallardo, F. and Colomer-Mendoza, F.J. (2010) 'Environmental assessment of alternative municipal solid waste management strategies. A Spanish case study', *Waste Management*, Vol. 30, No. 11, pp.2383–2395.

Brunner, P.H. and Rechberger, H. (2015) 'Waste to energy – key element for sustainable waste management', *Waste Management*, Vol. 37, pp.3–12.

Chen, I.C., Hegde, U., Chang, C.H. and Yang, S.S. (2008) 'Methane and carbon dioxide emissions from closed landfill in Taiwan', *Chemosphere*, Vol. 70, No. 8, pp.1484–1491.

Chen, X., Geng, Y. and Fujita, T. (2010) 'An overview of municipal solid waste management in China', *Waste Management*, Vol. 30, No. 4, pp.716–724.

Cherubini, F., Bargigli, S. and Ulgiati, S. (2008) 'Life cycle assessment of urban waste management: energy performances and environmental impacts. The case of Rome, Italy', *Waste Management*, Vol. 28, No. 12, pp.2552–2564.

Coelho, L.M.G. and Lange, L.C. (2018) 'Applying life cycle assessment to support environmental sustainable waste management strategies in Brazil', *Resources, Conservation and Recycling*, Vol. 128, pp.438–450.

Confederation of European Waste-to-Energy Plants (CEWEP) (2015). *Waste-to-Energy and Recycling* [online] http://www.cewep.eu/information/publicationsandstudies/studies/healthandenvironment/577.May__Review_of_Environmental_and_Health_Effects_of_Waste_Management_municipal_solid_waste_and_similar_wastes_in_the_UK.html (accessed 22 August).

Cooper, D.R. and Gutowski, T.G. (2017) 'The environmental impacts of reuse: a review', *Journal of Industrial Ecology*, Vol. 21, No. 1, pp.38–56.

Couth, R. and Trois, C. (2012) 'Sustainable waste management in Africa through CDM projects', *Waste Management*, Vol. 32, No. 11, pp.2115–2125.

Couth, R., Trois, C. and Vaughan-Jones, S. (2011) 'Modelling of greenhouse gas emissions from municipal solid waste disposal in Africa', *International Journal of Green House Control*, Vol. 5, No. 6, pp.1443–1453.

Cucchiella, F., D'Adamo, I. and Gastaldi, M. (2014) 'Strategic municipal solid waste management: a quantitative model for Italian regions', *Energy Conservation and Management*, Vol. 77, pp.709–720.

Dijkgraaf, E. and Vollebergh, H.R.J. (2004) 'Burn or bury? A social cost comparison of final waste disposal methods', *Ecological Economics*, Vol. 50, Nos. 3–4, pp.233–247.

Emery, A., Davies, A., Griffiths, A. and Williams, K. (2007) 'Environmental and economic modelling: A case study of municipal solid waste management scenarios in Wales', *Resources, Conservation and Recycling*, Vol. 49, No. 3, pp.244–263.

Erkut, E., Karagiannidis, A., Perkoulidis, G. and Tjandra, S.A. (2008) 'A multicriteria facility location model for municipal solid waste management in North Greece', *European Journal of Operational Research*, Vol. 187, No. 3, pp.1402–1421.

European Commission (2010) *Being Wise with Waste: The EU's Approach to Waste Management* [online] http://ec.europa.eu/environment/waste/pdf/WASTE%20BROCHURE.pdf (accessed 20 August 2015).

European Commission (2015a) *Directive 2008/98/EC on waste (Waste Framework Directive)* [online] http://ec.europa.eu/environment/waste/framework/ (accessed 19 August 2015).

European Commission (2015b) *Waste* [online] http://ec.europa.eu/environment/waste/landfill/index.htm (accessed 19 August 2015).

European Environment Agency (2013) *Municipal Waste Management in Finland* [online] https://www.eea.europa.eu/publications/managing-municipal-solid-waste/finland-municipal-waste-management/view (accessed 24 August 2015).

Ferrao, P., Ribeiro, P., Rodrigues, J., Marques, A., Preto, M., Amaral, M., Domingos, T., Lopes, A. and Costa, E. (2014) 'Environmental, economic and social costs and benefits of a packaging waste management system: a Portuguese case study', *Resources, Conservation and Recycling*Vol. 85, pp.67–78.

Ferrari, K., Gamberini, R. and Rimini B. (2016) 'The waste hierarchy: a strategic, tactical and operational approach for developing countries. The case study of Mozambique', *International Journal of Sustainable Development and Planning*, Vol. 11, No. 5, pp.259–770.

Gentil, E.C., Gallo, D. and Christensen, T.H. (2011). Environmental evaluation of municipal waste prevention', *Waste Management*, Vol. 31, No. 12, pp.2371–2379.

Gharfalkar, M., Court, R., Campbell, C., Ali, Z. and Hillier, G. (2015) 'Analysis of waste hierarchy in the European waste directive 2008/98/EC', *Waste Management*, Vol. 39, pp.305–313.

Habib, K., Schmidt, J.H.and Christen, P. (2013) 'A historical perspective of global warming potential from municipal waste management', *Waste Management*, Vol. 33, No. 9, pp.1926–1933.

Hazra, T. and Goel, S. (2009) 'Solid waste management in Kolkata India: practice and challenges', *Waste Management*, Vol. 29, No. 1, pp.470–478.

Jibril, D.J., Sipran, I.B., Sapri, M., Shika, S.A., Isa, M. and Abdullah S. (2012) '3 R's critical success factor in solid waste management system for higher education institutions', *Procedia – Social and Behavioral Sciences*, Vol. 65, pp.626–631.

Johari, A., Ahmed, S.I., Hashim, H., Alkali, H. and Ramli, M. (2012) 'Economic and environmental benefits of landfill gas from municipal solid waste in Malaysia', *Renewable and Sustainable Energy Reviews*, Vol. 16, No.5, pp.2907–2912.

Joos, W., Carabias, V., Winistoerfer, H. and Stuecheli, A. (1999) 'Social aspects of public waste management in Switzerland', *Waste Management*, Vol. 19, No. 6, pp.417–425.

Kirkeby, J.T., Birgisdottir, H., Bhander, G.S., Hauschild, M. and Christensen, T.H. (2007) 'Modelling of environmental impacts of solid waste landfilling within the life-cycle analysis program EASEWASTE', *Waste Management*, Vol. 27, No.7, pp.961–970.

Kirkeby, J.T., Birgisdottir, H., Hansen, T.L., Christensen, T.H., Bhander, S.G. and Hauschild, M. (2006) 'Evaluation of environmental impacts from municipal solid waste management in the municipality of Aarhus, Denmark (EASEWASTE)', *Waste Management and Research*, Vol. 24, No. 1, pp.16–26.

Liamsanguan, C. and Gheewala, S.H. (2008) 'A decision support tool for environment assessment of MSW management systems', *Journal of Environmental Management*, Vol. 87, No. 1, pp.132–138.

Manga, V.E., Forton, O.T. and Read, A.D. (2008) 'Waste management in Cameroon: a new policy perspective', *Resources, Conservation and Recycling*, Vol. 52, No. 4, pp.592–600.

Margallo, M., Dominguez-Ramos, A., Aldaco, R., Bala, A., Fullana, P. and Irabien, A. (2014) 'Environmental sustainability assessment in the process industry: a case study of waste-energy plants in Spain', *Resource, Conservation and recycling*, Vol. 93, pp.144–155.

Margallo, M., Taddei M.B.M., Hernandez-Pellon, A., Aldaco, R. and Irabien, A. (2015) 'Environmental sustainability assessment of the management of municipal solid waste incineration residues: a review of the current situation', *Clean Technologies and Environmental policy*, Vol. 17, No. 5, pp.1333–1353.

Marshall, R.E. and Farahbakhsh, K. (2013) 'Systems approaches to integrated solid waste management in developing countries', *Waste Management*, Vol. 33, No. 4, pp.988–1003.

Massaruto, A. (2007) 'Municipal waste management as a local utility: options for competition in an environmentally-regulated industry', *Utility Policy*, Vol. 15, No. 1, pp.9–19.

Maulini-Duran, C., Artola, A., Font, X. and Sanchez, A. (2014) 'Gaseous emissions in municipal wastes composting: effect of the bulking agent', *Bioresource Technology*, Vol. 172, pp.260–268.

Menikpura, S.N.M., Sang-Arun, J. and Bengtsson, M. (2013) 'Integrated waste management: an approach for enhancing climate co-benefits through resource recovery', *Journal of Cleaner Production*, Vol. 58, pp.34–42.

Mesjasz-Lech, A. (2014) 'Municipal waste management in context of sustainable urban development', *Procedia – Social and Behavioral Science*, Vol. 151, pp.244–256.

Ministry of Environment (2013) *Waste and Waste Management* [online] http://www.ymparisto.fi/en-US/Consumption_and_production/Waste_and_waste_management (accessed 21 August 2015).

Mmereki, D. (2018) 'Current status of waste management in Botswana: a mini-review', *Waste Management and Research*, Vol. 36, No. 7, pp.555–576.

Mohee, R., Mauthoor, S., Bundhoo, Z.M.A., Somaroo, G., Soobhany, N. and Gunasee, S. (2015) 'A current status of solid waste management in small island developing states: a review', *Waste Management*, Vol. 43, pp.539–549.

Moreno, A.I., Arnaiz, N., Font, R. and Carratala, A. (2014) 'Chemical characterization of emissions from a municipal solid waste treatment plant', *Waste Management*, Vol. 34, No. 11, pp.2393–2399.

Moy, P., Krishnan, N., Ulloa, P., Cohen, S. and Brandt-Rauf, P.W. (2008) 'Options for management of municipal solid waste in New York: a preliminary comparison of health risks and policy implications', *Journal of Environmental Management*, Vol. 87, No. 1, pp.73–79.

Nehrenheim, E. (2014) *Waste Management: Introduction*, in: Reference Module in Earth Systems and Environmental Sciences, Elsevier.

Nzihou, A., Themelis, N.J., Kemiha, M. and Benhamou, Y. (2012) 'Dioxins emissions from municipal solid waste incinerators (MSWIs) in France', *Waste Management*, Vol. 32, No. 12, pp.2273–2277.

Rada, E.C., Ragazzi, M., Lonescu, G., Merler, G., Moedinger, F., Raboni, M. and Torretta, V. (2014) 'Municipal solid waste treatment by integrated solutions: energy and environmental balances', *Technologies and Materials for Renewable Energy, Environment and Sustainability (TMREES-EUMISD). Energy Procedia*, Vol. 50, pp.1037–1044.

Sanjeevi, V. and Shahabudeen, P. (2015) 'Development of performance indicators for municipal solid waste management (PIMS): a review', *Waste Management and Research*, Vol. 33, No. 12, pp.1052–1065.

Song, Q., Wang, Z. and Li, J. (2013) 'Environmental performance of municipal solid waste strategies based on LCA method: a case study of Macau', *Journal of Cleaner Production*, Vol. 57, pp.92–100.

Thanh, H.T., Yabar, H. and Higano, Y. (2015) 'Analysis of the environmental benefits of introducing municipal organic waste recovery in Hanoi city, Vietnam', *Procedia Environmental Sciences*, Vol. 28, pp.185–194.

Tian, H., Gao, J., Hao, J., Lu, L., Zhu, C. and Qui, P. (2013) 'Atmospheric pollution problems and control proposals associated with solid waste management in China: a review', *Journal of Hazardous Materials*, Vols. 252–253, pp.142–154.

Ulfik, A. and Nowak, S. (2014) 'Determinants of municipal waste management in sustainable development of regions in Poland', *Polish Journal of Environmental Studies*, Vol. 23, No. 3, pp.1039–1044.

US Environmental Protection Agency (USEPA) (2015a) *Non-hazardous Waste Management Hierarchy* [online] http://www.epa.gov/wastes/nonhaz/municipal/hierarchy.htm (accessed 26 August 2015).

US Environmental Protection Agency (USEPA) (2015b) *Wastes: Non-Hazardous Waste – Municipal Waste* [online] http://www.epa.gov/wastes/nonhaz/municipal/backyard/env.htm (accessed 26 August 2015).

US Environmental Protection Agency (USEPA) (2018) *Reducing and Reusing Basics* [online] https://www.epa.gov/recycle/reducing-and-reusing-basics#main-content (accessed 27 June 2018).

Vrijheid, M. (2000) 'Health effects of residence near hazardous waste landfill sites: a review of epidemiologic literature', *Environmental Health Perspective*, Vol. 108, No. 1, pp.101–112.

Williams, I.D. (2015) 'Forty years of waste hierarchy', *Waste Management*, Vol. 40, pp.1–2.

World Bank (2018) *Solid Waste Management* [online] http://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management (accessed 18 April 2018).

Zaman, A.U. and Swapan, M.S.H. (2016) 'Performance evaluation and benchmarking of global waste management systems', *Resources, Conservation and Recycling*, Vol. 114, pp.32–41.

Zhang, D.Q., Tan, S.K. and Gersberg, R.M. (2010) 'Municipal solid waste management in China: status, problems and challenges', *Journal of Environmental Management*, Vol. 91, No. 8, pp.1623–1633.