Journal of Cleaner Production 129 (2016) 234–248

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Combined material flow analysis and life cycle assessment as a support tool for solid waste management decision making

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ARTICLE INFO

Article history:
Received 3 August 2015
Received in revised form 29 October 2015
Accepted 18 April 2016
Available online 26 April 2016

Keywords:
Life cycle assessment
Material flow analysis
Solid waste management
Decision support
Greenhouse gas emissions

ABSTRACT

Material flow analysis (MFA) and life cycle assessment (LCA) have both widely been applied to support solid waste management (SWM) decision making. However, they are often applied independently rather than conjointly. This paper presents an approach that combines the MFA and LCA methodologies to evaluate large and complex SWM systems from an environmental perspective. The approach was applied to evaluate the environmental performance, focusing on greenhouse gas (GHG) emissions, of a local authority SWM system and to compare it with alternative systems to assess the potential effectiveness of different waste policy measures. The MFA results suggest that national recycling targets are unlikely to be met even if the assessed policies are implemented optimally. It is likely that for the targets to be met, investigated policies would need to be combined with additional policies that target reductions in waste arisings. The LCA results found landfilling of residual waste to be the dominant source of GHG burdens for the existing system, whilst material reprocessing was found to result in GHG benefits. Overall, each of the alternative systems investigated were found to result in lower GHG impacts compared to the existing system, with the diversion of food waste from the residual waste stream found to be potentially the most effective strategy to reduce GHG emissions. The results of this study demonstrate that the complementary methodologies of MFA and LCA can be used in combination to provide policy and decision makers with valuable information about the environmental performance of SWM systems.

1. Introduction

Currently, around 1.3 billion tonnes of municipal solid waste are generated annually worldwide and generation levels are projected to almost double by 2025, driven by rapid population growth, urbanisation, and socio economic development in developing countries (Hoornweg and Bhada-Tata, 2012). A substantial proportion of this waste material can be viewed as a resource. As demand for natural resources continues to rise, there is increasing pressure on the world's natural resource base, which is having severe environmental consequences (Hertwich et al., 2010). At a global scale, climate change is a serious international concern and the extraction, processing, and use of natural resources contributes directly to climate change through the burning of fossil fuels, whilst the disposal of materials in landfills contributes through emissions of greenhouse gases (GHG). Improving solid waste management (SWM) by recovering value in the form of material and energy resources can contribute towards enhanced resource efficiency and GHG mitigation efforts (UNEP, 2010).

The waste management sector is under increasing pressure to improve its environmental performance. In the European Union (EU), Member States are legally obligated to formulate and implement regional policy instruments to meet the environmental SWM objectives and targets outlined in a broad international legal framework. Article 4(1) of the EU Waste Framework Directive establishes the "waste hierarchy", a five step priority order of waste management comprising, in descending order of priority, prevention, preparation for reuse, recycling, other recovery (e.g. energy from waste), and disposal (EC, 2008). Under the terms of Article 21(1) of the EU Waste Framework Directive, all waste management decisions must be undertaken in line with the waste hierarchy. The Landfill Directive sets a target for member states to reduce the amount of biodegradable municipal solid waste going to landfill to 35% of 1995 levels by 2016 (EC, 1999). A target of achieving 50%

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http://dx.doi.org/10.1016/j.jclepro.2016.04.077
0959-6526/

Nomenclature

AD	anaerobic digestion
CCGT	combined cycle gas turbines
CHP	combined heat and power
EC	European Commission
ELCD	European Life Cycle Database
EU	European Union
GHG	greenhouse gas
GWP	Global Warming Potential
HWRC	household waste recycling centre
ILCD	the International Reference Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IVC	in-vessel composting
LACW	local authority collected waste
LCA	life cycle assessment
LCI	life cycle inventory
LDA	large domestic appliances
MBT	mechanical biological treatment
MFA	material flow analysis
MRF	material recovery facility
NRW	Natural Resources Wales
OWC	open windrow composting
RDF	refuse-derived fuel
SWM	solid waste management
WAG	Welsh Assembly Government
WG	Welsh Government

recycling of key household waste materials (paper, glass, metals, and plastics) is established in the Packaging and Packaging Waste Directive (EC, 1994). Moreover, at a broader level the EU is committed to reducing its GHG emissions by at least 20% and 40% of 1990 levels by 2020 (EC, 2009) and 2030 (EC, 2014), respectively. Managing resources to maximise environmental sustainability and contribute towards the achievement of national targets set by the EU entails important strategic and investment decisions by local waste managers, who are simultaneously tasked with maintaining a reliable and economical waste removal service to residents under increasing budgetary pressures. To reduce the burden on local waste managers and promote environmental sustainable practices, there is a need for strong waste policies that guide and enable effective local decisions and actions.

Analytical tools are required to assist local and national governments in evaluating the environmental performance of potential policy measures and local decisions (Turner et al., 2011). Such tools must be capable of handling the increasing complexity of modern 'integrated solid waste management' systems. Modern SWM encompasses a large number of waste treatment technologies, such as incineration, composting, and anaerobic digestion (AD) that are each designed to manage specific waste streams. Many of these technologies provide additional functions, such as secondary materials production and energy production, that necessitate interaction with other sectors, such as manufacturing, agriculture, and energy production (Giugliano et al., 2011). Furthermore, modern SWM systems comprise a global network of facilities, each with distinct technological facets and different levels of operational performance. It is necessary that analytical tools used to support decision making in complex, interdependent systems, such as SWM, adopt a whole system approach that reflects this complexity (Blengini et al., 2012).

In this paper we apply an approach that combines two systems based methodologies, material flow analysis (MFA) and life cycle assessment (LCA), to quantitatively evaluate a complex, municipality-scale SWM system and use scenario analysis to assess the potential effectiveness of different national waste policy measures. The novel contribution of this paper can be summarised as follows:

- Application of a combined MFA and LCA approach to evaluate a complex, multi waste stream SWM system at the meso level.
- Novel use of publically available waste data to comprehensively model waste flows through the system.
- Provision of information to national government regarding the potential effectiveness of waste policy measures.
- Assistance to local government in identifying optimal SWM solutions.

1.1. Case study

Wales is a constituent country of the UK that covers an area of 20,779 km^2 with an estimated population of 3.1 million in 2014 (ONS, 2015). Wales comprises 22 unitary authorities that are individually responsible for arranging waste collection and disposal. The Welsh Government (WG) has introduced a broad and ambitious sustainable development strategy that aims to make sustainable development the core principle of all national and sub national policy and decision making (HMSO, 2015; WAG, 2009). Two key national targets for 2050 have been set: 1) achieving "zero waste" (i.e. eliminating landfilling as far as possible) and 2) reducing national GHG emissions by at least 80% below 1990 levels (HMSO, 2008; WAG, 2010a,b; 2011). Furthermore, the WG have also set a target of a 3% reduction in national GHG emissions per year until 2050, to which waste management is required to contribute (WAG, 2010a).

The city of Cardiff is the capital of Wales and is located in the south of the country. The city covers an area of 140.3 km^2, of which around 76 km^2 is considered urban, and has a population of approximately 341,100 and a dwelling stock of 135,796. The city has a reported recycling rate of 52.2%, marginally below the national average of 52.3% (StatsWales, 2015b).

The Council operates an alternate weekly kerbside collection service for household residual waste and dry recyclables. Waste materials collected for recycling include paper, card, aluminium cans, steel cans, mixed plastics, and mixed glass. Garden and food waste are each collected separately on a weekly basis from households, whilst an optional absorbent hygiene products collection service operates fortnightly. A bespoke bulky waste collection service is also offered. There are four household waste recycling centres (HWRC) and 14 bring sites (recycling banks) located across the city. The Council also runs services for the collection of wastes from: commercial organisations, street cleaning, fly tipping, and municipal parks/grounds.

2. Methodology

A combination of methodologies was applied in this study to quantitatively evaluate the environmental performance of Cardiff's local authority collected waste (LACW) management system and those of alternative systems. LACW comprises all solid waste collected by a local authority. A static MFA approach was applied to

[2] Question 100 is a question in WasteDataFlow that asks local authorities to record the physical flows of collected wastes through all treatment facilities until those wastes reach their end destination.