Waste Management 32 (2012) 1009–1018

Contents lists available at SciVerse ScienceDirect

Waste Management

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

Assessing recycling versus incineration of key materials in municipal waste: The importance of efficient energy recovery and transport distances

Hanna Merrild, Anna W. Larsen *, Thomas H. Christensen

Department of Environmental Engineering, Technical University of Denmark, Miljoevej, Building 113, DK-2800 Kongens Lyngby, Denmark

ARTICLE INFO

Article history:
Received 13 June 2011
Accepted 17 December 2011
Available online 20 January 2012

Keywords:
Recycling
Incineration
LCA
Household waste
Transport
EASEWASTE

ABSTRACT

Recycling of materials from municipal solid waste is commonly considered to be superior to any other waste treatment alternative. For the material fractions with a significant energy content this might not be the case if the treatment alternative is a waste-to-energy plant with high energy recovery rates. The environmental impacts from recycling and from incineration of six material fractions in household waste have been compared through life cycle assessment assuming high-performance technologies for material recycling as well as for waste incineration. The results showed that there are environmental benefits when recycling paper, glass, steel and aluminium instead of incinerating it. For cardboard and plastic the results were more unclear, depending on the level of energy recovery at the incineration plant, the system boundaries chosen and which impact category was in focus. Further, the environmental impact potentials from collection, pre-treatment and transport was compared to the environmental benefit from recycling and this showed that with the right means of transport, recyclables can in most cases be transported long distances. However, the results also showed that recycling of some of the material fractions can only contribute marginally in improving the overall waste management system taking into consideration their limited content in average Danish household waste.

1. Introduction

Recycling of materials such as paper, cardboard, glass, plastic, steel and aluminium from municipal solid waste is high on the agenda in many countries because material recycling is considered to be superior to any other treatment alternative. Recent reviews of life cycle assessment studies including comparisons of recycling and incineration for different recyclable material fractions (Tyskeng and Finnveden, 2007; Villanueva and Wenzel, 2007; Waste and Resources Action Programme, 2006) and recently published life cycle assessments not included in the reviews (e.g. Morris, 2005; Luoranen et al., 2009; Salhofer et al., 2007; Schmidt et al., 2007) conclude that recycling in general is preferable to incineration from an environmental point of view for most of the materials studied. However, for the material fractions paper, cardboard and plastics the results are more ambiguous than for the material fractions glass, steel and aluminium due to a number of factors which all can be related to high energy content of these fractions and to the system boundaries of the modelling.

Waste management in Denmark is characterized with a high level of materials collected for recycling (33% of the household waste in 2006) and a high level of incineration (58% of the household waste in 2006) according to the national statistics (Danish Environmental Protection Agency, 2008). Recycling is encouraged by the Danish waste tax system, which imposes a tax around 50 Euro per tonne of waste incinerated while waste collected for recycling is not taxed. The environmental benefit of recycling versus incineration is however often debated. Three issues play an important role in this debate. One issue is related to the fact that renewable energy sources are high on the political agenda and that Danish incinerators today are effective waste-to-energy plants with high energy recovery rates, producing both electricity and heat. The electricity production may reach 24–26% of the lower heating value (LHV) of the waste and the heat recovery may be so high that the overall energy recovery may exceed 100% of the LHV where flue gas condensation has been introduced (Damgaard et al., 2010). The recovered energy is likely to substitute for coal-based energy and thus ascribe significant environmental saving to the incineration of waste. A second issue is related to the fact that waste incinerators now frequently recover both magnetic iron as well as aluminium for recycling. The third issue is related to the fact that many recyclables today are traded on a world market and thus often subject to long transport distances contributing to the environmental burden of the material recycling.

All three issues reduce the benefits of source separation and recycling of household waste in Denmark versus incineration. Thus we believe that there is a need for a closer assessment of material recycling in comparison with incineration with energy recovery

* Corresponding author. Tel.: +45 4525 1551; fax: +45 4593 2850.
E-mail address: awla@env.dtu.dk (A.W. Larsen).

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doi:10.1016/j.wasman.2011.12.025

considering high-performance technologies for both alternatives. For that purpose, the environmental burdens from treatment of six recyclable materials were systematically modelled by use of life cycle assessment as described in details in Section 2. The modelling involved (1) quantification of the environmental burdens from incineration and recycling of each material, (2) calculation of the distances that the materials can be transported without compromising the possible benefits of recycling and (3) evaluation of the significance of each material considering the potential quantity found in Danish household waste.

2. Modelling

2.1. The modelling approach

The modelling was performed in three steps.

Firstly, the environmental capacities for the recyclable material fractions paper, cardboard, glass, plastic, steel and aluminium were modelled. The environmental capacity is here defined as the 'room' allowed for environmental loads from collection, pre-treatment and transport of source-separated material when recycling it instead of incinerating it as residual waste. It is calculated as the difference between the environmental impacts from the residual waste treatment system (including collection and transport of residual waste, incineration, and substituted energy) and the environmental impacts from the material recycling (including recycling and substituted products), see Eq. (1). This means that it is the response to a change in the waste management system that is modelled, assuming that the basic handling is collection and incineration of unsorted waste. The functional unit of this modelling step was one tonne of recyclable material.

$$\text{Environmental capacity} = (C + T + I - SE) - (R - SP) \quad (1)$$

where C, collection of the residual waste; T, transportation of residual waste; I, incineration; SE, production of substituted energy; R, recycling; SP, production of substituted product.

Secondly, a number of hypothetical scenarios for collection, pre-treatment (two technologies) and transport (five means of transport) were modelled with the aim of comparing the magnitude of environmental loads from these life cycle stages with the environmental capacity found in the first step of the modelling. This would allow for assessing how critical the collection, pre-treatment and transport of recyclables are for the benefits of recycling. More specifically, it was investigated how far recyclables could be transported without compromising the benefits of recycling. The break-even distances, by which the total environmental impacts from material recycling would be equal to the impacts from the residual waste treatment system were calculated for all combinations of materials, means of transport and impact categories. The functional unit in this modelling step was also one tonne of recyclable material.

Finally, as the third step, the results for each material fraction were weighed with the amount of the fraction in Danish average household waste and the potential environmental impacts were compared to each other considering how much material is available for recycling within one tonne of waste. The results for one tonne of a single material fraction can tell us if we have an environmental capacity or not, while the results for the content in one tonne of household waste can tell us something about the environmental capacities' relative potentials. The source separation will never reach the full potential, but these results can give an indication of how important the environmental impact potentials found in the environmental capacity calculations are in a system perspective. Considering one tonne of mixed waste can tell us where environmental gains easily can be obtained by increasing the recycling rate. The functional unit was in this modelling step one tonne of household waste.

2.2. The life cycle assessment method and model

The potential environmental impacts were found by modelling in EASEWASTE, a life cycle assessment modelling tool developed for waste management systems (Kirkeby et al., 2006). The model is built up as a linear steady-state model, i.e. the consequences are the same for every tonne. In reality the environmental burdens are however likely to be a non-linear function of the collection rate (Ekvall et al., 2007). For systems with a very low or a very high recycling rate the linearity is thus not a valid assumption. The minimum and maximum recycling rates for the results to be valid have not been established, however if the participation is fair and the system will be working for many years it is fair to assume that the environmental loads and benefits are distributed evenly over a large number of tonnes. All emissions in the inventories, including upstream and downstream emissions, were converted to potential environmental impacts and normalized by the average contribution by one person in 1 year. The life cycle assessment method EDIP97 with updated normalization references (valid for a person in EU-15 in year 1994) was used (Stranddorf et al., 2005; Wenzel et al., 1997). The results are presented for four impact categories: acidification (AC), global warming (GW), nutrient enrichment (NE) and photochemical ozone formation (POF). These categories are very relevant for assessment of emissions from energy processes, which are the central issue in this study. Furthermore, the characterization method for these impacts are better established than for the toxicity impacts and resource consumption, where both methodological uncertainty and lack of reliable data reduce their trustworthiness. Normalization references for the impact categories are shown in Table 1.

3. Data

3.1. Recycling

The products produced from the recyclable material were assumed to substitute the equivalent products produced from virgin material. The material recycling module in EASEWASTE accounts for the inventory related to the recycling technology and credits for the inventory related to the virgin manufacturing technology according to a substitution ratio. The substitution ratio consists of two factors: the material loss, which is specific for each particular recycling technology, and the material quality loss, which is a generalized factor for each material fraction. Table 2 shows the material losses for the chosen technology datasets and the material quality loss rates recommended as default values by the Danish EPA (Dalum Papir A/S, 2008; DTU Environment, 2008; Schmidt and Strömberg, 2006; Skjern Papirfabrik A/S, 2006). The use of recyclables in manufacturing of new products was assumed not to influence the market situation for the product in question. In

Table 1
Normalization references for the life cycle assessment method EDIP97 (Stranddorf et al., 2005).

Impact category	Characterization unit	Normalization reference (characterization unit per person per year)
Acidification	kg SO_2- equivalents	74
Global warming	kg CO_2- equivalents	8700
Nutrient enrichment	kg NO_3- equivalents	119
Photochemical ozone formation	kg C_2H_2- equivalents	25