WRATE: Waste LCA for Municipal Waste Strategies

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EXECUTIVE SUMMARY

In December 2005, The European Commission published the draft Thematic Strategy on the Sustainable Use of Natural Resources and the draft Thematic Strategy on the Prevention and Recycling of Waste. Both strategies recommend the use of Life Cycle thinking as a robust and scientific mean for a more sustainable management of waste and resources.

A waste Life Cycle Assessment (LCA) tool, called Waste and Resources Assessment Tool for the Environment (WRATE) has been developed on the behalf of the Environment Agency for England and Wales, Scottish Environment Protection Agency and Department of Environment, Northern Ireland. This tool provides life cycle information to municipal authorities, central government and other stakeholders involved in more sustainable and integrated municipal waste strategy.

The paper highlights the latest waste LCA innovations, based on the recent research findings. This includes the database structure based on the ISO 14048 standard and the calculation engine. The paper also aims at explaining the advantages and limitations of including waste management data directly from technology providers. Is the data representative of the local conditions? Finally the paper describes the importance of a visually effective graphic user interface to ensure that complex LCA information can be communicated to a range of stakeholders with different level of scientific knowledge or even different language.

The paper presents the innovations used in WRATE such as the LCI calculation of 12 process stages per process. Other innovations include the elemental mass balance of waste throughout the waste management system, the change of the language used in WRATE, the electronic exchange of waste data to support team work or the separation of between system default data and user defined data.

A comprehensive database is held within WRATE, including current waste management processes from waste collection containers to final disposal, associated with the most common practice in the industry for the recycling, treatment and recovery of Municipal Solid Waste (MSW). The inventory of waste management processes is probably the most comprehensive data collection that has been undertaken in Europe with 160 waste management processes integrated in WRATE and available to

all the users. The paper describes the advantages and limitations of using individual and specific process data versus generic data.

One common problem observed while using a LCA tool is its apparent complexity. Another problem is the perceived difficulty in obtaining quality data required by the user, such as waste input or type of facility, to complete a LCA for an integrated waste management strategy. The tool has been designed with these two issues in mind to help the non-expert user to complete a LCA and obtain meaningful information to minimise the environmental impacts associated with the management of municipal waste. On one hand, the user has the possibility to use default data (waste composition, energy mix, waste management process). On the other hand, WRATE has been designed with a highly visual and simple graphic interface, with the support of a user group, to ensure that waste LCA could be used and communicated effectively to a wide range of stakeholders.

INTRODUCTION

Twenty years ago, the waste management industry was mainly a disposal industry where waste was collected at kerbside, transported and disposed to landfill with almost non-existent environmental controls. Logistically speaking, the waste management system was relatively simple. In the last twenty years, the waste industry has seen a revolution in the way we handle our waste and mainly due to increased knowledge in the significant environmental impacts created by the simple disposal of waste in the environment. With the years, waste arisings have increased with the increased consumption levels. The growth in waste has actually exceeded the annual Growth Domestic Product (GDP) in the UK (NRWF, 2004). With the increased quantity of waste, waste has also become more complex and therefore more difficult to manage. Finally, in order to reduce the environmental impacts of waste disposal, the waste industry has gradually modified the management of waste by adding new technologies to collect, segregate and treat waste. The diversity of waste management facilities is now very clear however identifying the environmental impacts of alternative waste management facilities has been relatively poorly documented, leading to the development of technologies, policies and regulations that are potentially worse for the environment.

Many countries have adopted the use of a variety of tools to get a better understanding of the environmental impacts associated with waste management, although they tend to be isolated cases rather than the norm. Methods such as the Environmental Impact Assessment (EIA), is often used but usually applies to single, site specific technologies. EIA cannot easily provide information for a complete waste management system.

Life Cycle Assessment (LCA), on the other hand, has been considered as a holistic, robust and scientifically based methodology to identify the environmental impacts of waste management systems, however it is not site specific. The advantage of LCA is that it models the environmental impacts and the benefits of the waste management system in its integrity. It gives an indication of the different impacts to air, land and water, which allows decision makers to avoid waste management strategies that are not environmentally sound. It also allows regulators and policy makers to develop better environmental regulations.

The European Commission has recently proposed the Thematic Strategy on the Sustainable Use of Natural Resources (EC, 2005) and the draft Thematic Strategy on the Prevention and Recycling of Waste (EC, 2005) which is actively promoting the use of life cycle thinking for the management of waste and resources. These thematic strategies, overarching all the environmental Directives, are a strong indication that LCA is a long term approach that should be employed for the development of

new or "better" regulation and therefore should also be employed at the national, regional and local level to ensure that the environmental dimension is carefully considered when managing waste.
A waste Life Cycle Assessment (LCA) tool, called Waste and Resources Assessment Tool for the Environment (WRATE) has been developed by Golder Associates and ERM on the behalf of the Environment Agency for England and Wales, Scottish Environment Protection Agency and Department of Environment, Northern Ireland. This tool provides life cycle information to municipal authorities, central government and other stakeholders involved in more sustainable and integrated municipal waste strategy.

DEFINITION OF WASTE LCA

Waste LCA is method that calculates the environmental costs and benefits to land, water and air of waste management from the production of the waste to its final disposal. The environmental costs and benefits are calculated for each waste management processes during their whole life cycle, from construction, operations, maintenance to decommissioning. Waste LCA does not take into account the manufacturing and usage phase of the waste when it was a product but calculates the impacts of its collection, transport, recycling, treatment, recovery and disposal from the point of production of the waste at household.

WRATE STRUCTURE

Database

WRATE has been designed to ensure that complex environmental and waste management information can be analysed and communicated simply to a wide group of stakeholders, ranging from the public, non governmental organisations (NGO), elected members and regulators.
WRATE is a LCA modelling software based on databases where user input is kept to a minimum to facilitate the modelling exercise. It includes the following databases:

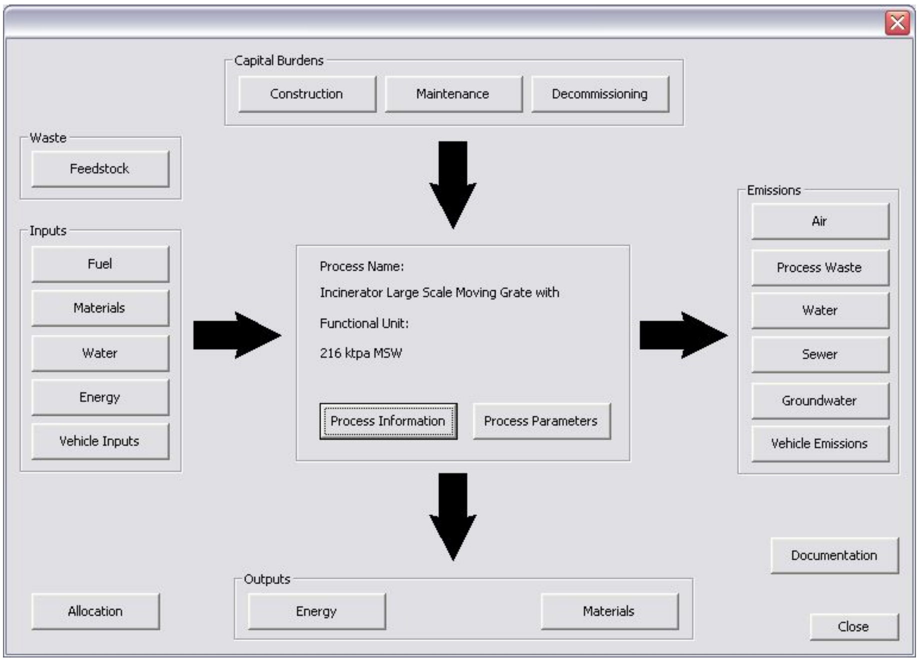
- Electricity mix;
- Waste composition;
- Foreground processes;
- Background inventories of emissions; and
- Life Cycle Impact Assessment methodologies.

The electricity mix database is comprised of all the information related to electricity generation mix, country and year of the study, generation efficiency, electricity losses during electricity transport and marginal electricity production. 40 countries have already been included in the tool. The electricity mix can affect the results significantly, therefore the choice of country and year of study is critical for the model. The electricity mix can also be defined by the user.

The second database represents the composition and quantity of waste. It includes pre-defined elemental waste composition for each waste fraction, default waste composition, calorific value, moisture and ash content of the waste. The users have the possibility to use their own waste composition but are not able to amend the elemental composition of the waste.

The foreground processes database provides a list about 160 waste management processes currently used in the industry. Data has been principally collected in the UK and to a lesser extent in the rest of the European Union (EU). Few processes have been collected outside the EU. This database includes all the information necessary for the calculation of the LCA. It comprises of 12 process stages (*e.g.* construction inputs and outputs, direct process burdens), as indicated in Figure 1. It is important to note that it also includes about 300 reports and other assumptions files directly available from the software to ensure maximum transparency of the tool. This database is considered as one of the most exhaustive waste technology database in the world. In addition, the user has the ability to create new process.

Figure 1. WRATE Data collection template showing the 12 process stage off a process.



The background inventory includes a large database of environmental burdens of materials used by the waste management processes (*e.g.* the environmental cost of 1 kg of concrete throughout its life cycle). 135 common materials have been included in the database.

A large number of Life Cycle Impact Assessment methodologies have been included in the software. This database provides the information necessary for calculating the environmental impacts (*e.g.* global warming potential) of the environmental emissions (*e.g.* carbon dioxide, methane). These impact assessment methodologies have been compiled from research work across the world.

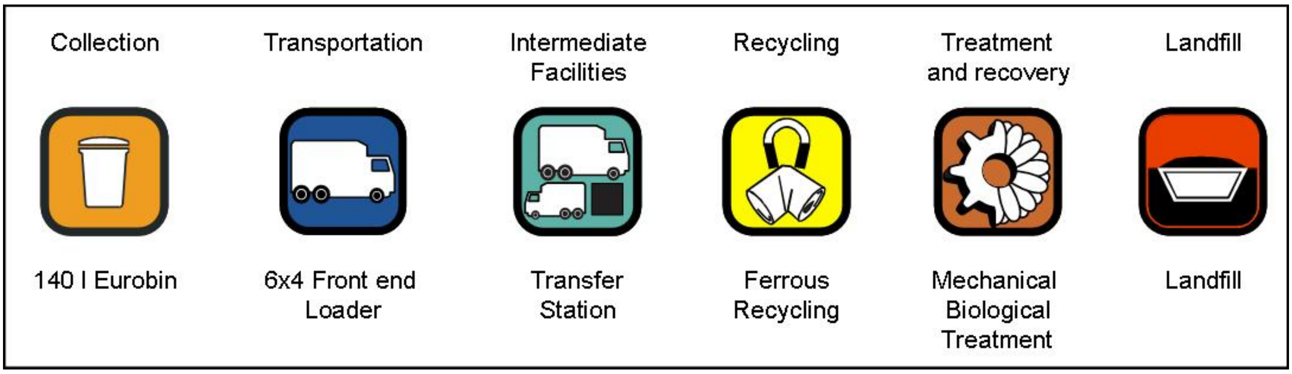
It should be noted that the database structure has been designed to keep system default data separate from user defined data to optimise the integrity of peer reviewed data and ensuring consistent quality of the software.

Waste Management Model Used in WRATE

The WRATE waste management model is a linear model originating from the waste arising to the final disposal of the residual waste. It is possible to model open-loop recycling (aluminium is sent for recycling outside the system boundaries of waste management and is recycled in another product). It is however not possible to feed resource streams back to a waste management process. For example, it is not possible to feed compost back to the same composting plant to improve its degradation. Similarly it is not possible to feed recycled steel back into the waste management system for its use as a construction material (It is possible to use recycled steel for the construction of a process but not from the steel produced by the waste management system itself).

In order to improve the communication of waste management systems to a variety of stakeholders, it was important to provide a simple and visual colour coding showing different types of waste management categories in the linear model.
In WRATE, a complete waste management system is modelled in 6 stages as indicated in Figure 2.

Figure 2. Waste Management Categories in WRATE.



It should be noted that no restriction has been placed on the number of processes used in a system. Therefore it is possible to model a very simple waste management system or a complex one. For instance, it is possible to model a local initiative or a large region using the waste management categories, mentioned above, and their associated waste management processes.

DATA QUALITY FROM TECHNOLOGY PROVIDERS

One of the main issues facing LCA software is the reliability of the data. LCA uses a large amount of data originating from a variety of sources from different countries. There are two approaches to obtain LCA data. One approach is to undertake extensive research and attempt to create a laboratory scale of a large scale process. The limitation of this methodology is that the number of processes that can be reproduced in the laboratory environment is potentially small. The second limitation is that it is necessary to extrapolate the laboratory small scale results to the industrial scale and therefore inaccuracies may arise. The advantage is that there is a higher certainty on the relationship between the inputs and outputs (We know exactly and consistently how much carbon dioxide is emitted by burning 1 kg of waste).

Another school of thought (used for the development of WRATE) is to collect real life data from existing industrial scale facilities. The limitation is that one relies on the information provided by the technology providers, which require additional data quality check to ensure compliance with the ISO standard and robustness of the data provided. Some information is deemed to be commercially confidential, other information is simply not collected if there is no regulatory requirement to do so (Thomas *etal*, 2005). The advantage of this approach is that the LCA information collected represents the typical relationship between the inputs and the outputs of existing plants or technologies (a typical quantity and composition of waste will have a typical emission factor for a typical waste management process). The main advantage is that it is possible, although still expensive, to obtain realistic data from many different technologies providers, which can then be utilised by the users to meet their specific and local waste management needs.

In order to minimise the data quality problem associated with the collection of industrial scale technologies, a data collection template was designed based on the requirements of the ISO 14048 standard. The LCA data is then validated by a central Government LCA expert (in the UK) to check the consistency and the reliability of the data. The validation process also highlights any data gaps. Following the validation stage, the technology data is then peer-reviewed by a third party who is a LCA expert in the particular technology. To ensure maximum transparency, comprehensive documentation has been provided in the tool for each technology. This includes specific technical reports, intermediate calculations, assumptions, pictures of the technology and flow diagrams.

THE IMPORTANCE OF WASTE COMPOSITION

As indicated earlier, the objective of waste LCA is to get a better understanding of the environmental costs and benefits of waste management and identify waste management alternatives that are less environmentally damaging. To understand the environmental emissions (the outputs) of waste management, it is critical to have a good understanding of the types and quantity of waste entering the system (The inputs). WRATE has been designed to ensure that the appropriate level of waste information is included in the model. For instance, the municipal waste is categorised in 10 different municipal waste streams as indicated below:

- Bulky Household
- Commercial and Office waste
- Civic Amenities (recycling centres)
- Household
- Street Sweepings
- Park Waste
- Building Waste (municipal source)
- Highway waste
- Litter

Each waste stream has a specific fractional composition made of 15 fractions (paper and card, plastic, …). Each of these fractions includes sub-fractions (newspaper and plastic film). Each waste fraction has a preset elemental composition. WRATE is provided with default compositional data to ensure that the user can make a LCA model. However, it is obvious that the waste composition of a city will be different than the waste composition of another city. It is therefore very important for municipalities, willing to undertake a LCA of their existing and future waste management system, that a detailed waste composition analysis is undertaken.
According to Friðriksson *etal* (2002), data for composition of waste with respect to waste fractions is developed on national level in many countries, for specific waste treatment plants and for specific municipal waste management companies. This data should be used if a local waste composition analysis is not available.

GEOGRAPHIC AND TIME ASPECTS

As briefly pointed out earlier, the location and date of the LCA study is very important for obtaining realistic LCA results. Waste composition, for example, varies significantly from one country to another and from a region to another due to different cultures, different climatic conditions and other factors. Waste composition is also changing with changing consumption patterns. We tend to consume more packaged and prepared food with increased economical development and therefore the waste composition is significantly different between now and twenty years ago. It is expected that waste composition is likely to change in the future. Future variation in waste composition (and waste quantity) should be forecasted to ensure that future waste management strategies are accurate.

The electricity mix represents the sources of energy that produce a unit of electricity. It is considered to be a significant factor in LCA results. This is dependent on the location of the study. The electricity mix is rather different in different countries, due to the energy policy of the country. For instance, according to ERM (2002) in the UK in 2002, electricity is mainly produced from a mix of 33% coal, 36% gas and 25% nuclear. While for France, the electricity is mainly produced from a mix of 4% of coal, 4% gas, 78% nuclear and 12% hydropower. Furthermore, the electricity mix is changing every year due to the construction of new power plants and the decommissioning of others. The environmental impacts of electricity produced are different in different countries due to their different electricity mix. A problem arises when the boundaries of a waste management system is across several countries. This should be clearly explained in the assumptions of the goal and scope of the study if this is the case.

WRATE includes a variety of countries with known and forecasted electricity mixes based on national energy policy. The location and date of the study are required parameters for the model to be validated. The calculations of the LCA results cannot be undertaken until a choice has been made to select the country and the date of the study.

COMMUNICATION OF ENVIRONMENTAL INFORMATION

According to Aumonier (2004), LCA results need to be clearly explained to stakeholders such as policy makers, officers in municipalities, elected councillors, the public and NGOs. The challenge is that the majority of stakeholders are often non-scientists. Aumonier emphasises that the LCA practitioner should be very clear on the assumptions taken that include or exclude specific parameters. The system boundaries should also be clearly understood by the audience. The environmental benefits of material and energy recovery should also be communicated. Finally, the different environmental impacts should be presented to avoid any pre-conceptions that the stakeholders might have. More importantly, stakeholders should reach consensus concerning the significance of the impacts and should agree on the potential trade-off between impacts before the LCA study is undertaken otherwise one may face a strong opposition when the results are shown to these stakeholders.

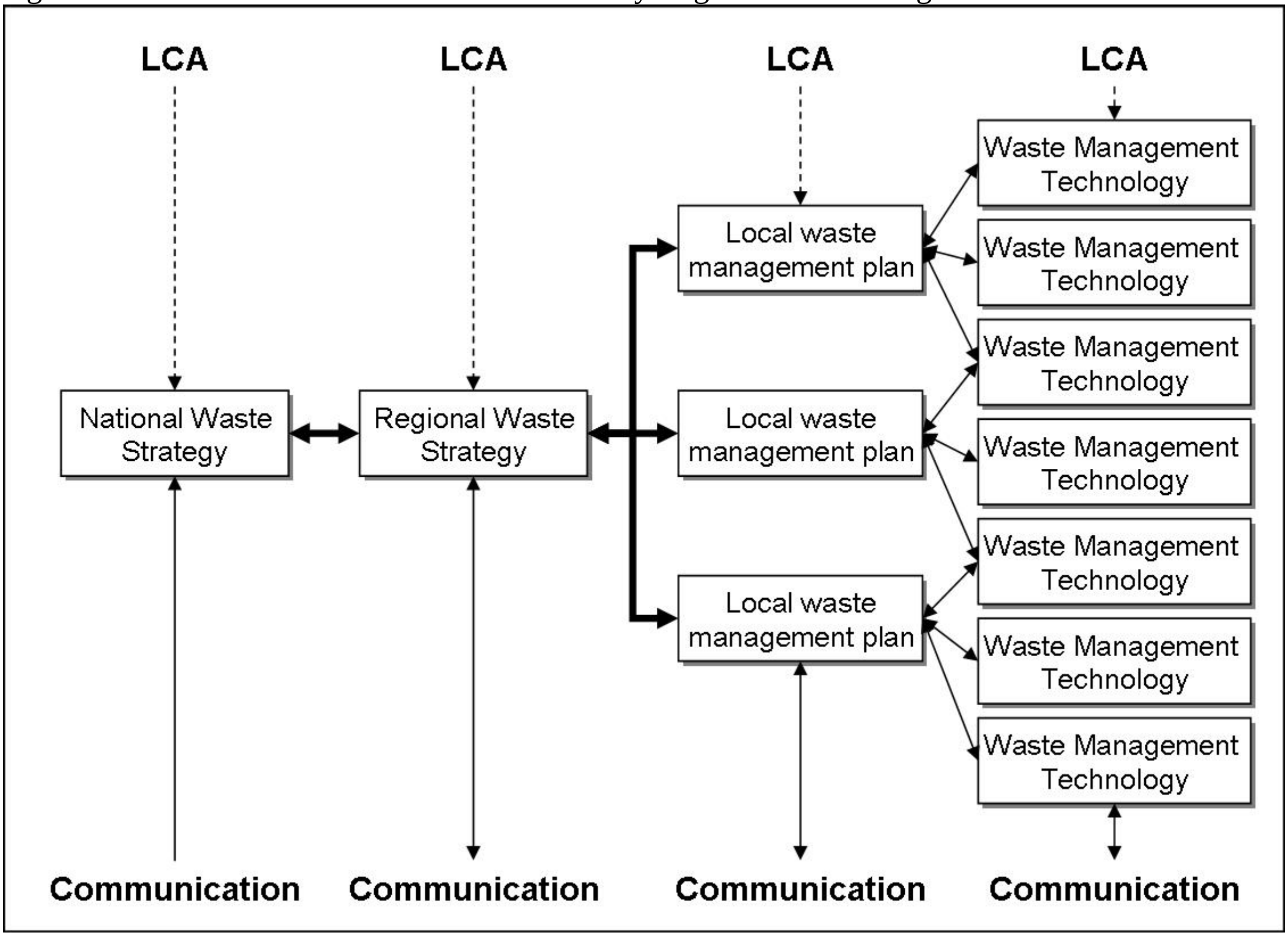
As indicated, communicating LCA is a major challenge to ensure that all the stakeholders have a good understanding of the different aspects of the LCA study. WRATE has been designed for communicating complex environmental data in a simple way without loosing the detailed information. For instance, two levels of results are present in WRATE. Summary results show very simple data with one figure for 6 default environmental impacts and some key information of the quantity of waste treated by waste management category. The detailed results allows for the display of data using a variety of filters, sorting facilities and graphical displays.

To improve the communication of the results, efforts have been taken to minimise the use of the scientific notation. Finally, the waste management process icons, used in the waste management map in WRATE, have been designed to be presented to multicultural and multilingual communities simultaneously. Further, the user interface of the software can be translated by the change of a single file without the need to decompile the software.

There is often a legal requirement at the planning and development stage of a new waste management facility or a new waste management strategy to engage in stakeholder participation during the decision-making process. This is a particular challenge in the waste sector since waste management is often associated with a strong NIMBY (Not In My Back Yard) factor (Hardin *etal*, 2001). WRATE is designed to explain and address the environmental concerns of a waste management scenario or a variety of options by explaining, for example, the impacts to human health.

In the European Union, there is a requirement for each Member State to submit a waste management strategy which necessitates the development of local waste management plans. WRATE can be used for this exercise and has the possibility to generate LCA results for a concurrent number of local plans to get a better understanding of the environmental costs and benefits within a region or at a national level as indicated in Figure 3.

Figure 2. Use of LCA and communication at every stage of waste management.



FEATURED INNOVATIONS

One of the innovations in WRATE is the ability to calculate the LCA based on the elemental mass balance. For example it is possible to model a reduction of cadmium in the air emissions of an incinerator if the plastic component, known to have a significant amount of cadmium embedded in it, is removed from the thermal process. However the model cannot determine the quantity of molecules, such as dioxin, “manufactured” by a waste management technology.

Another innovative feature in WRATE is the transparency of the data. All the parameters, assumptions and equations defining a waste management process are easily accessible and can be modified as a user defined process. Further, all the documentation is available electronically and is included in the tool.

WRATE can model the environmental performance of all the 12 stages of a process concurrently or independently for a single process or for several processes. For example, it is possible to analyse the environmental performance of the construction of different composting plants. Usually this type of information is aggregated in one set of results because of the duration of the calculations.

Another innovation was to ensure that the user has reliable data that cannot be tampered with. On the other hand, it is important that the user has the flexibility to modify process information if required. To provide a solution that meets both needs, the software was designed with a physical separation of the data included in the software (System database) from the data provided by the user (User database). Any process produced by a user will be highlighted as a user-defined process in the produced report. This is very important because it avoids erroneous or “manipulated” data to be introduced in the model unknowingly.

According to Thomas and McDougall (2005), biogenic sources of carbon tend to be excluded from the LCA of a waste management system. WRATE provides life cycle inventory for biogenic (*e.g.* wood) and fossil carbon (*e.g.* fuel) separately and provides impact assessment for the emissions of fossil carbon. This is an important and innovative aspect because the model defines more realistically the environmental impacts of carbon emissions since only the fossil carbon has a known potential impact on the environment. Other models that do not take into account this aspect will tend to overestimate the environmental impacts of carbon emissions. This is especially true for the thermal processes that combust waste of heterogeneous nature of fossil and biogenic sources

LIMITATIONS OF THE SOFTWARE

One of the main limitations of WRATE is the inability to model accurately the management of non-municipal waste. WRATE can model some non-municipal waste that have a similar composition to municipal waste. One of the reasons of this limitation is the lack of reliable data available for the vast diversity of waste types originating from non-municipal sources and the number of treatment and recovery processes that are present in the market. There is also a lack of information concerning the co-treatment of non-municipal waste and municipal waste. New research is needed to address this limitation.

Another limitation is that the software does not have the ability to undertake automatic sensitivity analysis. Sensitivity analyses are important for understanding the significance of a particular factor and evaluate whether this factor should be included or excluded from the study. However, a guidance document is being prepared by the Environment Agency that will be available to the users.

As demonstrated in the communication section of this paper, WRATE calculates a range of six default environmental impacts. The challenge resides when a group of stakeholders have to reach consensus on the significance of the selected environmental impacts. What is more important to the stakeholders? Global warming or eutrophication? To answer this question a weighting factor can be introduced in the LCA study. WRATE does not provide an internal weighting of the different environmental impacts as further research is needed to provide a robust weighting methodology.

CONCLUSION

Waste management has evolved drastically in the last twenty years. It has become more diverse, more complex, with higher quantity of waste being produced. Environmental impacts that were not considered in the past are now required. Waste LCA brings a holistic approach to the environmental costs and benefits of waste management systems and allows decision makers, politicians and other stakeholders to have a better understanding of the environmental optimisation of their waste management strategy. Waste LCA also provides the ability to strategists and decision makers to develop a more integrated waste management and therefore integrate waste management in the sustainable development agenda.

WRATE has been developed to bring some elements of answers for the environmental issues of waste management systems. The use of LCA is promoted at all the levels from the European Commission to the local municipalities. Communicating environmental information about a waste management strategy is critical to ensure a democratic decision-making process and make more informed decisions on the various waste management options that should be implemented at the local or national level. WRATE has been developed to aid the decision-making process and to communicate complex environmental information simply and visually. WRATE has been developed with the latest international research, however more research will be necessary to address its limitations. The key aspect of WRATE is that it is a platform that already has comprehensive databases. This platform will continuously incorporate more technologies, more default waste composition, more energy mixes. There will be a continuous update of the data to ensure that software can respond to the growing needs of managing our waste and our resources more responsibly and more sustainably.

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