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Municipal solid waste management from a systems perspective

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Abstract

Different waste treatment options for municipal solid waste have been studied in a systems analysis. Different combinations of incineration, materials recycling of separated plastic and cardboard containers, and biological treatment (anaerobic digestion and composting) of biodegradable waste, were studied and compared to landfilling. The evaluation covered use of energy resources, environmental impact and financial and environmental costs. In the study, a calculation model (ORWARE) based on methodology from life cycle assessment (LCA) was used. Case studies were performed in three Swedish municipalities: Uppsala, Stockholm, and Älvdalen.

The study shows that reduced landfilling in favour of increased recycling of energy and materials lead to lower environmental impact, lower consumption of energy resources, and lower economic costs. Landfilling of energy-rich waste should be avoided as far as possible, partly because of the negative environmental impacts from landfilling, but mainly because of the low recovery of resources when landfilling.

Differences between materials recycling, nutrient recycling and incineration are small but in general recycling of plastic is somewhat better than incineration and biological treatment somewhat worse.

When planning waste management, it is important to know that the choice of waste treatment method affects processes outside the waste management system, such as generation of district heating, electricity, vehicle fuel, plastic, cardboard, and fertiliser.

Keywords: LCA; LCC; Environmental systems analysis; Waste management; Recycling; Simulation model; ORWARE; Scenarios; Case study

1. Introduction

Due to political decisions, more actions are taken by society towards more sustainable waste management solutions. On the European level, directives on landfilling [1,2] of waste are implemented. As some 15% of the total municipal waste flow then has to be redirected from landfilling to other treatments, these institutional changes will most probably lead to major changes in Swedish waste management.

In Sweden, producers' responsibility for packages and tires was introduced during the late 1990s [3]. A tax on all landfilled waste was imposed in January 2000. In 2002, a ban on landfilling of combustible waste was introduced, and three years later, 2005, organic waste will be included [4]. Today, the capacity to treat this waste does not exist in Sweden, but plans are made mainly for an extension of the incineration capacity. Today, 22 incinerators are in use in Sweden, and another 20 are being planned for [4]. In Sweden, the public opinion concerning incineration is relatively tolerant compared to other European countries. There is however a debate as to whether an increased incineration capacity was the aim of the imposed legislation and suggestions about an incineration tax has been raised [5].

As energy is recovered from waste for use in district heating, the Swedish waste management is also affected by the energy system. The Swedish energy system is bound to gradually change as nuclear power reactors

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are decommissioned in line with a parliamentary decision. Instead renewable energy sources are being introduced on to the energy market, of which waste partly could be seen as one. This means that, besides the regulations in waste management enforcing energy recovery from waste, the need for fuels for generating heat and power will also influence the planning of future waste management.

However, it is not only by incineration that waste can be used for energy recovery. Recycling of nutrients and materials reduces the need for energy intensive extraction and production of these resources, and the biogas obtained from anaerobic digestion can be used as vehicle fuel.

1.1. Objective

The aim of the study was to identify the most energy efficient, most cost efficient and least polluting waste management option from a systems perspective.

Other system studies of waste management [6–11] performed in Sweden and abroad have been reviewed. A conclusion from the review is that system studies of municipal solid waste are not as broad as our study and do not have the same kind of scenario construction as made here.

2. Method

The study was performed as case studies in three Swedish municipalities. A simulation model of the material and energy flows in waste management based on life cycle assessment (LCA) was used in the quantification of emissions, energy use and financial costs. The model ORWARE (*or*ganic *wa*ste *re*search) is based on general figures, assumptions and equations and was therefore adapted to each one of the three municipalities. For more information on ORWARE, see for example [12–15].

Eight scenarios comprising different recycling options (Table 1) were set up for each municipality. In this paper, the results from the Stockholm study are presented and the other two case studies are only used for comparison.

Landfilling has often been pointed out as the least favourable treatment method. However, it has been included as a reference scenario in order to emphasize this. Together with incineration, it is the only treatment method that can handle mixed household waste. Apart from these two, recovery of materials (e.g. plastic, glass or metal) and recovery of nutrients (e.g. nitrogen and phosphorus) from organic waste are methods that can be combined with the former mentioned methods landfilling and incineration. For the recycling scenarios, incineration is considered as the only plausible treatment method for the unsorted waste. Therefore, the combined effects of materials recycling and landfilling of residual waste have not been studied.

The emissions from the system studied are classified and characterised using methodology from LCA [16,17] into the following environmental impact categories:

- Global warming potential (GWP)
- Acidification potential (AP)
- Eutrophication potential (EP)
- Formation of photochemical oxidants (excluding NO_x)
- NO_x-emissions
- Heavy metals (input/output analysis).

In addition to the environmental impact categories above, the consumption of primary energy carriers, the net energy use, and the financial costs for the system are calculated.

The environmental results are also aggregated using monetary weightings for emissions. The monetary weightings are based on willingness-to-pay estimations from [18], except for eutrophicating emission valuations, which are based on [19]. Evaluation of resource use has not been performed in this study.

The financial costs and the aggregated environmental costs are in turn aggregated into welfare economic costs. This aggregation is adjusted for environmental taxes on vehicle fuels (energy taxes on diesel (SEK 0.15/kWh) and petrol (0.37 /kWh) and carbon dioxide taxes on diesel (SEK 0.1523/kWh) and petrol (SEK 0.1408/kWh)) and landfill tax (SEK 250/ton waste) to avoid double counting.

3. Model

In the ORWARE model, the waste management system consists of treatments and transports, according to Fig. 1. In all submodels, the annual turnover (use of) of materials, energy and financial resources in the processes are calculated. Materials turnover is characterised by (1) the supply of waste materials and process chemicals, (2) the output of products and by-products, and (3) emissions to air, water and crops. Energy turnover is the use of different energy carriers such as coal, oil, or biomass, and the recovery of heat, electricity, hydrogen, and biogas from waste. The financial turnover is defined as monetary costs for the processes included.

The materials flow cradle in the model is "waste in bin" from different sources, such as households and industries. Thus, the environmental and economic impact from the waste sources (comprising activities such as cleaning, sorting and transport to recycling