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Evaluation of life cycle inventory data for recycling systems

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ABSTRACT

This paper reviews databases on material recycling (primary as well as secondary production) used in life cycle assessments (LCA) of waste management systems. A total of 366 datasets, from 1980 to 2010 and covering 14 materials, were collected from databases and reports. Totals for CO_2-equivalent emissions were compared to illustrate variations in the data. It was hypothesised that emissions from material production and the recycling industry had decreased over time due to increasing regulation, energy costs and process optimisation, but the reported datasets did not reveal such a general trend. Data representing the same processes varied considerably between databases, and proper background information was hard to obtain, which in turn made it difficult to explain the large differences observed. Those differences between the highest and lowest estimated CO_2 emissions (equivalents) from the primary production of newsprint, HDPE and glass were 238%, 443% and 452%, respectively. For steel and aluminium the differences were 1761% and 235%, respectively. There is a severe lack of data for some recycled materials; for example, only one dataset existed for secondary cardboard. The study shows that the choice of dataset used to represent the environmental load of a material recycling process and credited emissions from the avoided production of virgin materials is crucial for the outcome of an LCA on waste management. Great care and a high degree of transparency are mandatory, but advice on which datasets to use could not be determined from the study. However, from the gathered data, recycling in general showed lower emission of CO_2 per kg material than primary production, so the recycling of materials (considered in this study) is thus beneficial in most cases.

1. Introduction

The reuse and recovery of resources from municipal waste contribute to sustainable development, and in the future, together with waste prevention, they will be a strong focus in many parts of the world (European Commission, 2011; Hoornweg et al., 2013). Companies and public authorities will be forced to use life cycle approaches to identify the best options for future waste management systems, including recycling. To carry out a life cycle assessment (LCA), there is a need for life cycle inventory (LCI) data to ensure a representative assessment. LCI data on waste management processes involved in recycling, including source separation, collection, transport and upgrading of recyclables, are readily available (for example, Merrild et al., 2012). However, LCI data on the actual industrial recycling of recovered materials can be found in external databases. LCI data on the remanufacturing of materials recovered from solid waste must include the environmental load of the manufacturing process employed to convert recovered materials into a new material (henceforth called 'secondary'), as well as the environmental load credited as a result of avoiding virgin material production (henceforth called 'primary'). In 2006, the UK Waste and Recovery Action Programme published a hefty review of LCA studies on recycling versus incineration and landfilling (WRAP, 2006). The review presented variations in the results taken from the studies, but did not look into the inventories behind the LCAs.

Many databases containing remanufacturing LCI data are available. However, selecting the right dataset out of the many published since 1980 for a specific LCA model is not particularly straightforward despite the existence of various guidelines (ISO, 2006; European Commission, 2010). ISO standard 14044 (ISO, 2006) and the ILCD Handbook (European Commission, 2010) describe the data quality requirements for LCIs. However, data quality indicators are typically not documented in the available datasets. There are a large number of waste-specific LCA models (e.g. EASEWASTE, WRATE,

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MSW-DST) (Gentil et al., 2010) as well as generic LCA models (e.g. SIMAPRO, GaBi, Umberto) and databases (e.g. Ecoinvent, US LCI, ELCD) in use, but there has been little discussion in the literature as to what dataset is most appropriate for a given LCA study, and no comparison has been made between these different data sources.

To assess data quality used in LCAs, Weidema and Wesnaes (1996) provided the pedigree matrix. This system ensures an overview of the relevance of a dataset for a given assessment. The matrix is used for LCA studies, and the scoring of the data is linked to the scope of the study. Factors to consider when assessing data quality include the age of the data, the level of detail in the background description and the technical and geographical representativeness.

The goal of this study was to provide an overview of the challenges involved in choosing representative datasets for material recycling and virgin material production processes. Challenges come in the form of the transparency of databases and documentation on background information for datasets. For a quantitative assessment of multiple databases, CO_2-equivalents was selected as an indicator parameter for environmental load, and its value was used to compare data across a range of recyclable materials found in available data sources.

2. Databases and choosing datasets

LCI databases on material recycling processes come from a variety of sources, the major ones of which are large public and commercial databases such as Ecoinvent (2013), PE International (2013), US Life Cycle Inventory Database (US LCI, 2013) and the European reference Life Cycle Database (ELCD, 2013). These databases may also be accessed through commercial LCA modelling tools, including Simapro (PRé, 2013), Umberto (ifu Hamburg, 2013) and GaBi (PE International, 2013). In addition, there are a number of smaller models dedicated to specific applications (municipal waste, packaging materials, fuels, biofuels, etc.) which have accompanying databases (e.g. EASETECH (Clavreul et al., 2014) and SWOLF (Levis et al., 2013)).

A total of 26 databases and sources were identified for this study, including the 366 material datasets for 14 materials presented in Table 1. Another 46 potential sources of LCI data were identified but not included due to language issues, closed websites, a prohibitive fee structure or because the data were not fully compatible with this study. The authors have licences for Simapro and GaBi–LCA tools which give access to many of the databases. No other licences were bought, and therefore some available databases were not included, even though these might be of good quality and up to date (e.g. Umberto (ifu Hamburg, 2013)). All data sources were identified by searching the internet, starting from the ELCD homepage which provides a comprehensive list of databases and sources. Scientific search engines (Web of Knowledge (2013), etc.) were also used to find scientific papers and relevant research reports.

2.1. Data selection criteria

The focus of this study was on data representing material production based on primary and secondary materials, including fibre (copy paper, cardboard, corrugated cardboard, newsprint), plastics (HDPE, LDPE, LLDPE, PET, PVC, PS, and PP), steel, aluminium and glass. The criteria for inclusion were that the material should be pure in an industrial context and preferably not a product, i.e. a steel ingot versus metal cans. In some cases products were included, for example in the case of glass, since most recycled glass comes from containers used for food and beverages.

Datasets were selected on the basis that it was possible to quantify CO_2-equivalent emissions, as this parameter was used as an indicator for dataset comparisons. CO_2 emission levels also provide an indication of the type of energy used in the dataset; for instance, high CO_2 emissions would indicate the high consumption of resource-demanding materials or of fossil energy. Datasets that were outliers in terms of CO_2-equivalents were specifically scrutinised to identify special conditions, as discussed below. CO_2-equivalents for biogenic CO_2 were considered to be zero, which is consistent with the definition for modelling biogenic carbon in waste management systems (Christensen et al., 2009; Muñoz et al., 2012).

Data documentation should describe the origin and age of the data, whether the data were measured, calculated or estimated, what was excluded, a careful description of the system boundaries and the organisation responsible for the data development. Unfortunately, complete documentation was never available and datasets with partial documentation were included.

2.2. Representative data

A representative dataset is one that embodies the assessed process, or the closest similar process, and detailed knowledge in this respect is required to know which process is most illustrative. This issue cannot be solved by applying Weidema and Wesnaes's (1996) pedigree matrix, though. For example, while HDPE manufacturing processes may be similar globally, the same cannot be said for paper, where each manufacturing facility tends to be unique and processes a specific set of fibre types that may vary over time. This makes it difficult to model a typical national average paper plant while a site-specific of an individual paper plant can be well-defined.

In the context of recycling, it is important to identify datasets that reflect industrial production processes where a good mix of scrap materials and virgin materials is used. Such processes are commonplace, but of course they do not provide separate data on virgin and recycled material manufacturing. Good documentation is critical to determine the net difference in increasing, for example, scrap recycling (actual process substituting and the actual substitution ratio). The energy used in production, in particular electricity, is usually a key contributor to an LCI. Thus, the documentation should be detailed about energy use, particularly in view of quantity and quality. The impacts caused by using electricity and applying heat vary a great deal between countries because of the different mix of energy sources. Therefore, it is important to use non-aggregated data in LCI datasets, in order to identify the contribution made by the energy use and potentially to change the process if the dataset is to be used in a different region with a different electricity fuel mix.

2.3. Description of material recovery from municipal solid waste for recycling

This section provides an overview of the key characteristics of the materials that are typically recycled from solid waste and are considered in this study, including copy paper, newsprint, cardboard, corrugated cardboard, container glass, steel, aluminium and plastics (high density polyethylene (HDPE), low density polyethylene (LDPE), linear low density polyethylene (LLDPE), polyethylene terephthalate (PET), polypropylene (PP), polyvinylchloride (PVC) and polystyrene (PS)).

2.3.1. Fibre materials

Copy paper, newsprint, cardboard and corrugated cardboard are all made from wooden fibre pulp. The pulp is produced from wooden materials by applying kraft, sulphite, mechanical or chemical-mechanical pulping methods (IPPC, 2001). The production of paper requires substantial amounts of water and energy.