Waste Management 81 (2018) 11–21

Contents lists available at ScienceDirect

Waste Management

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

Linking energy scenarios and waste storylines for prospective environmental assessment of waste management systems

Grégoire Meylan [a,*], Melanie Haupt [b], Mert Duygan [c], Stefanie Hellweg [b], Michael Stauffacher [c]

[a] Center for Business in the Americas, School of Management and Law, ZHAW Zurich University of Applied Sciences, 8401 Winterthur, Switzerland
[b] Chair of Ecological Systems Design, Institute for Environmental Engineering, ETH Zurich, 8093 Zurich, Switzerland
[c] Transdisciplinarity Lab, Department of Environmental Systems Science, ETH Zurich, 8092 Zurich, Switzerland

ARTICLE INFO

Article history:
Received 26 August 2017
Revised 3 August 2018
Accepted 10 September 2018

Keywords:
Energy scenarios
Life cycle assessment
Maximally diverse scenarios
Municipal solid waste
Storyline and Simulation Approach (SAS)

ABSTRACT

Multiple international and supranational organizations call upon changes in current waste management practices to play a key role in developing more sustainable economies. Life cycle assessment (LCA) is a popular method used to assess the sustainability of future waste management options. The uncertainties about future energy systems and waste compositions, however, may lead to ambiguous LCA results. One way to deal with this challenge is the development of joint energy and waste scenarios to investigate the robustness of waste management options. To date, joint energy and waste scenarios rely on the integration of large economic and engineering models. Complex models can hamper the transparency required for decision-makers to understand and implement LCA recommendations. Here we present the alternative of combining diverse energy scenarios and stakeholder-based waste storylines. This is a more qualitative approach than previous sustainable energy/waste evaluations and has a double aim: to address upfront the energy and waste composition sensitivity and enhance transparency by both relying on well-documented energy scenarios and involving stakeholders in the waste storyline formulation. We apply the approach to the Swiss municipal solid waste (MSW) management system in the context of the energy transition away from nuclear power. Three energy scenarios capture how radical the transition might be, while the storylines reflect societal developments and waste policies leading to low, high, and average MSW amounts. The approach delivers feasibility spaces of energy systems and waste compositions as input to the LCAs. It ensures a high level of transparency, which, in conjunction with the participation of decision-makers, has the potential to increase the chances of implementation of the recommendations based on LCA results.

1. Introduction

Any decision affecting the far future, such as an investment in long-term infrastructure or the enactment of a new regulation, requires (i) scrutinizing various options and (ii) assessing these options against various criteria, which may include environmental impacts, economic benefits and costs, and social acceptance (Füssel, 2007; Lempert, 2003; Trutnevyte et al., 2012). Waste management is a typical case in which decisions are made with implications reaching far into the future. Waste treatment infrastructure, such as incineration plants with a lifetime of some 25 years (DEFRA, 2014) and longer, are key components of waste management. Different levels of authorities enact waste management regulations that are intended to last for several decades for the sake of legal certainty. Revision of these regulations comes from the need to adapt to changing circumstances such as the emergence of new technologies or due to pressure exerted by developments in other sectors like the energy transition, climate change, etc. (Allen et al., 2011; Geels and Schot, 2007).

In the years to come, many countries should see a stark increase of long-term decisions in the field of waste management, as this sector will play an important role in the initiated and upcoming transitions to low-carbon and sustainable economies. The Intergovernmental Panel on Climate Change (IPCC) indicated in its Fourth Assessment report that the contribution of waste management to reducing global greenhouse gas (GHG) emissions so far had been underestimated due to poor data (Bogner et al., 2008). The IPCC named waste prevention, material recovery (i.e., reuse or recycling) and energy recovery (e.g., incineration and industrial co-combustion) as important mitigation measures in terms of

* Corresponding author at: ZHAW Zurich University of Applied Sciences, Stadthausstrasse 14, P.O. Box, 8401 Winterthur, Switzerland.
E-mail address: melg@zhaw.ch (G. Meylan).

https://doi.org/10.1016/j.wasman.2018.09.017
0956-053X/

indirect reduction of GHG emissions (e.g., through improved energy efficiency), energy benefits, and fossil fuel use offsets. More recently, the United Nations Environment Programme (UNEP) heralded the potential contribution of waste management towards meeting the Sustainable Development Goals (SDGs) (Wilson, 2015). Waste management is present in more than half of the 17 SDGs, making it a key aspect for sustainable development. To support its case for improving waste management, UNEP claims that 10–15% of global GHG emissions could be avoided through improved solid waste management (20% by including waste prevention) (Wilson, 2015).

Life cycle thinking allows one to assess the long-term impacts of different options in various fields, including waste management. Such studies focus on different assessment criteria depending on their goal and scope. In a prospective life cycle assessment (LCA), the analyst models future changes of environmental flows in all life cycle stages of a product or service arising from a decision (or no decision) and assesses the resulting environmental impacts (Frischknecht et al., 2005; Guinée et al., 2011; Hellweg and Milà i Canals, 2014; Pennington et al., 2004; Rebitzer et al., 2004). Complementing the environmental perspective of LCA, prospective life cycle costing (LCC) and social or societal life cycle assessment (sLCA) focus on future economic costs and social impacts, respectively (Hunkeler, 2006; Hunkeler et al., 2008). Prospective LCA has become a popular method amongst decision-makers to assess future waste management options. In the UNEP report cited above, LCA was used to estimate the GHG savings. Likewise, the IPCC recommends the use of LCA to quantify the contributions of waste management to GHG emissions reductions. The EU uses LCA as a key decision-support tool in waste management, as its Waste Directive (European Parliament and Council, 2008) allows member-states to depart from the long-established waste hierarchy (prevention, reuse, recycling, energy recovery, landfilling) if clear-cut LCA results support doing so in a given context. Ongoing debates make it clear that LCA will continue to play an important role in the EU's revised Waste Directive, which integrates the concept of Circular Economy (Haupt and Zschokke, 2017).

The current practice of LCA in waste management, however, suffers from a number of deficits that need to be tackled if the method is to adequately inform long-term decisions. Laurent and colleagues reviewed 222 LCAs of solid waste management systems. They compared these studies and their results (Laurent et al., 2014a), identified common inconsistencies and malpractices, and provided corresponding guidance (Laurent et al., 2014b). The comparison showed that waste management LCA findings strongly depend on the energy system (see also Boesch et al. (2014)) and on the waste composition. In their review (Laurent et al., 2014b), Laurent and colleagues noted a lack of transparency in modeling energy credits. Energy credits are the benefits that arise from recovering heat and electricity created by waste incineration and replacement of the corresponding amounts of energy converted from primary fuels. Heat and electricity credits used in the reviewed studies reflected either the national electricity and heat supply mixes or a marginal energy supply. In the latter case, heat from waste incineration replaces heat from the energy system that is expected to be displaced. Most of the 222 LCAs did not justify the choice of national electricity and heat supply mixes or marginal energy supply, with 25% not even indicating the data types used for energy credit modeling. It appears that LCA practitioners often resort to average or marginal data without justifying their choice, although the results of waste management LCAs are highly sensitive to energy systems. Laurent et al. (2014b) further highlighted the poor description of waste composition in LCAs of solid waste management systems and the lack of transparency with respect to waste composition data sources. Yet different waste stream parameters such as nutrient contents, material quality, and heating values are of paramount importance for the proper modeling of energy and material credits.

Given the importance of LCA for decisions in future infrastructure investment like waste management, it is urgent to tackle the fundamental challenge of adequately addressing the sensitivity to future energy mixes and waste composition. Münster et al. (2013) demonstrate how the construction of joint scenarios of energy and waste sectors constitutes a viable approach to deal with this challenge. They recommend that such scenarios reflect those dimensions most important to the LCA results. Arushanyan et al. (2017) implemented this approach for the case of all wastes in Sweden in the project Towards Sustainable Waste Management (TOSUWAMA). In TOSUWAMA, qualitative scenarios of societal development with researcher and stakeholder inputs served as input to a model of the Swedish economy (Tyskeng and Dreborg, 2008). This Computable General Equilibrium (CGE) model was in turn soft-linked with a systems engineering model of Swedish waste management (Ljunggren Söderman et al., 2016). The output of the systems engineering model was assessed by means of LCA. Also, TOSUWAMA evaluates the impact of various policy measures on waste management performance. The study authors name complexity and uncertainty of the models as the main limitations to TOSUWAMA. Pfenninger et al. (2014) argue that model complexity is an obstacle to transparency. The economic and engineering models entail many implicit assumptions hardly accessible to decision-makers. Yet, such assumptions lead to the energy credits and waste compositions used in ensuing prospective LCAs.

The goal of this paper is to present a methodological approach for developing energy and waste scenarios that enable both a robust and transparent modeling of energy credits and waste composition in prospective waste management LCAs. A robust approach is defined as having the primary aim of the explicit use of diverse future energy credits and waste compositions. Transparency is realized through the use of well-documented, existing energy scenarios to derive energy credits as well as the involvement of stakeholders in the process of developing assumptions for future waste compositions. We illustrate the approach with a demonstrative case study of municipal solid waste (MSW) management in Switzerland. We close the paper with a systematic comparison of our approach and that used by Arushanyan et al. (2017).

2. Methodological approach: combining existing energy scenarios and storylines of waste composition

2.1. Rationales

2.1.1. Existing energy scenarios: transparency, robustness, consistency

Scenarios of energy systems on the global, continental, national, and regional scales are numerous and the practice of energy system scenario construction goes back several decades. The International Energy Agency (IEA, 2016) and Greenpeace, with its country scenarios "energy [r]evolution" (Teske and Klingler Heiligtag, 2013), are just some of the multilateral and non-governmental organizations developing such scenarios, while governmental agencies develop scenarios for national energy policies. Today, decision-makers mainly rely on energy system scenarios for climate policy. Scenarios inform decision-makers of the implications of potentially conflicting goals on the energy system, including energy supply security and mitigation of nuclear power risks. Energy scenarios are of predictive, explorative, or normative types (Börjeson et al., 2006; Münster et al., 2013). Once the scenario type is defined, scenario analysts rely on different frameworks, mainly optimization or simulation, to model supply and demand of electricity and heat. Providing a broad review of existing scenarios,