Journal of Cleaner Production 130 (2016) 143–154

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Analysis of the environmental performance of life-cycle building waste management strategies in tertiary buildings

David Zambrana-Vasquez [a], Ignacio Zabalza-Bribián [b, *], Alberto Jáñez [a], Alfonso Aranda-Usón [c]

[a] Research Centre for Energy Resources and Consumption (CIRCE), CIRCE Building – Campus Río Ebro, Mariano Esquillor Gómez, 15, 50018, Zaragoza, Spain
[b] Research Centre for Energy Resources and Consumption (CIRCE) – Universidad de Zaragoza, CIRCE Building – Campus Río Ebro, Mariano Esquillor Gómez, 15, 50018, Zaragoza, Spain
[c] Universidad de Zaragoza, C/ Pedro Cerbuna, 12, 50009, Zaragoza, Spain

A R T I C L E I N F O

Article history:
Received 23 March 2015
Received in revised form
8 February 2016
Accepted 9 February 2016
Available online 17 February 2016

Keywords:
Municipal solid waste
Construction and demolition waste
Life cycle assessment
Eco-efficiency
Industrial ecology

A B S T R A C T

At urban level, the generation Municipal Solid Waste and Construction and Demolition Waste is mostly related to the life-cycle of buildings. An evaluation method based on Life Cycle Assessment methodology is presented in this paper to make an analysis of the environmental performance of different life-cycle building waste management strategies in tertiary buildings. As a case study, several waste management strategies considering a tertiary building located in the city of Zaragoza in Spain, are studied. The aim of the case study is to compare the environmental impacts, in terms of Global Warming Potential, of the scenarios proposed focussing on the waste minimisation and avoidance of landfilling of at least 10% for the Municipal Solid Waste generation during a building's use stage, and Construction and Demolition Waste generated during its construction and end-of-life. In case of Municipal Solid Waste, the results show that when a recovery scenario includes energy recovery from the residual fraction of the mechanical-biological treatment plant in the form of Refuse Derived Fuel, greater benefits in terms of the Global Warming Potential are obtained than with current scenarios of landfill deposition of the residual fraction. On the other hand, in case of Construction and Demolition Waste, a similar situation can be observed in case of an increase of the recovery rates of metals.

1. Introduction

Over the last years, in Europe, waste management is becoming increasingly complex due the growing generation of different waste streams that need tailored management systems, e.g., Municipal Solid Waste (MSW) and Construction and Demolition Waste (CDW). On the one hand, MSW consists of all waste generated in urban and municipal environments (Kreith, 1994). In 2010, more than 250 million tonnes of MSW were generated in the EU-27 countries (Eurostat Data Centre on Waste, 2012). On the other hand, CDW arises from the construction and total of partial demolition of buildings and civil infrastructure. Currently, CDW accounts for approximately 25%–30% of all waste generated in the EU (European Commission, 2014).

At urban level, the generation MSW and CDW is mostly related to the life-cycle of buildings. In these sense, several waste management strategies have been developed in order to an efficient use of the resources following the European legislation, mainly the Waste Framework Directive 2008/98/EC (European Parliament, 2008). Regarding MSW, from the point of view of the waste management hierarchy included in this Directive and when facing scarce alternatives for reuse, recycling and material supplies; energy recovery from the residual fraction of MSW after mechanical-biological treatment (MBT) plants becomes an option to be considered in lieu a landfill (Zambrana Vasquez et al., 2012). During the last decade, MBT plants in European countries have been the subject of active research because they represent important technological alternatives in MSW management. This active research was focused mainly on (i) the literature review of models and tools in waste management practices at EU level, considering different systems engineering models to solid waste management system analysis (Pires et al., 2011); (ii) mass balance research, e.g a mass balance divided in three steps (mechanical operations, biological

* Corresponding author. Tel.: +34 976761863; fax: +34 976732078.
E-mail address: izabal@unizar.es (I. Zabalza-Bribián).

http://dx.doi.org/10.1016/j.jclepro.2016.02.048
0959-6526/

Nomenclature

i. Variables

Ea	CO_2-eq emissions avoided, [t]
Eg	CO_2-eq emissions generated, [t]

ii. Greek Symbols

β	difference between generated and avoided CO_2-eq emissions, [t]

iii. Subscripts and Superscripts

Subscripts

i	MSW and CDW management system
j	scenario for MSW and CDW treatment and recovery methods
x	subsystem or activity within the MSW management system i
y	MSW treatment and recovery method considered in scenario j

iv. Acronyms

CDW	Construction and Demolition Waste
EPD	Environmental Product Declaration
LCA	Life Cycle Assessment
GHG	Greenhouse Gas
GWP	Global Warming Potential
LCI	Life Cycle Inventory
MBT	Mechanical-biological treatment
MSW	Municipal Solid Waste
RDF	Refuse Derived Fuel
SRF	Solid Recovered Fuel
tCO_2-eq	tonnes of CO_2 equivalent
HHV	Higher Heating Value
LHV	Lower Heating Value
tkm	tonnes per kilometre

operations and whole process) (De Araújo Morais et al., 2008) and waste fractions characterization, mass and biogas emissions reduction and biostability of the organic fraction from the mechanical–biological treatment plant in Mende, France (Bayard et al., 2010); (iii) different analysis of the organic fraction and its implications in the management efficiency, e.g., the assessment of the potential end uses and sustainable markets for organic residue from MBT (Farrell and Jones, 2009), the analysis of the improper materials in the composting process in 10 different MBT plants in Castilla y León, Spain (Montejo et al., 2010), several alternatives for organic waste management in Umbria region in Italy (Buratti et al., 2015) and the assessment of biological processes and sample analysis in different Austrian MBT plants (Tintner et al., 2010); (iv) the assessment of the implementation of new technologies, e.g., the experiment of low-cost MBT without material splitting for size reduced MSW as possible and suitable scenario in France (Lornage et al., 2007); (v) the energy recovery and production of alternative fuels, e.g., the determination of the main energy properties of MSW and Refuse Derived Fuel (RDF) for energy recovery (Montejo et al., 2011) and the assessment of biodrying technology as variation of aerobic decomposition for the production a high quality solid recovered fuel (SRF) in MBT plants (Velis et al., 2009); and (vi) the environmental assessment through the application of Life Cycle Assessment (LCA) methodology to the operation of the MBT plant of Ano Liossia in Attica, Greece (Abeliotis et al., 2012) and Zaragoza's MBT plant (Zambrana Vasquez et al., 2012), as cases studies.

On the other hand, CDW has been identified over last years as a priority waste stream by the European Union due its high potential for recycling and reuse. According to the report "Management of CDW in the EU - requirements resulting from the Waste Framework Directive and assessment of the situation in the medium term" conducted on behalf of the European Commission (European Commission (DG ENV), 2011), the level of recycling and re-use of CDW varies from less than 10% and over 90%. Additionally, from the Waste Framework Directive 2008/98/EC, the art. 11.2 stipulates that the Member States shall take the necessary measures designed to achieve that by 2020 a minimum of 70% (by weight) of non-hazardous CDW shall be prepared for re-use, recycled or other material recovery (including backfilling operations using waste to substitute other materials) (European Parliament, 2008). In this sense, several strategies have been developed around the European countries following this target objective supported by different waste management systems and technologies for separation and recovery of CDW (European Commission (DG ENV), 2011). These strategies are also studied by Pacheco-Torgal (2013) which introduces an overview of the recycling of CDW, under the aforementioned recycling target for 2020, and by Hiete (2013) which makes an analysis of the technologies in waste management plants for CDW fractions, changes in CDW supply in terms of quality and quantity and the demand of recycled aggregate materials. Also, against the CDW recycling target for 2020, Dahlbo et al. (2015) have focused their research on the combination of material flow analysis (MFA), LCA and environmental life cycle costing (ELCC) for the assessment of the performance CDW management system in Finland.

In this context, accurate assessment of the environmental implications of material and energy recovery from the residual fraction refused by MBT plants and from the CDW, which is landfilled, is essential in planning and promoting waste management methods at urban level. Such assessment would help to reduce the environmental impacts of waste management strategies, lower the consumption of energy resources, ensure safe and environmentally sound waste disposal, and reduce associated economic costs.

According the roadmap to a Resource Efficient Europe,[1] there is a challenge to improve the environmental performance of the current waste management strategies from a Life Cycle Thinking approach, and considering the recent published Life cycle indicators by the Joint Research Centre (JRC) (Manfredi and Goralczyk, 2013). Thus, the life cycle thinking can aid decision-making in the selection of the best available technologies to minimise the environmental impact of building waste management strategies through their entire life cycle. Appropriate design and construction can reduce the environmental impact of buildings over their entire life cycle (Polster et al., 1996). Also, decisions during these stages are connected with the generation of MSW and CDW, including their management. Ekanayake and Ofori (2004) have demonstrated that the design phase of a building has a major influence on waste generation.

Several studies in the literature have focused on different aspects of the environmental impact generated at different stages of MSW management. From these studies, several discuss the

[1] EC – European Commission, Roadmap to a resource efficient Europe. COM, vol. 571 Final (2011) Available online at http://ec.europa.eu/environment/resource_efficiency/pdf/com2011_571.pdf.