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Identification and testing of potential key parameters in system analysis of municipal solid waste management

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ABSTRACT

Life cycle assessment (LCA) and life cycle costing (LCC) are well-established methods used for many years in many countries for system analysis of waste management. According to standard LCA procedure the assessment should include improvement analysis, in many cases this is performed by simple sensitivity analyses. An obstacle to perform more thorough sensitivity analyses is that it is hard to distinguish input data important to the results, i.e. key parameters. This paper further elaborates sensitivity analyses performed in an environmental system analysis for a hypothetical Swedish municipality. In this paper, the method to identify and test input data that can be categorised as potential key parameters is described. The method and the results from computer simulations of the identified parameters are presented, and some conclusions are drawn regarding the robustness of the results for environmental impact from municipal solid waste management. The major conclusion is that the results are robust. Changes in results, when changing the preconditions, are often small and the changes observed do not lead to new conclusions; i.e., a change of ranking order between treatment options.

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1. Introduction

Management of municipal solid waste (MSW) in Sweden can be considered as a complex activity. The waste management system relies on different players like the municipality, entrepreneurs and companies. Many technologies are involved such as incineration, composting and material recycling. The treatments provide several functions like district heating, electrical power and biogas, as well as impacts on both the environment and the economy. Some parts of the system are de-regulated (e.g. recycling of packages) meanwhile some parts are not; in Sweden the municipality is obliged to establish a waste plan and incineration and landfilling is regulated by EU directives (Council of European Union, 1999; European Parliament and the Council of the European Union, 2000). In order to comprehend the dynamics of this system, a system approach is often needed. In this paper the system approach consists of a combination of life cycle assessment (LCA) and life cycle costing (LCC), cf. Carlsson Reich (2005).

In previous research (Eriksson et al., 2005) the environmental and economic impact from municipal solid waste management in three Swedish municipalities were studied using LCA and LCC. Different treatment options were analysed in various scenarios. The scenarios are described in detail in the mentioned paper but a short description is inserted here for the sake of understanding. In total seven scenarios were studied. One scenario was incineration of all MSW. Another scenario was putting all waste in a sanitary landfill with gas recovery and leachate treatment. The other scenarios included source separation of a particular waste fraction where the remaining waste always was incinerated. In three scenarios the organic waste was sorted out and thereafter treated by anaerobic digestion or by composting. One scenario comprised material recycling of plastic packages that had been source separated. In the last scenario cardboard packages were source separated and sent to material recycling. From each scenario different functional units were calculated: electricity, district heating, cardboard pulp, plastic granules, plant available nitrogen and phosphorus and vehicle transport by bus and/or car. The concept of system expansion was used, meaning that when the waste management system did not deliver these functional units, conventional production systems were used. The environmental impact assessment (ISO, 1997) was made for following environmental impact categories: global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), and formation of photochemical oxidants (PhOx). In addition to the environmental impacts studied, NO_X-emissions, consumption of primary energy carriers, net energy use, and financial costs for the system were calculated. The environmental results were also aggregated using monetary weightings for emissions.

Despite the fact that geographical data and process data were different for the three case studies, the internal ranking between treatment options with respect to environmental impact, con-

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sumption of primary energy carriers, and costs were almost identical for the three different municipalities.

In a follow-up study (Sundqvist et al., 2002a), sensitivity analyses of the results from the first research (Eriksson et al., 2005) were performed. The follow-up study was applied to a hypothetical Swedish municipality to identify single parameters crucial to the results for the total system.

LCA of waste management has been carried out in many countries for many years (Aumonier, 1996; Cheng et al., 2000; Powell, 2000; Beccali et al., 2001; Björklund and Finnveden, 2005; Özeler et al., 2006; Liamsanguan and Gheewala, 2008). Studies combining LCA with cost estimations are sometimes found, e.g. Emery et al. (2007). But system analysis studies often lack a thorough sensitivity analysis which is needed if the intentions with LCA to also perform improvement assessment (ISO, 1997) are to be met. Reasons for not performing improvement analysis can be many but one could be that due to the large amount of data handled in the LCA, researchers face a problem in how to distinguish the most important data. A neighbouring area to sensitivity analysis is uncertainty analysis, where elements like probabilities, confidence intervals and Monte Carlo simulations are used. However, often these uncertainties are unknown for most inventory data.

2. Aim of the paper

This paper investigates the robustness of the results presented in Eriksson et al. (2005) and is actually a further development of the work reported in Sundqvist et al. (2002a). The paper describes a method for the identification and testing of potential key parameters. It also describes results from computer model simulations where the parameters were tested. The testing of the parameters is made as a thorough sensitivity analysis, stated as a vital part of the LCA procedure (ISO, 1997).

3. Method

The method used in this paper is a thorough numerical sensitivity analysis of the input data used in a combined LCA and LCC of municipal solid waste management in Sweden. It must be stressed that just numerical factors are changed, the equations are not. The method is described in five steps.

The first step is to identify and select input data parameters of interest for further studies. All possible parameters are categorised as follows: (1) municipal parameters – which depend on the geography, demography, etc. of the municipality; (2) plant specific parameters – which describe technical performance for treatment facilities; and (3) general parameters – which do not change from municipality to municipality; e.g., data for the compensatory processes, emission factors for vehicles, characterisation factors and heat values.

For each category, parameters are of two different types: (1) discrete choices – parameters that influence the system design, e.g. the type of compensatory fuel and (2) process data – parameters which are always used, such as the emission factors for treatment processes. For each type reasonable values are to be found. A value can be of different types: (1) given value (such as a degree of efficiency), even if there may be great uncertainties, (2) uncertain value in the future (such as the waste amount per capita); and (3) Inexact value (such as an emission factor), as specific values may be hard to find, instead average values or "typical" values are often used. To learn more about data uncertainties in LCA of waste management, see Björklund (2002).

All input data to the study in focus, in our case a computer model, is then assessed from different perspectives with respect to their impact. In our case this assessment was performed as expert judgement. The experts are researchers with specialities in agricultural science, environmental technology, energy technology, etc. and they are all experienced systems analysts. The experts are highly skilled and possess thorough knowledge about the technical processes and their environmental and economic performance, as well as how these processes are linked together in a Swedish waste management system.

If a given input data is to be addressed as a potential key parameter, at least one of the following conditions had to be fulfilled: (1) large impact on direct emissions, energy recovery, fuel consumption, and use of resources for the specific process, (2) new conclusions about how to treat that specific waste fraction, (3) other conclusions about the design of the whole waste system and finally (4) a change in conclusions for the overall result.

The second step in the analysis is to set proper intervals for the potential parameters. Values found in the literature as well as in official reports for existing plants or a variation based on percentages of the initial value (e.g., ±10%) are applied.

The third step is to cluster the parameters. To be able to handle the large number of parameters, they have to be grouped into different clusters. In our case this was also made to delimit the number of time-consuming simulations and furthermore because a change of one parameter at a time probably would not cause significant changes in the total system. The different clusters are described in detail in the results. The parameter clusters in our study were:

1. Choice of compensatory heat- and power generation, known as being important in LCA (cf. Ekvall and Finnveden, 2000);
2. Design of the incineration plant, as a major part of the waste in each scenario is incinerated;
3. Transports;
4. Economic valuations;
5. Performance of the landfill process;
6. Waste characteristics, as this may affect the whole system;
7. Recycling process parameters, as these processes often are less developed compared to a well-established technology such as incineration).

The fourth step is to perform a test and to evaluate the clusters. We used computer simulations with the model ORWARE (Eriksson et al., 2002) for testing. The simulation results were evaluated by the authors of this paper. The evaluation was made with respect to the following questions: Is there a change in the order of ranking for the different scenarios? How are the functional units changed? Each impact category had to be checked for the core system as well as for the total system.

The fifth step is to evaluate the consequences of changing the parameters. What is e.g. meant by a *significant* change? One suggestion is that the order of ranking for the scenarios should change. The results were also compared with other LCA studies, predominantly Finnveden et al. (2000).

4. Results

In the following the original simulation results are referred to as the base scenarios. All sensitivity analysis results are then compared to these. More detail information about assumptions, etc. can be found in an earlier version of this paper, found in Eriksson (2003).

4.1. Power generation

Different methods for electrical power generation in the compensatory system – natural gas combi cycle (base scenario), coal condense power or Swedish power mix – were examined. The Swedish average electricity production is based mainly on

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