Waste Management 40 (2015) 157–166

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Life cycle assessment of integrated waste management systems for alternative legacy scenarios of the London Olympic Park

Olga Parkes [1], Paola Lettieri *, I. David L. Bogle [1]

Department of Chemical Engineering, University College London, Torrington Place, London WC1E 7JE, UK

ARTICLE INFO

Article history:
Received 7 July 2014
Accepted 11 March 2015
Available online 30 March 2015

Keywords:
Environmental assessment
Life cycle assessment (LCA)
Integrated waste management systems (IWMS)

ABSTRACT

This paper presents the results of the life cycle assessment (LCA) of 10 integrated waste management systems (IWMSs) for 3 potential post-event site design scenarios of the London Olympic Park. The aim of the LCA study is to evaluate direct and indirect emissions resulting from various treatment options of municipal solid waste (MSW) annually generated on site together with avoided emissions resulting from energy, materials and nutrients recovery. IWMSs are modelled using GaBi v6.0 Product Sustainability software and results are presented based on the CML (v.Nov-10) characterisation method.

The results show that IWMSs with advanced thermal treatment (ATT) and incineration with energy recovery have the lowest Global Warming Potential (GWP) than IWMSs where landfill is the primary waste treatment process. This is due to higher direct emissions and lower avoided emissions from the landfill process compared to the emissions from the thermal treatment processes. LCA results demonstrate that significant environmental savings are achieved through substitution of virgin materials with recycled ones. The results of the sensitivity analysis carried out for IWMS 1 shows that increasing recycling rate by 5%, 10% and 15% compared to the baseline scenario can reduce GWP by 8%, 17% and 25% respectively. Sensitivity analysis also shows how changes in waste composition affect the overall result of the system. The outcomes of such assessments provide decision-makers with fundamental information regarding the environmental impacts of different waste treatment options necessary for sustainable waste management planning.

1. Introduction

In the last few decades waste management has evolved from being an industry mainly focusing on waste treatment and its final disposal to currently being an industry that contributes considerably to energy supply and materials recovery (Astrup et al., 2014).

Sustainable waste treatment planning is a difficult task due to the availability of different waste treatment facilities, their technological and environmental performance and diverse markets for recovered energy and materials (Eriksson and Bisaillon, 2011). Waste treatment planning for mega-event projects such as the Olympic Games or FIFA World Cup is even more complex because of the multiple stages of different duration, complex planning process and involvement of various stakeholder groups. Although the main focus of mega-event projects is the actual event, legacy is definitely the longest and the most important phase from the perspective of the overall environmental effects because this is where the long-term impacts will occur. Legacy is typically comprised of the redevelopment phase (demolition of temporary event facilities, construction of new buildings and infrastructure), which lasts approximately 2 years and an open-ended post-event operational phase (operation of the post-event site as a residential/commercial city area) (GIZ AgenZ, 2013). The focus of this work is the open-ended post-event operational legacy phase.

This paper illustrates how life cycle assessment (LCA) tool can be applied in the planning process of the waste treatment options for mega-event projects. 10 integrated waste management systems (IWMSs) have been evaluated for 3 proposed post-event site design scenarios using LCA technique. The IWMSs investigated reflect the current waste management strategy in the UK which support advanced treatment solutions (i.e. gasification and anaerobic digestion (AD)) against traditional technologies such as incineration and landfill (DEFRA, 2013a).

The paper aims to address the following questions:

1. Which legacy scenario should be considered the 'best option' in terms of the lowest environmental impacts associated with waste treatment of MSW annually generated on site given a set of 10 IWMSs?

* Corresponding author at: Torrington Place, London, WC1E 7JE, UK. Tel.: +44 (0) 207 679 7867; fax: +44 (0) 207 383 2348.
E-mail addresses: o.parkes@ucl.ac.uk (O. Parkes), p.lettieri@ucl.ac.uk (P. Lettieri).
[1] Tel.: +44 (0) 207 679 7867.

http://dx.doi.org/10.1016/j.wasman.2015.03.017
0956-053X/

2. What type of waste management facilities can provide the optimum environmental solution and, therefore, should be implemented and why?

The next section provides an overview of the LCA methodology used in the current study. Section 3 presents a case study and an outline of the IWMSs. The LCA results and the results of a hot-spot and sensitivity analysis are presented in Section 4. Conclusions and future work are summarised in the final section.

2. LCA methodology for the assessment of integrated waste management systems

In this study an attributional LCA with a system expansion was applied to perform an environmental evaluation of the proposed integrated waste management systems. The overall framework of the methodology was adopted from Clift et al. (2000), where foreground and background systems are identified. The foreground system is a set of processes whose choice or method of operation is affected directly by decisions based on the study. The background system includes all other processes interacting with the foreground system, normally through materials and energy transfer (Clift et al., 2000). The advantage of using this method is the ability of a system to reproduce the real situation and to avoid difficult allocations as recommended in the ISO standards (ISO, 2006a,b). The overall scheme of the LCA methodology developed in this study is provided in Fig. 1.

The foreground system (highlighted in grey in Fig. 1) includes emissions associated with different waste treatment facilities considered in the study: anaerobic digestion (AD), composting, materials recycling facility (MRF), mechanical biological treatment (MBT), Energy-from-Waste (EfW) via incineration, advanced thermal treatment (ATT) and landfill. Emissions resulting from the transportation of MSW to/from the transfer station to the waste treatment plants and emissions from the transportation of compost and digestate to the arable land are also included in the foreground system. Emissions in the foreground system are referred to as direct emissions. Emissions arising from the processes in the background system are referred to as indirect and avoided emissions (Clift et al., 2000; Bernstad and la Cour Jansen, 2012). The background system includes supply of electricity, diesel and other materials to the foreground system (indirect emissions), and production of energy, mineral fertilizers and virgin materials (avoided emissions). The details of the system boundary including generation and utilisation of the secondary resources recovered from the foreground system are provided in the description of each IWMS in Section 3.

In recent years, LCA has been further developed and widely used as a tool for the environmental assessment of various integrated waste management systems due to its ability to deal with complexities and interactions associated with such systems (Blengini et al., 2012a). The LCA methodology has been used in many studies to assess the environmental performance of various IWMS as well as materials and energy recovery strategies (e.g. Eriksson et al., 2005; Cherubini et al., 2009; Spoerri et al., 2009; Fruergaard et al., 2009; Christensen et al., 2009a; Fruergaard and Astrup, 2011; Giugliano et al., 2011; Rigamonti et al., 2009, 2013; Meylan et al., 2013, 2014). Moreover, a number of different models and software tools have recently been developed (e.g. Harrison et al., 2001; Kaplan et al., 2009; Eriksson and Bisaillon, 2011), which were used as a decision-making tool for waste management planning in different regions.

There is an on-going debate within the LCA community regarding biogenic carbon dioxide emissions. Some LCA studies consider biogenic CO_2 emissions as neutral in relation to GWP (Boldrin et al., 2009); others account for biogenic emissions, therefore the GWP factor is considered to be 1 (Blengini, 2008a,b; Lee et al., 2007). Christensen et al. (2009b) argue that biogenic CO_2 emissions can be seen both as neutral and contributing to GWP, as long as a consistent accounting method has been applied throughout a specific system and to all systems compared.

In this study, biogenic carbon is accounted for in all processes and biogenic CO_2 emissions are characterised as contributing to GWP. Detailed description of the integrated waste management systems analysed in this study and life cycle inventory are provided in Section 3.

3. Case study

The Queen Elizabeth Olympic Park is the legacy of the London 2012 Olympic and Paralympic Games. The total area of the Queen Elizabeth Olympic Park is 2.5 km^2. The Mayor of London defined the Park and surrounding area as ‘London's single most important regeneration project for the next 25 years’ (OPLC, 2010). This work presents LCA analysis of 10 IWMSs for three potential site design scenarios of the post-event Olympic Park. Scenarios were developed based on the recent urban strategies addressing the need for more residential and commercial space in Central London (The London Plan, 2014). An outline for each scenario is presented in Sections 3.1–3.3. More details are provided in Supplementary Material.

3.1. ‘Business as Usual’ scenario – BAU

The ‘Business as Usual’ scenario is based on the current proposal by the London Legacy Development Corporation (LLDC, 2012), which builds on the typical London mixed residential/commercial area with 2–3 stories houses and 4–5 stories apartment blocks. The future area will include a site consisting of 5 new neighbourhoods with approximately 11,000 new homes (including the Athletes Village) alongside with education, health and community facilities. The Park will also provide a great business opportunity with 62,000 m^2 of flexible commercial space in the Broadcast Centre and 29,000 m^2 of flexible office space in the Press Centre and close connection to the City of London and Canary Wharf (LLDC, 2012).

3.2. ‘Commercial World’ scenario – CW

The ‘Commercial World’ scenario is based on the assumption that only a few new residential blocks will be built in the Park comprising of 1000 apartments. The rest of the area will be a mixture of different types of commercial offices and small industrial units. It is estimated that the total floor area of all commercial buildings will be approximately 3,000,000 m^2. The site will also have 5 operating Olympic sports venues, 3 schools and nurseries, a health centre, a number of various size restaurants and retail units. Great transport links and proximity to the City and Canary Wharf business area could potentially make the Park a new commercial hub in the heart of East London.

3.3. ‘High rise, high density’ scenario – HRHD

The ‘High rise, high density’ scenario is based on the assumption that the Park will comprise a mixture of 20- and 30-stories residential and commercial buildings. The total floor area of all residential buildings is estimated to be approximately 900,000 m^2; the total floor area of all commercial buildings is approximately 2,000,000 m^2. The Park will also have numerous community facilities and social infrastructure, hotels, restaurants, supermarkets and retail units. With more people moving to cities each year, there is a

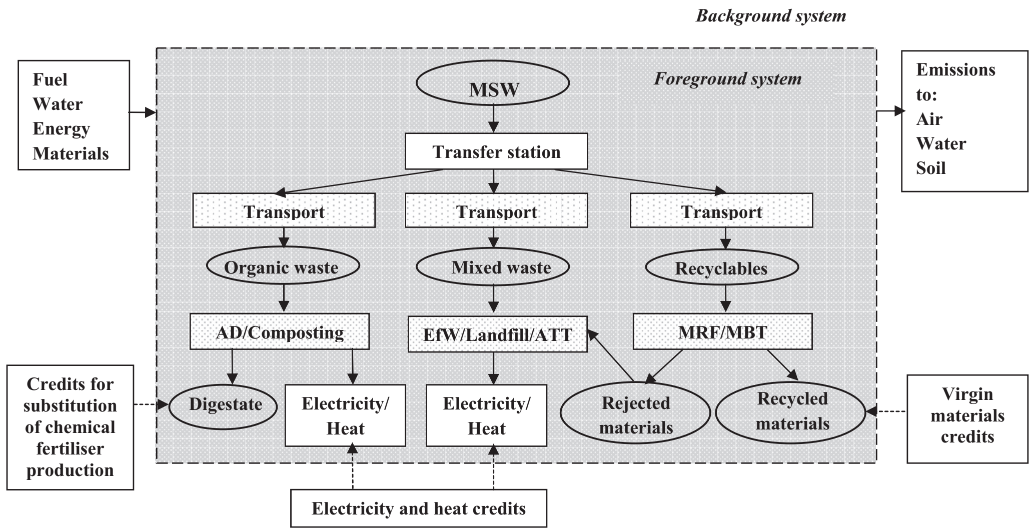

Fig. 1. Overall scheme of the integrated waste management systems analysed in the present study.

need to utilise land to its maximum potential. Thus, new high rise developments present an opportunity to accommodate more people in those areas where there is a shortage of land.

3.4. Waste composition and quantities

The amount of household waste generated at the Queen Elizabeth Olympic Park was calculated based on the estimated number and types of residential dwellings for the 3 proposed design scenarios. On average, each resident produces 457 kg of MSW per year (DEFRA, 2011). The average data on waste composition in England is based on the data published by DEFRA (2013a). Household recycling rate in London area is estimated to be 40% (EEA, 2013), which refers to the separation efficiency in the households. In this work, it is assumed that the same recycling rate is applied to all recycling fractions.

Waste composition for non-residential venues was estimated based on the assumptions of the proposed number of schools, offices, restaurants and sports venues for each of the design scenarios. Table 1 provides the estimated amounts of the MSW generated per year in residential and non-residential venues of the London Queen Elizabeth Olympic Park and recycling rates. The amounts of MSW for each legacy scenario were estimated based on the quantities of waste generated in each type of building, number of residents and floor areas of the non-residential buildings (Supplementary Material).

Composition of waste in non-residential venues varies significantly depending on a venue type. A summary of waste composition and recycling rates for residential and non-residential venues is provided in Table 2.

In residential venues, 23% of ‘Other’ waste category is comprised of textiles (3%), waste electrical and electronic equipment (WEEE) (2%), wood (4%) and ‘other’ waste (DEFRA, 2013a). In other venues, ‘Other’ waste category is assumed to be non-recyclable mix comprised of 1/3 organic, 1/3 paper and 1/3 plastic waste.

3.5. Functional unit

It is reported that when LCA is used as a decision making tool for a specific geographical region, the functional unit (FU) should be chosen as the total waste produced in this region in a given time (i.e. one year) (Cherubini et al., 2009). In the current study, the functional unit is the total amount of MSW potentially generated

Table 1
Estimated amounts of the MSW produced at the London Queen Elizabeth Olympic Park (tonnes per annum) for each of the proposed design scenarios.

	Business as usual	Commercial World	High rise high density
Residential buildings	8309	2883	20,086
Offices	1103	29,074	19,408
Sports venues	159	159	159
Restaurants	4200	3240	6780
Schools and nurseries	818	284	1978
Hotels	339	947	2759
Retail units	600	1000	3000
Medical centres	319	110	769
Total	15,847	37,697	54,939

at the Queen Elizabeth Olympic Park in one year of legacy period. The total estimated annual quantity of MSW generated for each of the proposed design scenarios are 15,847; 37,679 and 54,939 tonnes respectively.

3.6. Transport of waste and transportation distances

As mentioned before, transportation of waste to the transfer station and to waste treatment facilities is included in all scenarios. Collection of waste from individual households and home pre-treatment of waste for recycling are not included. Distances between the transfer stations and various facilities were calculated based on the locations of the nearest plants, farmland and landfill site. They are provided in Table 3.

The collection vehicles were modelled as Euro 3 trucks with payload capacity of 9.3 tonnes, volumetric capacity of 50 m^3, and diesel consumption of 2.18 kg per tonne of cargo (GaBi, 2014). The same type of truck is assumed to be used for transportation of all waste fractions to all facilities.

3.7. Impact categories considered in the current study

The environmental impacts of the proposed integrated waste management scenarios in the current study were evaluated using CML characterisation method (Guinée et al., 2002). The following impact categories were considered:

Table 2
Waste composition and recycling rates for non-residential venues (% of the total MSW quantity).

	Paper and cardboard	Organic waste	Plastics	Glass	Metals	Others	Recycling rate (%)	Reference
Residential buildings	23	34	10	6	4	23	40	DEFRA, 2011, 2013a
Offices, medical centres	60	21	7	3	3	6	67	UoE, 2011
Restaurants	24	44	9	14	3	6	46	WRAP, 2011
Secondary schools	53	20	14	2	3	8	45	Biffa, 2012
Primary schools, nurseries	53	13	12	3	3	1	45	Biffa, 2012
Sports venues	33	5	9	28	0	25	70	RW, 2013
Hotels	25	37	15	10	5	8	63	WRAP, 2011
Retail	40	36	17	1	0	6	61	WRAP, 2011

Table 3
Transportation distances considered in the study.

	Transfer station	MRF, MBT, composting	EfW plant, ATT plant	AD plant	Landfill	Farmland
Distance (km)	7	20	20	130	26	50

- Global Warming Potential (GWP) – accounts for greenhouse gases over 100 years.
- Acidification Potential (AP) – accounts emissions causing 'acid rain' formation.
- Eutrophication Potential (EP) – accounts for nutrients causing an increase in the rate of supply of organic matter in an ecosystem.
- Abiotic Depletion Potential (ADP) – fossil – accounts for the amount of energy contained in raw materials.

The environmental impacts were calculated using GaBi v6.0 applying CML (vNov.2010) (GaBi, 2014).

3.8. Integrated waste management systems

We have applied a consistent methodology whereby the same integrated waste management systems are considered for each legacy scenario. The IWMSs evaluated in this work reflect currently available UK waste management options such as recycling, incineration, landfill and composting as well as advanced treatment facilities (i.e. gasification and AD) which are currently being investigated and developed in the UK. Fig. 2 provides a general scheme of the 10 IWMSs evaluated in this study, with detailed description provided in Sections 3.8.1–3.8.6.

3.8.1. IWMS 1. Composting, recycling, landfill

In IWMS 1, the three MSW fractions are treated separately: source-separated organic fraction of municipal solid waste (OFMSW) is sent to the composting plant, recyclable materials are sorted out at the MRF, and the residual unsorted waste and rejected materials are sent to landfill.

3.8.1.1. Composting facility. Direct burdens from composting include emissions to air due to degradation of the organic matter, emissions to land, ground water and surface water. Indirect burdens include provision of diesel and electricity for transportation and pre-treatment of OFMSW and spreading of compost on arable land. In this study emissions were modelled using data from DEFRA (2004). The full inventory of emissions and by-products for all processes considered in this study is provided in Supplementary Material. Indirect burdens also include emissions resulting from the application of compost on land. The emissions were calculated using the methodology provided by Boldrin et al. (2009) on the basis of the composition of the organic waste presented in Table 4.

It is assumed that compost complies with PAS 100 (BSI, 2005) standards and can be applied on arable land instead of a mineral fertilizer. Avoided burdens account for the substitution of mineral fertilizer with nutrients (nitrogen N, phosphorus P and potassium K) recovered during composting processes and for the amount of carbon that stays bound in the soil after 100 years. Potential amounts of inorganic fertilizers replaceable by use of compost are 3 kg/t waste for N, 1.4 kg/t waste for P and 3.8 kg/t waste for K based on the compost output of 400 kg per 1000 kg of treated food waste (Boldrin et al., 2009). In the current study the amount of carbon bound in the soil is assumed to be 7% of the total carbon content of the compost material based on the average values (Smith et al., 2001; Brunn et al., 2006).

3.8.1.2. Materials recovery facility. In this study, a typical dry MRF process is considered (WRAP, 2007). At the MRF, 25 kWh of electricity and 3.4 l of diesel per tonne of waste treated are used for machineries' operation (Merrild et al., 2012). Four waste streams are assumed to constitute the recycling streams at MRF: glass, mixed plastics, mixed paper, and metals. In this study, metals' content has been assumed to consist of 30% non-ferrous and 70% ferrous metals (Cimpan and Wenzel, 2013). A part of the materials sent to the MRF will be rejected. In this study the reject rate for all fractions is assumed to be 10% (Palm, 2009). The amounts of waste streams (tonne per year) sent for recycling were estimated based on the total amount and composition of the MSW from residential and non-residential venues for three design scenarios, see Table 5.

The amount of electricity, natural gas and diesel used for the reprocessing of the different recycling streams was modelled using data from Cimpan and Wenzel (2013) for metals and plastics, from Wang et al. (2012) for paper and from Buttler and Hooper (2005) and Blengini et al. (2012b) for glass (Supplementary Material). The model of the MRF includes emission credits for the substitution of virgin materials with reprocessed materials. The substitution ratio in this study is considered to be 1:1 on a mass basis (Gentil et al., 2010).

3.8.1.3. Landfill site. In this work a conventional UK landfill is modelled to include leachate and gas handling. Distribution of landfill gas is: 22% flare, 28% utilisation for electricity production and 49% are emissions to the atmosphere (GaBi, 2014). The site specific data is used in this model (DEFRA, 2004). The model also takes into account fuels required for on-site machinery operation and electricity and thermal energy to be used on-site. Avoided emissions are calculated based on the substitution of electricity produced from landfill gas with the average UK grid electricity mix.

3.8.2. IWMS 2 – Composting, recycling, incineration with energy recovery

In IWMS 2 the total MSW is divided in three groups like in IWMS 1. Recyclable materials are sent to the MRF, OFMSW is sent to a composting facility and the residual waste is sent to an

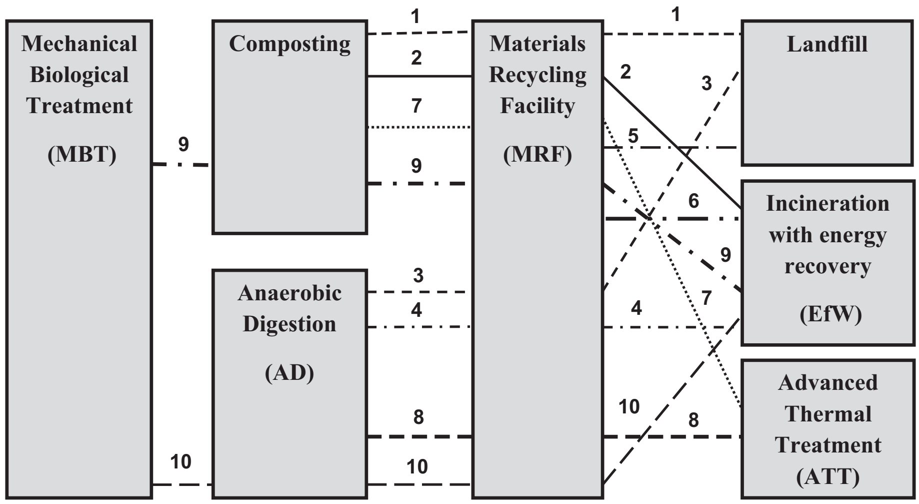

Fig. 2. Outline of 10 integrated waste management systems considered for each of the 3 legacy scenarios.

Table 4
Characteristics of OFMSW (Zhang et al., 2012).

	Value	Unit
Total solids	24	Fraction of a wet feedstock (by mass)
Volatile solids	91	% of Total solids
C content	47.6	% of Total solids
K content	3.43	% of Total solids
N content	3.44	% of Total solids
P content	1.29	% of Total solids

Energy-from-Waste incineration plant. Composting and recycling plants and the amount of waste sent to these facilities are assumed to be the same as described in Section 3.8.1.

3.8.2.1. Energy-from-Waste plant. In this study, a model for the incineration facility is based on the data for a typical UK EfW plant that meets the EU legal requirements. The net electrical efficiency of the incinerator considered in this study is 16% and the thermal efficiency is 43% (Murphy and McKeogh, 2004). The losses of electricity associated with export are assumed to be 7%. Credits for electricity and heat are modelled using data for the average UK energy mix (GaBi, 2014). Approximately 220 kg of bottom ash and 28 kg of the air pollution control residue are generated from incineration of 1 tonne of MSW. After recovery of ferrous metals from the bottom ash, both residues are sent to landfill (Jeswani et al., 2013). CO_2 emissions were estimated based on the methodology described in Jeswani et al. (2013).

3.8.3. IWMSs 3 and 4. Anaerobic digestion, recycling, landfill with energy recovery/incineration with energy recovery

IWMSs 3 and 4 include the same processes as IWMSs 1 and 2 apart from the facility for the treatment of the source-separated organic fraction of waste. In IWMSs 3 and 4, OFMSW is sent to the anaerobic digestion (AD) plant.

3.8.3.1. Anaerobic digestion plant. The AD process considered in this work is a continuous single stage, mixed tank reactor operating at a mesophilic temperature of 35 °C (Evangelisti et al., 2013, 2014). The amount of heat and electricity required for the process are assumed to be 13% and 11% of the biogas produced respectively (Berglund and Börjesson, 2006). In this work, the amount of biogas produced is calculated to be 118 N m^3/tonne of waste. The average volume of methane is 63% and the net calorific value of biogas is 23 MJ/N m^3 (Fruergaard and Astrup, 2011). Biogas produced in the AD process is combusted in a CHP unit to generate energy. The electrical efficiency of the CHP unit is assumed to be 33% and the thermal efficiency is 52% (Zglobisz et al., 2010). It is assumed that digestate produced during the AD process is in compliance with BSI PAS 110 specifications and can be used on arable lands instead of a mineral fertilizer (BSI, 2010). According to Møller et al. (2009), substitution rates for P and K are 100% and for organic N is 40%. Direct burdens include emissions from the AD process (including combustion of biogas in a CHP unit) and transportation of OFMSW and digestate. Indirect burdens also include emissions associated with application of digestate on land.

Table 5
Amounts of recyclable materials processed at the MRF (tonne per year).

Scenario	Paper and cardboard	Plastics	Glass	Metals	Total
BAU	2138	672	565	246	3620
CW	12,504	1663	909	688	15,764
HRHD	11,460	2249	1439	833	16,032

3.8.4. IWMSs 5 and 6. Recycling, landfill with energy recovery/incineration with energy recovery

Waste treatment processes in IWMSs 5 and 6 exclude separate treatment of OFMSW. Using data provided in Section 3.4, it was calculated that 2360; 5237 and 7339 tonnes of OFMSW can be recycled according to the current UK recycling rates in three proposed design scenarios respectively. In IWMSs 5 and 6 it is assumed that all organic waste (5032; 8563 and 14,182 tonnes for each design scenario) goes to landfill or to the incineration plant.

3.8.5. IWMSs 7 and 8. Composting/AD plant, recycling, ATT

In IWMSs 7 and 8, Advanced Thermal Treatment (ATT) (gasification) processes replace conventional processes of landfill and incineration for treating the residual MSW stream. The total waste is separated into 3 main streams as in IWMSs 1 and 2. OFMSW is treated in the composting plant in IWMS 7, and in the AD plant in IWMS 8. Composting, AD and recycling facilities in IWMSs 7 and 8 are identical to those described in Sections 3.8.1 and 3.8.2.

3.8.5.1. Advanced Thermal Treatment (ATT) process. ATT processes, such as gasification and pyrolysis, have several potential benefits over traditional combustion of solid wastes. ATT of municipal waste can reduce volume of solid waste, prevent dioxin formation, and reduce thermal NO_x formation (Zhang et al., 2012). Another advantage of ATT is better electrical generation efficiency compared to incineration. However, thermal efficiency of ATT processes is typically much lower than that produced by incineration and depends on different technologies (Murphy and McKeogh, 2004; ESTET, 2004; DEFRA, 2013b,c). Net electrical and thermal efficiency of the gasification process modelled in the current study are assumed to be 27% and 24% respectively (Murphy and McKeogh, 2004). The amount of energy required for start-up of the plant and for converting MSW into refuse derived fuel (RDF) are 397 kWh and 18.4 kWh/tonne respectively (Khoo, 2009). The average syngas yield is assumed to be 1.3 N m^3/kg MSW; low calorific value (LHV) of syngas is assumed to be 8.4 MJ/N m^3 (Zhang et al., 2012).

3.8.6. IWMSs 9 and 10. MBT, Composting/AD, recycling, incineration

Mechanical Biological Treatment (MBT) plants were modelled in IWMSs 9 and 10. IWMS 9 includes a composting facility and IWMS 10 includes an AD plant for treating OFMSW.

3.8.6.1. MBT process. The MBT process modelled in this study consists of two types of recycling facilities: a biological facility for the treatment of organic waste (composting facility in IWMS 9, AD plant in IWMS10) and an MRF facility for the dry recyclables. In this study, it is assumed that 15% of each waste fraction will be recovered in the MBT plant (CIWEM, 2013). In IWMS 9, the organic fraction recovered in the MBT process will be treated in the AD plant and the digestate will be used on arable land in compliance with PAS 110 (BSI, 2010). In IWMS 10, the organic fraction will be sent for composting. In the UK, MBT composts do not qualify for certification under PAS 100 (Environment Agency, 2009) and, therefore, cannot be used as a fertilizer on arable land. It is assumed that the MBT output is used in landfill remediation (Environment Agency, 2009) and no avoided burdens are considered for nutrients recovery. The residual waste is sent to the EfW incineration plant. In the UK, the amount of RDF sent to the EfW plant is estimated to be in the range of 22–50% (EC, 2003). In this study it is assumed that the amount of RDF is 376 kg per tonne of incoming waste (DEFRA, 2004).

4. Results and discussions

A complete life cycle assessment of 10 IWMSs was carried out for three potential design scenarios of the post-event Olympic Park. In this paper, first we present the LCA results for the 'Business as Usual' scenario in two impact categories – GWP and AP. Then, in Section 4.2, we present a comparative analysis where the results from LCA on the total environmental burdens associated with the treatment of 1 tonne of MSW for each legacy scenario are discussed. These results help identifying which of the proposed design scenarios and IWMSs result in the lowest environmental burdens. Hot-spot and sensitivity analysis are presented in Sections 4.3 and 4.4.

4.1. LCA results – 'Business as Usual' scenario

Figs. 3 and 4 show direct and indirect burdens and avoided burdens of the proposed IWMSs for the BAU scenario.

In waste management LCA, positive results describe a load to the environment or resource use, while negative values show savings. Savings occur when avoided burdens are larger than impacts associated with the waste treatment process. Thus, a negative value indicates an environmental benefit and the positive one specifies an environmental burden.

From Fig. 3 it can be seen that IWMSs 1, 3 and 5 with landfill as the primary waste treatment technology have the highest direct and indirect burdens and the lowest avoided burdens. IWMSs 7 and 8 with Advanced Thermal Treatment as the primary technology have the lowest impacts regarding GWP. These results can be explained by the fact that the amount of electricity generated from landfill gas (0.369 MJ/tonne MSW) is significantly less than the amount of energy generated from the EfW or ATT plants (1.03 and 2.95 MJ/tonne MSW respectively). At the same time, the GHG emissions associated with landfill process are higher than those resulting from other waste treatment facilities.

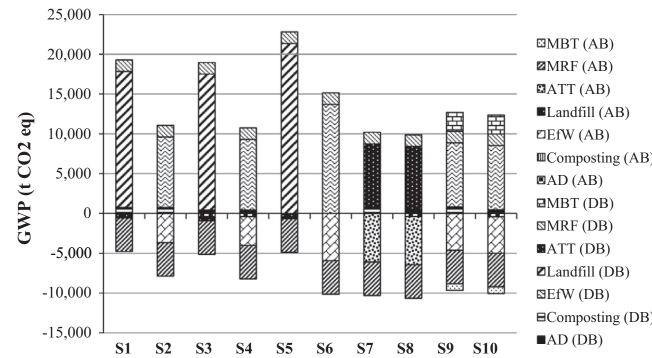

Fig. 3. Global Warming Potential (t CO_2-eq) (Direct and Indirect (DB) and Avoided (AB) burdens) – BAU scenario.

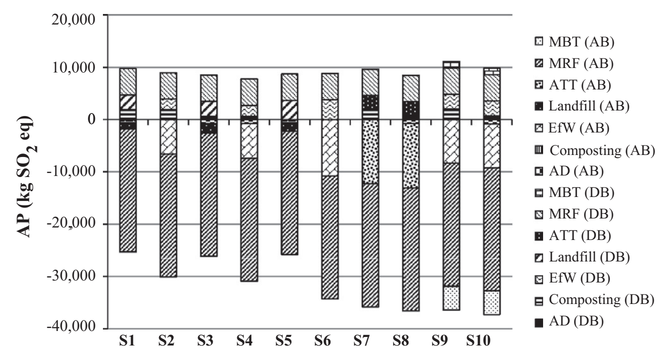

Fig. 4. Acidification Potential (kg SO_2-eq) (Direct and Indirect (DB) and Avoided (AB) burdens) – BAU scenario.

In terms of AP, all IWMSs considered in this study have negative total values due to high avoided burdens, particularly from the substitution of virgin materials with recovered ones and credits for electricity production (Fig. 4) Credits for substitution of energy and materials are estimated based on the data from Ecoinvent (2014) and GaBi (2014) databases (see Supplementary Material). IWMSs 8 and 10 show the highest avoided burdens followed by IWMSs 9 and 7. Similar results were obtained for EP and ADP-fossil, where IWMSs 1, 3 and 5 show the highest direct and indirect burdens and the lowest avoided burdens.

Overall, IWMSs that use ATT or incineration with energy recovery as the primary waste treatment technology proved to be the best options regarding the overall performance in all impact categories IMSWs with landfill as a primary waste treatment option show the highest environmental burdens in all categories. The results are in agreement with other LCA studies that showed that landfill technology is still the worst environmental option (Bovea et al., 2010; Cherubini et al., 2009).

4.2. LCA results for 3 scenarios

Table 6 presents the LCA results of the proposed IWMSs for 3 post-event legacy scenarios. The results are presented for 1 tonne of MSW.

Table 6
LCA results (per 1 tonne of MSW treated) for 10 integrated waste management systems (S1–10) for three proposed design scenarios of the post-event Olympic Park. Figures in bold indicate the lowest environmental burdens per 1 tonne of MSW.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
GWP (kg CO_2 eq per tonne of waste)										
BAU	916	203	873	160	1,131	316	32	−11	192	145
CW	759	**92**	**717**	**50**	969	**244**	−**19**	−**61**	**80**	**42**
HRHD	757	139	722	103	936	248	6	−30	124	87
AP (kg SO_2 eq per tonne of waste)										
BAU	−0.98	−1.33	−1.11	−1.46	−1.08	−1.61	−1.64	−1.77	−0.90	−1.03
CW	−**1.46**	−**1.76**	−**1.58**	−**1.88**	−**1.55**	−**2.12**	−**1.98**	−**2.10**	−**1.41**	−**1.52**
HRHD	−1.01	−1.31	−1.12	−1.42	−1.09	−1.58	−1.55	−1.65	−0.95	−1.06
EP (kg Phosphate eq per tonne of waste)										
BAU	0.41	−0.18	0.34	−0.25	0.60	−0.26	−0.20	−0.27	−0.01	−0.08
CW	**0.05**	−**0.40**	−**0.02**	−**0.46**	**0.24**	−**0.48**	−**0.40**	−**0.46**	−**0.27**	−**0.33**
HRHD	0.25	−0.23	0.19	−0.28	0.41	−0.29	−0.24	−0.29	−0.09	−0.15
ADP-fossil (GJ per tonne of waste)										
BAU	−4.9	−8.7	−5.4	−9.1	−4.9	−11	−9.4	−9.8	−10.2	−10.7
CW	−**7.4**	−**10.6**	−**7.9**	−**11**	−**7.5**	−**13.9**	−**10.9**	−**11.4**	−**12.1**	−**12.4**
HRHD	−5.1	−8.2	−5.5	−8.6	−5.2	−10.7	−8.7	−9.1	−9.5	−9.9

From Table 6 it can be seen that in regard to 1 tonne of MSW, the CW scenario shows the lowest environmental burdens in all impact categories considered in the current study. This can be explained by the fact that MSW generated in commercial buildings and communal facilities has higher quantities of recycling materials. Recycling rates in commercial buildings are also higher than in residential dwellings, which mean that more materials are recovered at the MRF and less MSW is being sent to waste treatment facilities (Table 2). This, in turn, results in higher avoided burdens and total environmental savings.

It has to be emphasised that the basis for comparison between three scenarios is only defined by the area in question – the London Olympic Park. The aim of the study is to identify the environmental burdens associated with waste management generated only within the site boundaries. In order to holistically evaluate environmental burdens associated with waste generated by people residing or working within the Olympic Park, it is necessary to evaluate waste generated by these people in other areas; however, this is beyond the boundaries of this study.

4.3. Hot-spot analysis for the BAU scenario for the processes considered

Fig. 5 provides the results of a hot-spot analysis in terms of GWP of different waste treatment process plants (MRF, AD, Composting, EfW, Landfill, ATT) considered in the 10 IWMSs. A hot-spot analysis highlights the relevant importance of avoided emissions for electricity and heat production, nutrients and materials recovery compared to direct process and transport emissions.

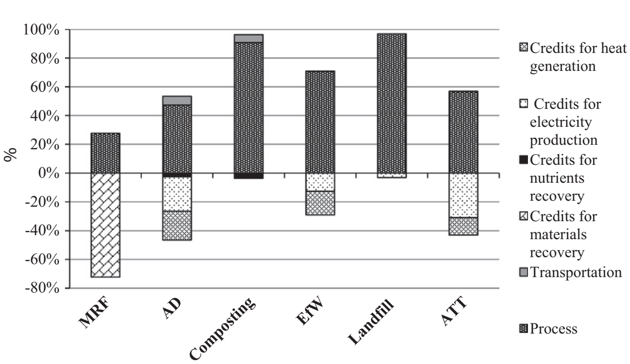

Fig. 5. Hot-spot analysis of the waste treatment processes – GWP. IWMS 1.

It can be seen that GHG emissions associated with the landfill process and impacts caused by the upstream processes in the background system account for almost 100% of the total emissions of landfill. In this case, emissions from the transportation of waste are negligible due to the estimated transportation distances between waste treatment facilities and waste generation points. Avoided emissions from electricity generation account for less than 2% of the total emissions. The composting process shows similar results where most GHG emissions result from the process itself.

Direct GHG emissions from the incineration and ATT processes are 70% and 58% of the total emissions respectively. Avoided emissions are significantly higher for the two thermal technologies compared to landfill due to higher credits for the production of electricity and heat.

AD technology has the highest environmental saving in terms of GWP due to the emission credits for the substitution of recovered electricity and heat, and substitution of chemical fertiliser with recovered nutrients from the digestate. GHG emissions associated with transportation of waste and spreading of the digestate on the arable land are similar to those for the composting process. Total CO_2 emissions resulting from processing 1 tonne of OFMSW in the AD and composing facilities are 70 and 302 kg CO_2-eq/tonne respectively, which is within the ranges provided in Møller et al. (2009) and Boldrin et al. (2009).

MRF illustrates the highest avoided emissions in terms of GWP (approximately 70% of the total emissions) due to the emission credits for substitution of virgin materials with recycled ones. This is in line with the outcomes of other LCA studies which prove that recycling results in higher environmental savings than other waste treatment options (Bovea et al., 2010; Slagstad and Brattebø, 2012; Mendes et al., 2004). Thus, a sensitivity analysis has been carried out to evaluate to what extent further environmental savings could be achieved if the recyclable content of MSW changes (i.e. paper and plastic).

4.4. Sensitivity analysis for BAU legacy scenario

In order to understand how the overall results of the model are affected by changes in certain parameters, two sensitivity analyses were carried out. Fig. 6 provides the results of a sensitivity analysis for IWMS 1 where the changes in recycling rates are considered. IWMS 1 was selected for the sensitivity analysis in this paper because it is one of the three scenarios (including IWMSs 3 and 5) which show the highest overall environmental burdens. Therefore, IWMSs 1, 3 and 5 could be considered as the reference

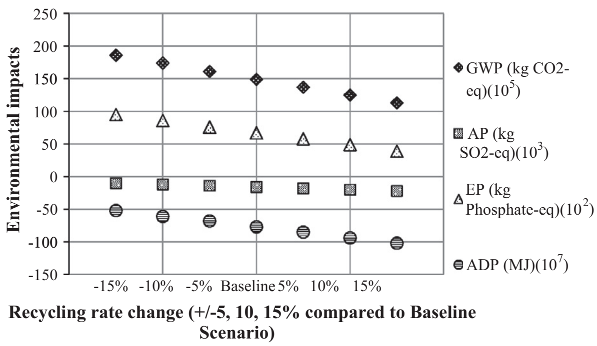

Fig. 6. Sensitivity Analysis for BAU scenario – IWMS 1. Changes in recycling rates (±5%, 10%, 15% of the average recycling rates applied in the current study).

case for the 'worst case scenario' as landfill is the primary waste treatment technology in these IWMSs.

It can be seen that an increase in the recycling rate results in improved environmental performance in all impact categories. Avoided emissions resulting from the substitution of virgin materials with recovered ones were calculated by subtracting the energy required for the production of virgin material from the energy required for recycling of each material. For all materials analysed in this study, energy consumption for the production of virgin materials is significantly higher than energy required for recycling, which is in line with the results of other studies (e.g. Rigamonti et al., 2009).

The highest environmental savings are achieved through aluminium recycling (8860 kg CO_2-eq/tonne) followed by plastics (1920 kg CO_2-eq/tonne) and glass (730 kg CO_2-eq/tonne). Hence, increase in recycling rates significantly improves GWP.

It can be seen that ADP-fossil and EP categories show similar trends and their performance improves with the increase of the recycling rates (see Supplementary materials for all environmental impact indicators). AP is the category that seems to be the least affected by changes in recycling rates.

Fig. 7 provides the results of the sensitivity analysis of IWMS 1 where changes in MSW composition are considered.

MSW is not a homogenous substance; the amount of various materials in a total waste stream may vary considerably depending on a number of factors such as seasonal variations of food consumption, recycling habits of residents in different areas and many others. Organic fractions are of the most importance as they can be treated by various technologies, sometimes with significant amounts of recovered energy due to their high caloric values. Thus, it is important to be able to estimate how changes in various

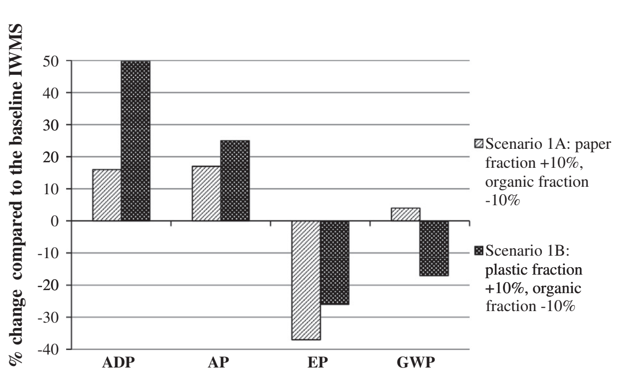

Fig. 7. Sensitivity Analysis for BAU scenario – IWMS 1. Changes in MSW composition – recyclable fractions.

waste fractions affect the overall results of the waste management system.

In Scenario 1A, the total paper fraction of waste was increased by 10% and the total organic fraction was reduced by 10% compared to the baseline values of scenario 1. From Fig. 7 it can be seen that the environmental burdens increased in all impact categories, except EP, which decreased by almost 40%. GWP is the least affected. The increase in GWP can be explained by the fact that the increase in paper fraction results in higher amount of paper also being sent to landfill, which is the primary waste treatment facility in IWMS 1. GWP of landfilling 1 tonne of paper (1120 kg CO_2-eq/tonne) is higher compared to GWP of landfilling other waste fractions including organic waste (701 kg CO_2-eq/tonne). Similar trends can be observed for ADP-fossil and AP impact categories. However, EP of landfilling 1 tonne of paper is less than that of landfilling 1 tonne of organic waste (3.87E−4 and 1.27E−3 kg Phosphate-eq respectively), which explains the reduction of the overall EP for IWMS 1.

In Scenario 1B, the total plastic fraction of MSW was increased by 10% and the total organic fraction was reduced by 10% compared to the baseline values of scenario1. It can be seen that ADP increased by 50% and AP increased by almost 25%. EP is reduced by almost 30% and GWP is reduced by almost 20%. This can be explained by the fact that GWP of landfilling of 1 tonne of plastic (72 kg CO_2-eq/tonne) is lower compared to GWP of landfilling 1 tonne of paper or organic waste. The results for EP show similar trends; landfilling of 1 tonne of plastic results in 1.97E−4 kg Phosphate-eq, which is lower than EP value for landfilling 1 tonne of organic waste (1.27E−3 kg Phosphate-eq). The opposite trends can be observed for ADP-fossil and AP impact categories, where the increase in plastic fraction results in higher overall impacts of the system.

The results of the sensitivity analysis provide valuable information regarding the changes of the total environmental impacts of IWMSs due to variations of waste composition and recycling rates. Thus, it can offer decision makers a more thorough analysis during the planning of waste treatment strategies. Other sensitivity analyses may also be carried out, such as an investigation of effects of changes of sorting and recovery efficiency and substitution rates on the overall results for the avoided burdens. However, this is beyond the scope of this paper.

5. Conclusions and future work

This paper provides the results of the environmental assessment of 10 integrated waste management systems for three potential legacy design scenarios of the London Queen Elizabeth Olympic Park. The assessment was carried out applying the LCA methodology with system expansion using GaBi v6.0 Product Sustainability Software.

The outcomes of the environmental evaluation of the IWMSs for different legacy design scenarios provide crucial information to decision makers when planning sustainable waste management strategies. The LCA results can assist decision making process by answering the questions framed in the beginning of this paper:

1. Which legacy scenario should be considered the 'best option' in terms of the lowest environmental impacts associated with waste treatment of MSW annually generated on site?
2. What waste treatment facilities can provide the best environmental solution and why?

The results of the current study demonstrate that the 'Commercial World' scenario shows the lowest environmental impacts from treatment of 1 tonne of MSW. This is due to the lowest environmental burdens in all impact categories for all IWMSs examined in this work. It has to be noted that only environmental burdens from waste management annually generated within the site boundaries was accounted for in this study.

The LCA results show that the most significant environmental savings in all IWMSs considered in this study are achieved through materials recycling at the MRF and through energy recovery from AD, EfW and ATT plants. This is evident from Figs. 3 and 4, which show avoided burdens from the substitution of energy and materials recovered from the processes and Table 6 which shows the total environmental burdens for each IWMS. To further highlight this, the results of a hot-spot analysis show that the avoided burdens from the MRF are almost three times higher than direct and indirect burdens, which indicate significant environmental savings resulting from the recycling process. The results provided in Table 6 show that GWP is the lowest for IWMSs 7 and 8 where ATT is the main technology; ADP is the lowest for IWMSs 6, 9 and 10 where incineration with energy recovery is used; AP is the lowest for IWMSs 6, 7 and 8; EP is the lowest for IWMSs 4, 6 and 8. Thus, the analysis shows that those IWMSs that include ATT or incineration with energy recovery provide best environmental solutions for all post-event design scenarios of the London Olympic Park considered in this study. At present, the following facilities are used for MSW treatment generated at the London Olympic Park: MRF, composting, incineration with and without energy recovery and landfill (JWDP, 2012).

It is clear that there is not a single waste management system that performs best in all impact categories. Moreover, in order to perform a complete sustainability assessment of the proposed site design scenarios, many other aspects need to be taken into consideration. Comprehensive assessment of the environmental impacts of the site should include other aspects such as emissions associated with energy consumption during construction, demolition and operation of venues; emissions from transportation of construction materials, residents and employees; embodied emissions from construction materials; emissions from water consumption and wastewater treatment. Moreover, economic and social aspects have also be assessed for each site design scenario.

Thus, further work will include economic evaluation of the costs and benefits of each IWMS, and social impact assessment of the proposed waste treatment facilities. The overall results will provide a holistic view of the proposed scenarios in terms of their economic, environmental and social impacts. Thus, the results will provide decision-makers with crucial information required for the long-term planning of waste management solutions.

Acknowledgments

The authors would like to acknowledge the Engineering and Physical Sciences Research Council (EPSRC) and the UCL Engineering Doctorate Centre for Urban Sustainability and Resilience for their financial support. Acknowledgements are due also to PricewaterhouseCoopers for useful discussions on the project.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.wasman.2015.03.017.

References

Astrup, T.F., Tonini, D., Turconi, R., Boldrin, A., 2014. Life cycle assessment of thermal waste-to-energy technologies: review and recommendations. Waste Manage. 37, 104–115.

Berglund, M., Börjesson, P., 2006. Assessment of energy performance in the life-cycle of biogas production. Biomass Bioenergy 30, 254–266.

Bernstad, A., la Cour Jansen, J., 2012. Review of comparative LCAs of food waste management systems – current status and potential improvements. Waste Manage. 13–12, 2439–2455.

BIFFA, 2012. The nature and scale of waste produced by schools in England. Available from http://www.biffa.co.uk/bigredbin.html (accessed 12.10.2012).

Blengini, G.A., 2008a. Applying LCA to organic waste management in Piedmont, Italy. Org. Waste Manage. 19 (5), 533–549.

Blengini, G.A., 2008b. Using LCA to evaluate impacts and resources conservation potential of composting: a case study of the Asti District in Italy. Resour. Conserv. Recycl. 53, 1373–1381.

Blengini, G.A., Fantoni, M., Busto, M., Genon, G., Zanetti, M.C., 2012a. Participatory approach, acceptability and transparency of waste management LCAs: case studies of Torino and Cuneo. Waste Manage. 32, 1712–1721.

Blengini, G.A., Busto, M., Fantoni, M., Fino, D., 2012b. Eco-efficient waste glass recycling: integrated waste management and greed product development through LCA. Waste Manage. 32, 1000–1008.

Boldrin, A., Andersen, J.K., Møller, J., Christensen, T.H., Favoino, E., 2009. Composting and compost utilization: accounting of greenhouse gases and global warming contributions. Waste Manage. Res. 27, 800–812.

Bovea, M.D., Ibáñez-Forés, V., Gallardo, A., Colomer-Mendoza, F.J., 2010. Environmental assessment of alternative municipal solid waste management strategies. A Spanish case study. Waste Manage. 30, 2383–2395.

Brunn, S., Hansen, T.L., Christensen, T.H., Magid, J., Jensen, L.S., 2006. Application of processed organic municipal solid waste on agricultural land – a scenario analysis. Environ. Model. Assess. 11, 251–265.

BSI, 2005. PAS100. Specification for Composted Materials. British Standards Institution.

BSI, 2010. PAS110. Specification for Whole Digestate, Separated Liquor and Separated Fibre Derived from the Anaerobic Digestion of Source-Segregated Biodegradable Materials. British Standards Institution.

Buttler, J., Hooper, P., 2005. Dilemmas in optimising the environmental benefit from recycling: a case study of glass container waste management in UK. Resour. Conserv. Recycl. 45, 331–355.

Cherubini, F., Bargigli, S., Ulgiati, S., 2009. Life cycle assessment (LCA) of waste management strategies: landfilling, soring plant and incineration. Energy 34 (12), 2116–2123.

Christensen, T.H., Simion, F., Tonini, D., Møller, J., 2009a. Global warming factors modelled for 40 generic municipal waste management scenarios. Waste Manage. Res. 27, 871–884.

Christensen, T.H., Gentil, E.C., Boldrin, A., Larsen, A.W., Weidema, B.P., Hauschild, M., 2009b. C balance, carbon dioxide emissions and global warming potentials in LCA-modelling of waste management systems. Waste Manage. Res. 27, 707–715.

Cimpan, C., Wenzel, H., 2013. Energy implications of mechanical and mechanical-biological treatment compared to direct waste-to-energy. Waste Manage. 33 (7), 1648–1658.

CIWEM, 2013. Mechanical Biological Treatment of Waste. The Charted Institution of Water and Environmental Management. <http://www.ciwem.org/knowledge-networks/panels/waste-management/mechanical-biological-treatment-of-waste.aspx> (accessed 11.09.13).

Clift, R., Doig, A., Finnveden, G., 2000. The application of life cycle assessment to integrated solid waste management: Part 1 – methodology. Process Saf. Environ. Prot. 78 (4), 279–287.

DEFRA, 2004. Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes. Defra, London.

DEFRA, 2011. Local Authority Collect Waste Management Statistics for England – Final Release of Quarters 1, 2, 3 and 4 2010/2011.

DEFRA, 2013a. Waste Management Plan for England. Department for Environment, Food and Rural Affairs.

DEFRA, 2013b. Incineration of Municipal Solid Waste. Department for Environment, Food and Rural Affairs.

DEFRA, 2013c. Advanced Thermal Treatment of Municipal Solid Waste. Department for Environment, Food & Rural Affairs.

EC, 2003. Refused derived fuel, current practice and perspectives (B4–3040/2000/306517/MAR/E3). European Commission-Directorate General Environment.

Ecoinvent, 2014. Ecoinvent v3.0 database. Ecoinvent Centre, Switzerland. http://www.ecoinvent.org.

Environment Agency, 2009. Using Science to Create a Better Place. The Use and Application to Land of MBT Compost-like Output-Review of Current European Practice in Relation to Environmental Protection. <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/291682/scho0109bpfn-e-e.pdf> (accessed 13.03.13).

Eriksson, O., Carlsson Reich, M., Frostell, B., Björklund, A., Assefa, G., Sundqvist, J.-O., Granath, J., Baky, A., Thyselius, L., 2005. Municipal solid waste from a systems perspective. J. Clean. Prod. 13 (3), 241–252.

Eriksson, O., Bisaillon, M., 2011. Multiple system modelling of waste management. Waste Manage. 31, 2620–2630.

EEA, 2013. Municipal Waste Management in the United Kingdom. European Environment Agency.

ESTET, 2004. The Viability of Advanced Thermal Treatment of MSW in the UK. Fitchner Consulting Engineers Ltd, Stockpot, UK.

Evangelisti, S., Lettieri, P., Borello, D., Clift, R., 2013. Life Cycle Assessment of energy from waste via anaerobic digestion: a UK case study. Waste Manage. 34, 226–237.

Evangelisti, S., Lettieri, P., Clift, R., Borello, D., 2014. Distributed generation by energy from waste technology: a life cycle perspective. Process Saf. Environ. Prot. http://dx.doi.org/10.1016/j.psep.2014.03.008.
Fruergaard, T., Astrup, T., Ekvall, T., 2009. Energy use and recovery in waste management and implications for accounting of greenhouse gases and global warming contributions. Waste Manage. Res. 27, 724–737.
Fruergaard, T., Astrup, T., 2011. Optimal utilization of waste-to-energy in an LCA perspective. Waste Manage. 31, 572–582.
GaBi, 2014. GaBi 6.0 Product Sustainability Software and Database. PE International, 2014.
Gentil, E.C., Damgaard, A., Hauschild, M., Finnveden, G., Eriksson, O., Thorneloe, S., Kaplan, P.O., Barlaz, M., Muller, O., Matsui, Y., Ii, R., Christensen, T.H., 2010. Models for waste life cycle assessment: review of technical assumptions. Waste Manage. 30, 2636–2648.
Giugliano, M.S., Cernuschi, S., Grosso, M., Rigamonti, L., 2011. Materials and energy recovery in integrated waste management systems. An evaluation based on life cycle assessment. Waste Manage. 31 (9), 2092–2101.
GIZ AgenZ, 2013. Mega-Events As An Engine for Sustainable Development. Agency for Market-Orientated Concepts. H. Reuffurth GmbH, Mühlheim am Main.
Guinée, J.B., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., Koning, A. de, Oers, van L., Wegener Sleeswijk, A., Suh, S., Udo de Haes, H.A., Bruijn, H. de, Duin, van R., Huijbregts, M.A.J., 2002. Handbook on Life Cycle Assessment. Operational Guide to the ISO standards. I: LCA in Perspective. IIa: Guide. IIb: Operational annex. III: Scientific background. Kluwer Academic Publishers, ISBN 1-4020-0228-9, Dordrecht, 692 pp.
Harrison, K.W., Dumas, R.D., Solano, E., Barlaz, M.A., Brill, E.D., Ranjithan, R., 2001. Decision support tool for life-cycle-based solid waste management. J. Comput. Civil Eng. 15, 44–58.
ISO, 2006a. ISO 14040 Environmental Management – Life Cycle Assessment – Principles and Frameworks.
ISO, 2006b. ISO 14044 Environmental Management – Life Cycle Assessment – Requirements and Guidelines.
Jeswani, H.K., Smith, R.W., Azapagic, A., 2013. Energy from waste: carbon footprint of incineration and landfill biogas in the UK. Int. J. Life Cycle Assess. 18, 218–229.
JWDP, 2012. Joint Waste Development Plan for the East London Waste Authority Boroughs. Local Plan/Local Development Framework.
Kaplan, P.O., Ranjithan, R., Barlaz, M.A., 2009. Use of life-cycle analysis to support solid waste management planning for Delaware. Environ. Sci. Technol. 45 (3), 1264–1270.
Khoo, H.H., 2009. Life cycle impact assessment of various waste conversion technologies. Waste Manage. 29, 1892–1990.
Lee, S.-H., Choi, K.-I., Osako, M., Dong, J.-I., 2007. Evaluation of environmental burdens caused by changes of food waste management systems in Seoul, Korea. Sci. Total Environ. 387, 42–53.
LLDC, 2012. Welcome to Queen Elizabeth Olympic Park. London Legacy Development Corporation.
Mendes, M.R., Aramaki, T., Hanaki, K., 2004. Comparison of environmental impact of incineration and landfilling in Sao Paolo City as determined by LCA. Resour., Conserv. Recycl. 41, 47–63.
Merrild, H., Larsen, A.W., Christensen, T.H., 2012. Assessing recycling versus incineration of key materials in municipal waste: the importance of efficient energy recovery and transport distances. Waste Manage. 32, 1009–1018.
Meylan, G., Seidl, R., Spoerri, A., 2013. Transitions of municipal solid waste management. Part I: scenarios of Swiss waste glass-packaging disposal. Resour. Conserv. Recycl. 74, 8–19.
Meylan, G., Ami, H., Spoerri, A., 2014. Transitions of municipal solid waste management. Part II: hybrid life cycle assessment of Swiss glass-packaging disposal. Resour. Conserv. Recycl. 86, 16–27.
Møller, J., Boldrin, A., Christensen, T.H., 2009. Anaerobic digestion and digestate use: accounting of greenhouse gases and global warming contributions. Waste Manage. Res. 27, 813–824.
Murphy, J.D., McKeogh, E., 2004. Technical, economic and environmental analysis of energy production from municipal solid waste. Renew. Energy 29 (7), 1043–1057.
OPLC, 2010. A Walk Around Queen Elizabeth Olympic Park, 2010. Olympic Park Legacy Company Limited, Stratford, London.
Palm, D., 2009. Carbon Footprint of Recycling Systems. MSc Thesis. Department of Energy and Environment, Chalmers University of Technology, Sweden.
Recycle Week, 2013. Editorial. Football stadium recycling. The beautiful game goes green. Available at: http://www.recyclenowpartners.org.uk/recycle_week.html (accessed 20.11.2012).
Rigamonti, L., Grosso, M., Giugliano, M., 2009. Life cycle assessment for optimising the level of separated collection in integrated MSW management systems. Waste Manage. 29 (2), 934–944.
Rigamonti, L., Falbo, A., Grosso, M., 2013. Improvement actions in waste management systems at the provincial scale based on a life cycle assessment evaluation. Waste Manage. 33 (11), 2568–2578.
Slagstad, H., Brattebø, H., 2012. LCA for household waste management when planning a new urban settlement. Waste Manage. 32–7, 1482–1490.
Smith, A., Brown, K., Ogilvie, S., Rushton, K., Bates, J., 2001. Waste Management Options and Climate Change. Final report to the European Commission, DG Environment. AEA Technology. Luxembourg: Office for Official Publications of the European Communities.
Spoerri, A., Lang, D.J., Binder, C.R., Scholz, R.W., 2009. Expert-based scenarios for strategic waste and resource management planning – C&D waste recycling in the Canton of Zurich, Switzerland. Resour., Conserv. Recycl. 53, 592–600.
The London Plan, 2014. Further Alterations to the London Plan Consolidated with Alterations Since 2011. Mayor of London.
UoE, 2011. Waste Management and Recycling Report 2011. The University of Edinburgh. Available at http://www.docs.csg.ed.ac.uk/estatesbuildings/waste/RWMReport2010-11FINAL.pdf (accessed 15.11.2012).
Wang, L., Templer, R., Murphy, R.J., 2012. A Life Cycle Assessment (LCA) comparison of three management options for waste papers: bioethanol production, recycling and incineration with energy recovery. Bioresour. Technol. 120, 89–98.
WRAP, 2007. An Analysis of MSW MRF Capacity in the UK. Business Growth Report. Waste and Resources Action Programme, Banbury, Oxon.
WRAP, 2011. The Composition of Waste Disposed of by the UK Hospitality Industry. Waste & Resources Action Programme, Banbury, Oxon.
Zglobisz, N., Castillo-Castillo, A., Grimes, S., Jones, P., 2010. Influence of UK energy policy on the development of anaerobic digestion. Energy Policy 38, 5988–5999.
Zhang, Y., Banks, C.J., Heaven, S., 2012. Anaerobic digestion of two biodegradable municipal waste streams. J. Environ. Manage. 104, 166–174.