A REVIEW OF APPROACHES FOR SELECTING INTEGRATED WASTE MANAGEMENT SCENARIOS FOR LIFE CYCLE ASSESSMENT STUDIES

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Abstract:
LCA is a decision support tool that evaluates the environmental impacts throughout the life cycle of a product or a process. This tool can also be used to assess the environmental performances of an integrated waste management system or to identify the one with the best performance through a comparative analysis of different scenarios. The result of the analysis depends primarily on how scenarios to compare are constructed, that depends on which fractions, and in what amounts, are sent to certain treatments/destinations.
In the first part of the paper, we will introduce the concept of scenario, how it be can classified and how it can be built, as is clear from the literature.
Then we will try to examine the criteria used in choosing the scenarios of waste management systems under the LCA, through a literature review. This critical review, which is the first phase of a larger study, highlights that arbitrary criteria are generally used in the selection of scenarios. In this way the best combination among all possible ones might not be considered; indeed, the best one among a discrete set of possibilities can just be identified.
Furthermore, the paper highlights the advisability to identify an LCA-integrated tool that allows one to find the most environmentally-sound scenario among all those theoretically possible.

Keywords: LCA, Life cycle assessment, integrated waste management system, scenario, case study review.

JEL classification: Q51

1. INTRODUCTION

An objective of the EU's policies is to minimize waste production through better use of resources and more sustainable consumption patterns. The approach of the EU to waste management is based on the following principles: waste prevention, recycling and reuse and the optimization of final disposal and monitoring. The waste hierarchy is the basis for selecting priorities in waste management (Del Borghi et al., 2009). It gives top priority to prevention, then reuse, recycling, recovery and, finally, disposal follows. The waste hierarchy does not attempt to assess the environmental impacts of a specific waste management system but provides guidelines for the preferred strategy for waste management if the available data for an environmental assessment is very limited (Kirkeby, 2005).

In waste management, waste can be subjected to various processes, such as landfilling, incineration with energy recovering, recycling, composting, each of this with specific consequences in terms of environmental impacts. Therefore, it is important to assess accurately the destinations of waste that minimize these consequences.

A system approach to waste management was proposed by W.R.Lynn in 1962 described as "viewing the problem in its entirety as an interconnected system of components operations and functions" (McDougall et al., 2003).

Kreith and Tchobanoglous (2002) have defined an integrated waste management system as "the selection and application of suitable techniques, technology and management programs to achieve specific waste management objective and goals".

In 1991 a task force of the UNECE (Economic Commission for Europe) published a Draft Regional Strategy in which there is a relevant definition of integrated waste management, which is defined as "process of change in which the concept of waste management is gradually broadened to eventually include the necessary control of gaseous, liquid, and solid material flows in human environment" (McDougall et al., 2003). Today the concept is broader and includes the use of different treatment technologies depending on situations, and overall approach being taken with respect to the analysis, optimization, and management of the whole system (Staniškis, 2005).

McDougall et al. (2003) define the integrated waste management system as a system of waste that has control over:

- All types of solid waste material;
- All sources of solid waste;

And it would include:

- Materials recycling;
- Biological treatment;
- Thermal treatment;
- Landfill.

To guarantee sustainable development regarding solid waste management three areas have to be ensured (Francke and McDougall, 1999):

1. Environmental sustainability
2. Economic sustainability
3. Social acceptance.

The concept of Life Cycle Thinking is appropriate to ensure environmental sustainability, because it is based on a holistic and systematic approach and covers all the phases of the life cycle from cradle to grave (Francke and McDougall, 1999).

Life Cycle Thinking and life-cycle-based approaches have become very important in the sustainability policies of the European Union (EU). According to ISO 14040:2006, LCA methodology is applied to assess the potential environmental impacts and resources used throughout a product's life cycle, i.e., from raw material acquisition to waste management (ISO, 2006).

Life cycle assessment (LCA) can provide qualitative and quantitative information on energy and resources consumption and production, and emissions, concerning a waste management system. LCA can also consider the environmental benefits (related to some options as recycling) (Baumann and Tillman, 2004). Therefore, the LCA tool can be used in policy- and decision-making to compare various potential management strategies in different districts or regions. The waste management is a complex system which cannot be limited to mere hierarchy of options but must include more processes. So, in the planning phase we can define the scenarios with the rate of waste that will be conveyed to the various treatment options/disposal.

As the first phase of a wider study we have carried out a critical review with the aim to provide an overview of how identification of these scenarios in LCA for integrated waste management systems is generally made.

The first part of the paper will introduce the concept of scenario, how it be can classified and how it can be built, as is clear from the literature. Then, we will outline the criteria using to choosing the scenarios of waste management systems under the LCA, as emerged in the literature review carried out. Finally, we will drawn some preliminary conclusive remarks.

2. SCENARIO DEVELOPMENT

The term "scenario" is typically used referring to the "the setting of frame conditions or a description of the system to be modelled" (Pesonen et al., 2000). Many definitions of scenario were given in the past years, in many areas such as the games or the military field. All the definitions in the literature include three basic elements: the description of alternative future situations, the pathway from the present to the future and the inclusion of uncertainty about the future (Pesonen et al., 2000).

Different methods to create scenarios have been defined. The SETAC-Europe LCA Working Group (Pesonen et al., 2000) has proposed the following steps:

1. *Preparation*. Definition of scenario space and key driving forces thought to be important to the future of the domain are listed.

2. *Development.* Definition of key measures (that might include forces such as economic growth, legislative environment, technological changes, etc) and events. Every scenario in the set will include projections of the same measure. Probable events, which can impact the key measures can shape the scenarios in several ways and should also be defined.
3. *Reporting and Utilisation.* The best documentation for scenarios is in most cases a simple set of charts and narratives describing the future presented by each scenario.

In general, scenarios are used by decision makers in the strategic processes introducing into analysis anticipations and assumptions. For scenario generation, forecasting or backcasting are used. According to Fukushima and Hirao, (2002), the forecasting analyzes the situation that can be obtained as a result of certain decisions when you can choose between different options, stating from the existing trends. Instead, backcasting starts from desirable future and looks at how this can be obtained (reverse path). In this way different scenarios are built, that are evaluated through different viewpoints (such as economic and environmental) by decision makers. The results returns to the scenario generation which continues until you get the most favourable one, as shown in Fig. nr. 1.

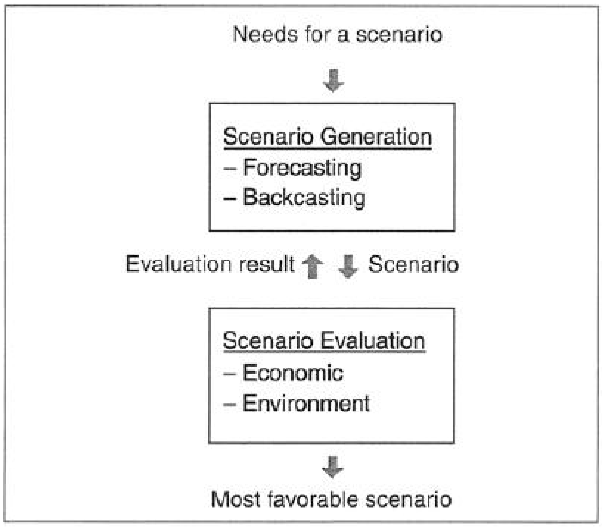

Figure 1. General framework of scenario development (Fukushima and Hirao, 2002).

According to Börjeson et al. (2006), a deeper classification can be made. Three different categories of scenarios can be distinguished: predictive, explorative and normative (summarized in Table nr. 1).

The ‘predictive scenario’ answers the question *What will happen?* in order to predict what is going to happen in the future. Moreover, this type of scenario can answer the question *What will happen, on the condition that the likely development unfolds?* (forecasts) or *What will happen, on the condition of some specified events?* (what-if scenarios), according to the kind of conditions they place in the predictions. When a forecast is performed, it is focused on the assumption that the resulting scenario represents the most likely development. Forecasts can be used as a support in planning and can be influenced by external factors such as economic events, natural phenomena, etc. These forecasts are suitable for short term, due to the fact that uncertainty is reduced in the development of external factors. Instead, in a what-if scenario one investigates what will happen in the near future, given certain events (external events and/or internal decisions) of great importance for future development.

Table 1. Summary of the scenario according to the classification proposed by Börjeson et al. (2006).

<table>
<tr><td rowspan="6">SCENARIOS</td><td rowspan="2">PREDICTIVE
What will happen?</td><td>Forecast
What will happen, on the condition that the likely development unfolds?</td></tr>
<tr><td>What-if
What will happen, on the condition of some specified events?</td></tr>
<tr><td rowspan="2">EXPLORATIVE
What can happen?</td><td>External
What can happen to the development of external factors?</td></tr>
<tr><td>Strategic
What can happen if we act in a certain way?</td></tr>
<tr><td rowspan="2">NORMATIVE
How can a specific target be reached?</td><td>Preserving
How can the target be reached, by adjustments to current situation?</td></tr>
<tr><td>Transforming
How can the target be reached, when the prevailing structure blocks necessary changes?</td></tr>
</table>

The ‘explorative scenario’ answer the question *What can happen?*. Its objective is to study situations that might occur, usually from different perspectives. Typically, a number of scenarios are built to have a wide range of possible developments. Unlike what-if scenario that starts from the present situation to built scenarios, explorative scenario has the starting point in the future and has a long time-horizon in order to analyze deeper changes. We can distinguish two types of explorative scenario: external and strategic scenario. The external scenario answers the question *What can happen to the development of external factors?*, focusing only on factors out of control of the relevant actors, and is used to help the assessment of policies and strategies. Instead, the strategic scenario answers the question *What can happen if we act in a certain way?*, aiming to describe the various possible consequences of strategic decisions. Strategic scenarios focus on internal factors (factors that could affect), and consider the external aspects. They describe how the consequences of a decision depend on what may occur in the future situation

Finally, the ‘normative scenario’ answer the question *How can a specific target be reached?*. The starting point is normative, and attention focuses on some future situations or objectives, and how to achieve them. Depending on how the system structure is treated, we can distinguish a preserving scenario (*How can the target be reached, by adjustments to current situation?*) and a transforming scenario (*How can the target be reached, when the prevailing structure blocks necessary changes?*). The goal of the preserving scenario is to discover how a target can be reached effectively. This can be done with an optimization model, or in qualitative way. The starting point of a transforming scenario, that is a backcasting study, is a high level goal that seems unreachable if the current development continues. A marginal adjustment of the current development is not sufficient and breaking the trend is needed to achieve the goal.

Now, we can identify which of these scenario categories are best suited to the LCA tool considering the background and the foreground system, and the attributional and consequential LCA.

The foreground and background systems are defined, respectively, as the part of the LCA model which include “processes on which measures may be taken as a result of decisions based on the LCA study”, and “processes which are not under the direct influence of the decision maker” (Baumann and Tillman, 2004). An attributional LCA is a model which describe the environmentally relevant physical flows between the system under study and the environment and is like a photo of the actual system; instead, a consequential model try to answer the question “what happens if”, so aim to identify changes in the environmentally physical flow when there are consequences following possible decisions (Finnveden et. al., 2009).

As analyzed by Höjer et al. (2008), forecasts can be used to assess the environmental aspects of all decisions on the background system, but only in its most important part. What-if scenarios are rarely used to describe the background system due to limited knowledge of the technological subsystem and the causal relationships involved. Essentially, a what-if scenario for the foreground system coincides with a comparative LCA. Instead, a strategic scenario can be seen as a comparative LCA that include external scenarios for the background system. In fact, it can be used for assessing different options for the foreground system under the influence of different external scenarios. For the normative scenario, the preserving is used to identify foreground system that meet a specified requirement. In this case options should be limited to decisions regarding the foreground system as are those who can influence decision-makers.

External scenarios are widely used in LCA for a waste management system. For example, when energy by fuel is replaced by energy recovered from incineration. In this case there will be change in the fuel system.

Transformative scenarios are not usually involved in LCA because they are used when great changes in a long-term are needed. For this reason there is a problem of availability of data necessary for an LCA (Höjer et al., 2008).

According to Börjeson et al. (2006) scenarios are developed in a process consisting of three phases that regards: the generation of ideas and data collection, the integration in which elements are combined into sets and the check of the consistency of the scenarios. Each phase is developed using techniques. In short: *generating techniques* aim to generate the collection of ideas, knowledge and views regarding an aspect of the future (examples of such techniques are workshops, panels and surveys); *integrating techniques* integrates parts into wholes and are often based on mathematical models; *consistency techniques* has as its main advantage the insurance of consistency between or within scenarios.

In the LCA framework, the SETAC-Europe LCA Working Group has defined scenario as “a description of a possible future situation relevant for specific LCA applications, based on specific assumptions about the future, and (when relevant) also including the presentation of the development from the present to the future" (Pesonen et al., 2000).

The structure of the scenarios is defined in the first phase of the LCA, the goal and scope definition, but it affects all other phases of the study. The frame conditions of scenarios defined give the framework for the modelling (that is done in the LCI and LCIA), and the models, in turn, have to follow these (Pesonen et al., 2000).

The SETAC-Europe LCA Working Group Scenario development in LCA has proposed two basic approaches in the context of the scenarios LCA: what-if scenario and cornerstone scenario (Pesonen et al., 2000).

The most used approach is the what-if scenario. It is used for studies in which researchers can set defined hypotheses on the basis of existing data in order to compare two or more scenarios. These are often studies that estimate how some specific changes may affect the environmental impacts within the present system. The result is the quantitative comparison of selected options. It is an approach used in case of short or medium term decision-making situations.

The cornerstone approach does not necessarily give a quantitative assessment. It is usually the base for further research as it provides guidelines. Different options are chosen, also very different from each other, that serve as a “cornerstone” of the studied field. Thus, the cornerstone approach gives an indication about the direction and possible alternative paths. It is a tool for long-term planning and, therefore, it has more a strategic objective than the previous approach.

The results of a cornerstone approach are often the basis for further research where the scenarios can be constructed with what-if approach. According to the authors, the cornerstone approach is more appropriate for strategic planning and research for the planning of public policies.

3. CRITICAL REVIEW

3.1. MATERIALS AND METHODS

The literature review carried out was focused on LCAs concerning integrated waste management systems, thus excluding the case studies assessing individual treatment options. Thirteen case studies have been reviewed: 11 of these are European, including 4 Italian papers. All of them are published in international journals, except for two research reports. The review was aimed at highlighting the criteria used to identify the integrated waste management scenarios to be evaluated by comparative LCA. Therefore we have omitted the results of these case studies, which are not relevant here.

3.2. RESULTS AND DISCUSSION

In some studies among those reviewed, the construction of scenarios was made taking into account European and national policies, with special emphasis to guidelines and targets for source-separated collection and landfilling.

In particular, the study by Emery et al. (2007), who analyzed four different scenarios related to Wales, is based just on this criterion. If the reference scenario (100% of waste landfilled) and the 100% incineration scenario are excluded, the other two scenarios meet, respectively, the recovery targets of the "Wise About Waste Wales" for the year 2009/2010, with a combination of recycling and composting, and the targets of the Landfill Directive for the year 2020 through a combination of recycling, composting and incineration with energy recovery.

Also the case of the Japanese city of Kawasaki (Geng et al., 2010) refers to the recycling targets set by the government for 2015, particularly in one of the scenarios analyzed. That study attempts to integrate municipal waste management and industrial symbiosis, through the involvement of firms located in that area. In scenario no. 1, the mixed waste paper is delivered to Corelex Papers for the production of toilet paper. In scenario no. 2 wasted plastics packaging is used by JFE as a reducing agent in steel-making processes. In scenario no. 3, the organic wastes from companies are treated for energy recovery in local biogas facilities. Residues from this process are used in cement production. Finally, in scenario no. 4, three recycling options are combined, with the following recycling rates set at government level: 62% paper, 69% plastics, 30% organic waste. All the remaining mixed wastes are sent to the four incinerators of Kawasaki for combined heat and power (CHP) generation.

In other case studies, the criterion of targets and policies is combined with other types of parameters. The Italian case of De Feo and Malvano (2009) starts from a scenario with a rate of 35% separate collection, which is the minimum level required by the Italian law, to develop nine additional scenarios through stepwise increases of 5%, up to 80%. At this separate collection rate two more scenarios have been identified entailing two different ways of waste treatment.

In the JRC report (Koneczny et al., 2007), referred to some European countries, six scenarios are assumed (in addition to the baseline). Some of these comply with the EU Directives and consider an increase in recycling and composting and the production of refuse derived fuel (RDF) in dedicated plants. Other scenarios include an intensive use of recycling, composting or incineration, respectively.

The recent study about Castellon de la Plana in Spain (Bovea et al., 2010) also combines varioius elements, notably: the recycling targets to be achieved by 2015 according to the "Spanish National Waste Plan", different collection models implemented at a national level, different treatment approaches for the biodegradable fraction, and the residual wastes that are landfilled. Twenty-four scenarios are analyzed and grouped into three systems which differ for the fractions and their shares. All systems are then analyzed considering two alternatives for biological treatment (composting or biogassification) and landfilling, with or without energy recovery (Fig. nr. 2).

SCENARIOS	COLLECTION SYSTEM (see Table 5)			TREATMENT			
				BIOLOGICAL TREATMENT		LANDFILL	
	1	2	3	COMPOSTING (A)	BIOGASIFICATION (B)	WITHOUT ENERGY RECOVERY (a)	WITH ENERGY RECOVERY (b)
1Aa - 1*Aa	x			x		x	
1Ab - 1*Ab	x			x			x
1Ba - 1*Ba	x				x	x	
1Bb - 1*Bb	x				x		x
2Aa - 2*Aa		x		x		x	
2Ab - 2*Ab		x		x			x
2Ba - 2*Ba		x			x	x	
2Bb - 2*Bb		x			x		x
3Aa - 3*Aa			x	x		x	
3Ab - 3*Ab			x	x			x
3Ba - 3*Ba			x		x	x	
3Bb - 3*Bb			x		x		x

Collection system	Bring system (street-side container)	Bring system (high-density materials banks)
1	Rest waste (89.98%)	Glass (2.26%) Packaging (1.85%) Paper/cardboard (5.51%)
2	Rest waste (86.53%) Packaging (4.29%)	Glass (3.29%) Paper/cardboard (5.89%)
3	Rest waste (79.17%) Putrescible (8.26%)	Glass (3.16%) Packaging (1.97%) Paper/cardboard (7.44%)

Figure 2. Alternative scenario proposed by Bovea et al. (2010) and the relative collection system implemented (fraction and percentage of collection).

Similar criteria are used by Rigamonti et al. (2009), who assumed three scenarios: 35%, 50% and 60% source-separate collection. The first one meets the Italian targets for 2007 (year of the study), the second one refers to the level of recycling which had been reached in some Italian districts in the previous years, and the third one is an estimation of the level that could be reached in the medium term at district-scale. From these two studies an additional selection criterion emerges consisting of making reference, as a good practice, to an already tested management model.

As we have seen from the aforementioned JRC case-study, as well as in a study for the Spanish town of Valencia (Bovea and Powell, 2006), another method for scenario definition is to focus on a particular treatment. In this paper, the scenarios proposed in the management plans combine two different types of waste collection (bring system and kerbside system) with different levels of source-separate and residual waste collection. The combination of these different types of collection is the basis for the creation of different scenarios. Besides the baseline scenario, referring to the situation in many areas of Valencia, the scenarios called *1/1v* and *2/2v* were defined.

In scenario *1/1v*, household wastes are divided into three fractions: putrescible waste, recyclable waste, and restwaste. This scenario emphasises the recovery of the putrescible fraction, which is sent directly to a composting facility, while the restwaste is landfilled without energy recovery (scenario 1), or with biogas recovery for energy production (scenario 1v). Glass and paper/cardboard are sent to a reprocessing facility, the light packaging (plastic, ferro-metal and non-ferro metal, paper/cardboard) to MRF (material recovery facilities) where they are separated in 5 fractions. Four of these are sent to reprocessing facilities, and the residues are landfilled with or without energy recovery (Fig. nr. 3).

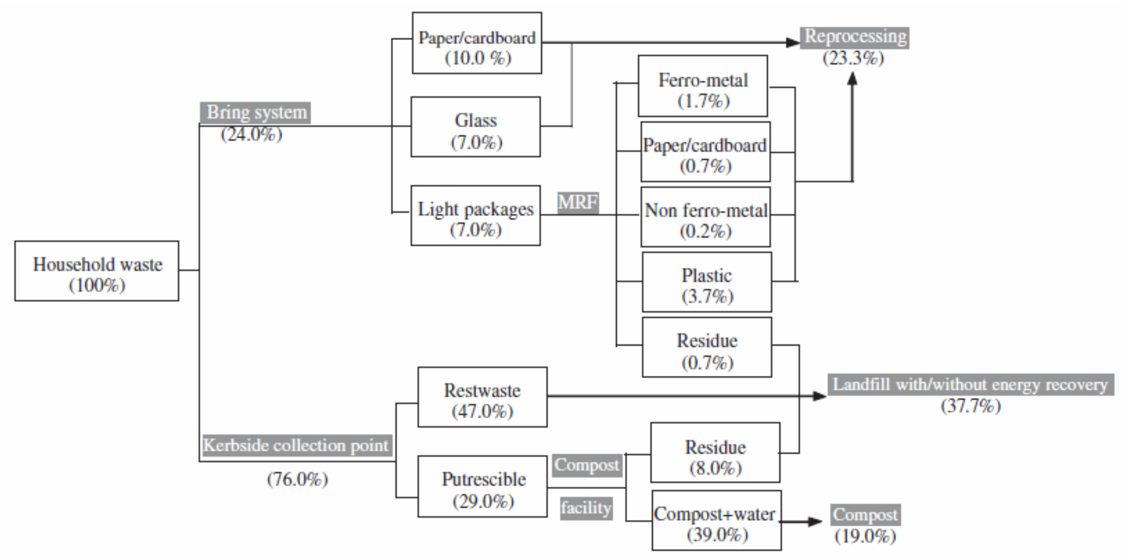

Figure 3. Flowchart of the scenario *1/1v* (Bovea and Powell, 2006).

Scenario *2/2v* emphasises the quality of the recovered materials, both organic and inorganic. The waste is separated into: putrescible, inorganic, recyclable, and restwaste. The putrescible fraction is sent to a composting facility. The inorganic fraction is sent to MRF, where recyclable recovered fractions (ferro-metal, paper/cardboard, glass, plastic) are sent to the processing facility. The residues from these facility, together with the residues from composting, and the remaining restwaste are landfilled without energy recovery (scenario 2) or with gas recovery for energy generation (scenario 2v) (Fig. nr. 4). This study shows that each fraction is sent to a single specific treatment.

The 2008 case study of Tianjin (Zhao et al., 2009) do not refer to any criteria for the choice of a few percentages. Excluding the baseline scenario S0, and with the exception of the S3 scenario, where a recycling rate of 30% was chosen according to data from U.S. EPA, and the S2 scenario, in which all waste is considered to be incinerated, for scenarios S4 (centralized composting) and S5 (anaerobic digestion) an arbitrary separation rate of 50% was assumed. Finally, the last scenario (S6) combines S3 and S5.

The case study of Torino District (Blengini et al., 2008), in Italy, offers four scenarios where recycling is emphasised. In the first two scenarios the separate collection is fixed at 52.1% and in the other two at 65.7%. Other processes involved are incineration with energy recovering, pre-treatment and landfilling. However, how these rates were set was not specified.

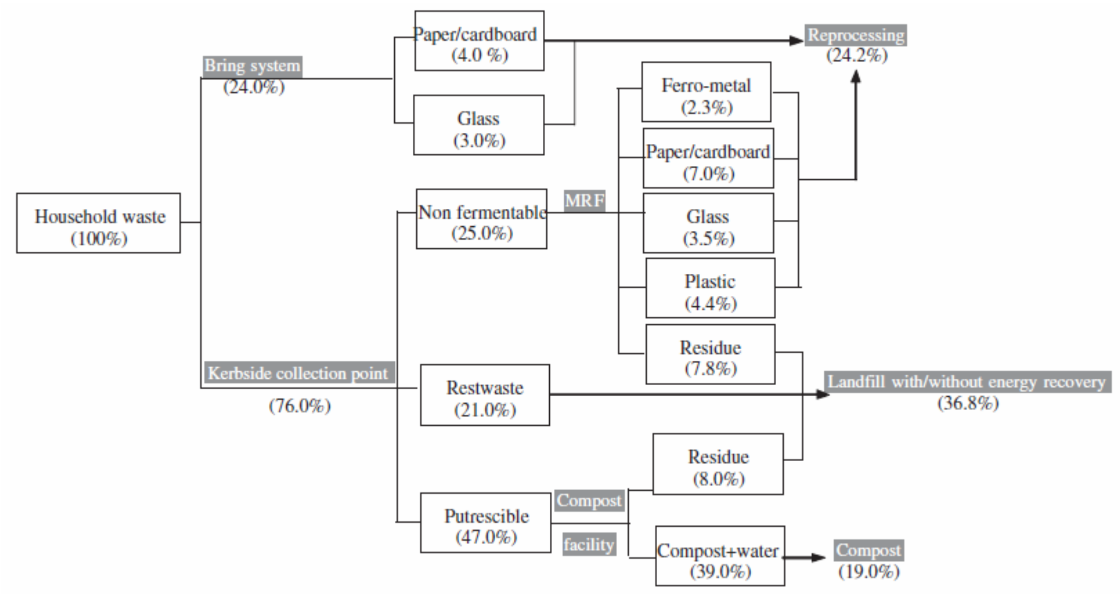

Figure 4. Flowchart of the scenario *2/2v* (Bovea and Powell, 2006).

In other two case studies scenarios were defined arbitrarily, disregarding criteria inspired by regulations, planning or best practices. This is the case for the Austrian study by Salhofer et al. (2007) where for each waste stream (such as waste paper, biogenic waste, residual waste, etc) different options were considered for collection, recycling and treatment. Then, eight scenarios were defined by combining more or less recycling of recyclables (e.g. waste paper or plastics) with two different treatments options for other types of waste (e.g. residual waste): MBP (mechanical-biological pre-treatment) and MSWI (municipal solid waste incinerator). After the team of experts has listed the options for each waste stream, final options were chosen and allocated to the various scenarios in collaboration with the designers and with the agreement of all parties involved. The term scenario is used to indicate a combination of options for individual waste streams, including effects on other waste streams.

In the Swedish study (Eriksson et al. 2005), the newspapers (75%), glass (70%) and metal containers (50%) are source separated and recycled outside the system studied. These processes are common to all scenarios and are therefore excluded from the system. The rest is included in the residual waste within the boundaries of the system. With regard to biodegradable waste, plastic (HDPE) and cardboard containers, the maximum limit practically attainable of separate collection in households (70%) was chosen, even if the actual percentage of source separation in Sweden had been estimated around 30%. The percentage of 70% is justified by the method of refining scenarios designed to bring out the differences between the various strategies.

A different case is the one developed for the Bologna District (Buttol et al., 2007) in which the building of two new incinerators is assessed, and scenarios are obtained by a projection of current data to the time when the plants will start to operate, taking in to account treating capacity of incinerating facilities.

Finally, another Spanish case (Muñoz et al., 2004) proposes three scenarios. However, the shares of each waste fraction sent to the various processes are not specified and general choice criteria – such as waste generation, environmental regulations at different levels, technological capabilities, the local context, potential market for the materials recovery – are referred to.

4. CONCLUSIONS

This review has confirmed that comparative studies for the assessment of integrated waste management systems consider discrete sets of scenarios, which are not identified according to scientific approaches, but are often based on rather unclear and arbitrary criteria. In any case, such criteria do not take into account all possibilities. In fact, however broad the spectrum of identified combinations can be, the best theoretical scenario might just not be included.

Therefore, it is appropriate to develop a tool that integrates LCA and that identifies the best scenario, from an environmental perspective, among all possible. This tool could be a useful support for decision making.

However, a major problem is that the traditional LCA models are static. This means that, in an integrated waste management system, they cannot give us information about the right time for investments in waste processing plants. Furthermore, LCA can identify the best management strategy to address the current needs of society, but investments in waste processing facilities are huge and cover many years. This means that a system currently available may not be any more helpful to meet the needs of future society. The problem can be solved through methods for future studies, such as those proposed by Börjeson et al (2006), and described previously.

A promising answer can be found, for example, in linear programming models, as discussed by Mercuri and Raggi (2004). The strength of these models is that, in principle, any combination of waste and treatment is omitted. On the other hand, its weakness is that the optimisation process should be carried out for a specific impact category at a time. That model could be improved and extended by simultaneously considering various impacts, and by also including economic issues.

Ekvall et al. (2007) state that the LCA tools are steady-state type and are not able to tell us what is the optimum mix of waste management. For example, if recycling is considered the best solution, this is not always true. With increasing amounts of waste, the better solution might be different due to, for example, the distance from plant, transportation costs, etc. Linear-programming (LP) models are linear models that account for boundary conditions. Optimising LP models for waste management systems can be integrated in an LCA. The ORWARE model and MIMES/waste are examples of LP models that integrate the life-cycle perspective and, also are tools for LCA (Eriksson et al., 2003). However, according to Ekvall et al. (2007), an LP model is not a very precise representation of the real system. Non-linear programming is useful for evaluating more complex non-linear relationships. But, a more complex system requires more data and high quality data for an LP model can be difficult to obtain. It is, for example, difficult to estimate the maximum collection rate that can be achieved through bring systems (Ekvall et al., 2007).

The project will continue on this path, trying to figure out if such an instrument can be identified and, if so, how to develop it.

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