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No zero burden assumption in a circular economy

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ABSTRACT

A majority of previous studies on environmental problems caused by waste generation have focused on waste disposal issues without fully highlighting the primary reasons behind the problems. As a consequence, efforts to reduce these problems are usually directed towards the stakeholders that provide waste treatment and disposal instead of the stakeholders that contribute to waste generation. In order to detect connections between different problems of sustainability and to suggest measures which may contribute to their solutions, this study provides a simplified overview of the mechanisms behind waste generation and management. The results from the study show that the only way to eliminate problems of sustainability is to apply an upstream approach by dealing with the primary problems which occur in the early stages of the system (e.g. overconsumption of products, as well as use of finite resources, toxic materials, and non-recyclable materials). By dealing with these problems, the emergence of secondary problems would be prevented. Thereby, stakeholders who have the highest possibility to contribute to the sustainable development of the waste generation and management are the stakeholders from the origin of the product’s life cycles, such as product developers, manufacturing companies, product users and policy makers. Different trade-off

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situations such as contradictions between economics, recyclability, energy efficiency, make it even harder to deal with issues of sustainability related to the system and to detect the stakeholders who may contribute to the development.

One of the main conclusions from this study is that when transforming society towards a circular economy, the traditional view of separate systems for production and waste management must be changed. In order to refer to all problems of sustainability and also cover the top steps of the waste hierarchy, life cycle assessment of waste management should include manufacture and use of products ending up as waste. Waste entering the waste management system with “zero burden”, by releasing the previous actors of the waste life cycle from any responsibility related to the environment (i.e. by shifting the total environmental burden into the waste management system), does not capture the problems with waste generation.

**Keywords**

Waste management, waste prevention, system approach, upstream thinking, resource management, sustainable development

**Abbreviations**

LCA - Life cycle assessment; Waste GM system – waste generation and management system

1. Introduction

One of the most frequently cited definitions of sustainability is the one presented in the report of the World Commission on Environment and Development “Our Common Future” (Brundtland, 1987). In this report the concept of “sustainable development” is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Based on this definition many other interpretations
have been developed. One of those interpretations is the Framework for Strategic Sustainable Development (FSSD), the result of an ongoing international consensus process between scientists and leaders in business and policy. It was initiated by the international organization The Natural Step (The Natural Step, 2015; Robèrt et al., 2007) in 1989. FSSD revolves around robust operational principles covering all elements of social and ecological sustainability, and contains guidelines for economically strategic ways to comply with those principles. The sustainability principles are then used as boundary conditions for re-design. The principles are stated as follows:

“In a sustainable society, nature is not subject to systematically increasing

(1) concentrations of substances extracted from the Earth’s crust,

(2) concentrations of substances produced by society,

(3) degradation by physical means

and, in that society

people are not subject to conditions that systematically undermine their capacity to meet their needs”.

The last principle (the social principle) has lately been elaborated into five social principles (Missimer et al., 2017a, Missimer et al., 2017b). The new social principles are that in a socially sustainable society, people are not subject to structural obstacles to: (4) health, (5) influence, (6) competence, (7) impartiality and (8) meaning-making.

The sustainability principles were used during the evaluation of many tools and concepts for sustainable development, and used as a basis for many case studies which include sustainable
development (Robèrt, 2000; Holmberg et al., 1996; Robèrt et al., 1997; Holmberg and Robèrt, 2000; Robèrt et al., 2007).

Despite the fact that there will always be some waste that is not possible to recycle, and that every material at some point will reach the end of its life and become waste (Sundberg, 2013), the *circular economy* can be considered as a long-term solution to these problems (European Commission, 2015). The circular economy is based on the idea that the materials from which products are made can be resurrected by entering a second life as recycled content in new products. In this way the economic value of the materials and resources are maintained, and the generation of waste is minimised. In order to provide a platform for development of a more circular economy, the European Parliament and the Council of the European Union (2006; The European Parliament and the Council of the European Union, 2008) have established a framework for handling of waste, known as the European *waste hierarchy*. The waste hierarchy shows in which order the different measures related to waste generation and disposal should be performed. The hierarchy consists of five steps, from the most favourable to the least favourable measures: prevention, reuse, material recycling, energy recovery and landfill disposal. In some research remanufacturing is also recognised as a measure which in most cases is more favourable then material recycling (World Trade Organization, 2005; Sundin et al., 2009). Remanufacturing (which can also be considered indirect reuse) is a process in which a no longer functioning product is disassembled, rebuilt and refurbished to be usable again. In this way the environmental problems which would arise at the end of the life cycle are avoided before they occur (World Trade Organization, 2005).

The recommendation that waste prevention should be a clear priority in waste management was first made by the European Commission in 2005 (COM, 2005). There are several studies conducted on waste management systems applying life cycle assessment (LCA) or a system
perspective. However, there is a lack of studies which have addressed waste prevention in relation to LCA (Laurent et al., 2013a). Laurent et al. (2013a) performed a critical review of 222 published LCA studies and found that only a few of them (Gentil et al., 2011; Nessi et al., 2012; Slagstad and Brattebø, 2012) explored the possibilities of waste prevention.

1.1 Aim

In this study a waste management system is expanded by also including the stakeholders connected to waste generation. In order to avoid any misunderstanding regarding the system boundaries applied in this study, the analysed system will be called the “waste generation and management system” (“waste GM system”) below.

The main aims of the study are to suggest and discuss measures which may contribute to the solutions of the problems of sustainability in the waste GM system and to discuss challenges which may arise in form of possible trade-off situations.

In order to fulfil these aims the authors present waste treatment and disposal processes, as well as the stakeholders that may directly or indirectly (e.g. by influencing other stakeholders’ decisions) contribute to sustainable development of the waste GM system, highlight the primary problems of lack of sustainability in the system (i.e., the problems which arise in the initial stages of the system), and discuss how these primary problems are connected to the problems of sustainability which arise in the following stages of the waste GM system.

Even though the focus of the study is on the Swedish waste GM system, the conclusions can be applied to other waste GM systems with similar properties as well. The results from the study can be used to evaluate existing and forthcoming measures and policy instruments, or as a basis for further research related to strategies for sustainable development of the system.
2. Methodology

The methodology includes field study, data collection, and system analysis of the waste GM system.

2.1 Field study

Field study was performed through a literature review of published journal articles and reports in the area of waste management research, as well as through a literature review of official documents related to this area published by the European Commission, the European Parliament and the Council of the European Union. We searched online databases to identify articles published on the topic of sustainable development of waste management systems. We focused on the most relevant studies within scientific sources published in peer-reviewed journals. The criteria for deciding which studies need to be considered were relevance with regard to the aim of the study, full-text availability, research discipline and date of publication. After selecting the articles we identified additional relevant studies through manual screening of cross-referencing. From a large number of studies performed in the area of waste management research we chose to pay special attention to those that include LCA application.

2.2 Data collection

The data presented in the results section were collected from Statistics Sweden (SCB) and from relevant publicly available reports published by the Swedish Environmental Protection Agency (Naturvårdsverket), the Swedish Waste Management and Recycling Association (Avfall Sverige), and an independent research and consultant company called Profu. The reports were published during the period from 2012 to 2017.
2.3 Systems analysis

A waste GM system is often complex, which requires a system approach (such as LCA). This is in order to enable better understanding of the system and above all, in order to handle possible trade-off situations which may occur between various sub-optimal choices that concern the analysed system (Ny et al., 2006; Byggeth and Hochschorner, 2006). Ny et al. (2006) strongly recommended applying the FSSD perspective (see section 1) on the LCA when dealing with sustainability issues related to the management of materials and products. This opens up a possibility for developing strategic cooperation between stakeholders in the system, i.e. for transforming the LCA to a “Strategic Life Cycle Management”. According to Broman and Robèrt (2017), applying the FSSD perspective includes a number of advantages. Some of the advantages are that the FSSD aids more effective management of system boundaries and trade-offs, enables easier avoiding of unknown problems, and opens up a possibility for more effective collaboration across disciplines and stakeholders (such as sectors, departments and organisations) which may have different values and preferences. For more details see Broman and Robèrt (2017). However, Robèrt (2000; Robèrt et al., 2002) pointed out that the framework can only be used for overall strategic planning, and that it cannot be an alternative to activities, concepts and tools for sustainable development. Once the framework has been applied, actions should be taken and different tools, such as metrics that are designed to indicate and audit progress towards sustainability (i.e. ecological footprinting, Factor X) should be used to monitor the process.

The identification of the system, system boundaries, system surroundings, and the interrelations between the system and system surroundings, as well as between the elements within the system should be made considering the specific research questions. It is also important to consider how the system may change over time, since the changes may open up
a possibility for development of new strategies or even precipitate a necessity for this (Churchman, 1968; Bertalanffy, 1972; Ingelstam, 2002).

Besides the possibility to detect and more easily deal with trade-off situations, another reason why the system approach is important when dealing with sustainability issues is a possibility to detect the primary problems by “looking upstream” in cause–effect chains. These primary problems usually cause new (secondary) problems further in the “life cycle”. The “upstream” approach opens up a possibility for solving these primary problems by affecting the stakeholders and processes at the beginning of the system (“life cycle”) rather than dealing with secondary problems by “looking downstream”, which usually is one of the basic errors during sustainable planning (Robèrt, 2000; Robèrt et al., 2007). Another important advantage with applying the “upstream approach” is that the complexity of the system is usually lowest at the beginning of the system (“life cycles”), which makes it easier and more possible to introduce measures and changes in order to solve the problems. Furthermore, new problems which may occur in the future will be avoided as well (Robèrt, 2000; Robèrt et al., 2007).

2.3.1 Application of the system analysis
The Swedish waste GM system is a part of the European waste GM system and as such highly subordinate to the European Energy and Climate policy (Naturvårdsverket, 2012). The reason why the focus of the study is not on the whole European waste GM system is due to varying local conditions in different European countries. According to Vergara and Tchobanoglu (2012), the local conditions which are important to consider when developing effective waste management strategies are:

- characteristics of local energy systems - examples are development of biogas market (e.g. biogas demand in the local transport sector or existing of the gas network), as well as development of district heating systems;
- waste composition and quantity, which, according to Christensen (2011) and Laurent et al. (2013b) vary depending on cultural, climatic, and socioeconomic conditions;

- different traditions and existing climate and energy strategies, which usually depend on the available local energy sources and on the local institutional coherence.

The Swedish waste GM system consists of a number of components (e.g. stakeholders and processes). The stakeholders interact with each other and their actions or decisions influence waste generation and treatment. As a result of their interdependence, every action taken on or by a stakeholder may have not only a direct consequence on this stakeholder but also secondary effects on other stakeholders and processes of the system. The interactions between the elements within a waste GM system and the interrelations between the system and systems surrounding can be material, energy, information, money and policy flows.

3. Results and discussion

Figures 1 and 2 provide a simplified overview of the Swedish waste GM system and its surroundings. The figures provide an overview of the most important stakeholders and processes, as well as material, energy and policy measure flows. The figures are based on a number of Swedish reports which include statistics and detailed descriptions of the Swedish waste GM system. While the system consists of the elements which may interact with each other, the system surroundings consist of elements and stakeholders which can influence the system’s performance but on the other hand cannot be directly influenced by the system. One example of such a stakeholder in the waste GM system is policy makers. The policy makers may have a large influence on all elements and stakeholders in the system but cannot be directly affected by the stakeholders inside the system.
Figure 1. A simplified overview of the Swedish waste generation system.
Figure 2. A simplified overview of the Swedish waste treatment and disposal system.
3.1 Stakeholders and processes in the Swedish waste generation and management system

Based on its origin, the waste treated in Sweden can be divided into different parts which are presented by parallel life cycles in Figure 1. Due to different stakeholders included in their life cycles different strategic approaches should be taken for each part of the waste.

3.1.1 Domestic waste from consumption

This waste originates from products consumed by product users (households and services, e.g. restaurants, companies, schools). In the year 2012, the generated domestic waste from consumption was approximately 23% (4.2 million tonnes in households and 2 million tonnes in services) of the total amount (27 million tonnes) of waste generated in Sweden excluding waste from the mining sector (Stenmarck et al., 2014).

A product’s life cycle generally consists of the following stages: product development, raw material production (extraction and transformation), production and packaging (manufacturing and assembly), distribution, use and end of life (product disposal). Since the use of finite resources and emissions are associated with each life phase, the environmental aspect of the whole life cycle should be considered (International Organization for Standardization, 2006). The stakeholders that are directly involved in these stages are: product development companies, manufacturing companies, product users, and stakeholders involved during the transportation of the products and the waste, as well as stakeholders involved in waste collection and disposal (presented later in this section).

If the product is produced in Sweden, all stakeholders included in the life cycle of waste generation are included in the system, starting with the product development companies and manufacturing companies (see Figure 1). This opens up a possibility to deal with primary problems of sustainability in the product’s life cycle by looking upstream in the cause-effect chain (e.g. to influence the choice of the feedstock material which product development companies make or to influence the choice of the type of the energy which the manufacturing
companies use), instead of dealing with secondary problems of sustainability which arise later in the life cycle as consequences (see section 2.3).

However, if the product is imported to Sweden, it is not always possible to influence the production directly, especially in countries which are not EU members. According to Statistics Sweden (SCB, 2013), the biggest group of imported products in the year 2012 was machinery and transport equipment (e.g. industrial machinery, electronics and passenger cars). This group of products can be of specific interest for further research when discussing sustainable development of the waste GM system, particularly since approximately 10% of the hazardous waste generated in Sweden in 2012 (approximately 275 ktonnes) originated from discarded vehicles (Stenmarck et al., 2014). Theoretically, there is a possibility to include new criteria in regulations for importing products to Sweden. However, the materials from which the imported products are made cannot be controlled sufficiently well and this would also be partly in contradiction to principles of the free market.

It is also important to mention that there is a group of products which can be considered our “old sins”. These products are already included in the system, and there is no possibility to apply the upstream approach in order to prevent the secondary problems since mistakes at the beginning of the product’s life cycle (such as e.g. choice of fossil-based or toxic raw materials) were probably already made. The only way to reduce negative influence on the environment caused by the waste from consumption of these products is through better waste sorting and recycling, and through better waste treatment and disposal.

3.1.2 Domestic waste from production (industrial waste)
Stakeholders that participate in generation of the waste are the manufacturing industry in which the waste in generated, as well as the producers of the products used during manufacturing. Industrial waste generated in Sweden in 2012 was approximately 6 million tonnes (excluding the mining sector). A larger part of the industrial waste was generated in
the pulp and paper industry, the metal industry and the food, beverage and tobacco industry
(approximately 29%, 26% and 19%, respectively) (Naturvårdsverket, 2012; Stenmarck et al.,
2014). Approximately 37% of the industrial waste was treated internally. Some
manufacturing companies have internal material recycling included in the production process
(e.g. some manufacturers of rubber and plastic products, and manufacturers of fabricated
metal products), while some companies recycle waste from other industries (e.g. cement and
lime industry) (Stenmarck et al., 2014).

3.1.3 Imported waste
The amount of imported waste to Sweden in 2012 was approximately 1.8 million tonnes
(SCB, 2017a). According to Naturvårdsverket (2016), the largest share (more than 85%) of
this waste is imported for energy recovery. The most obvious way to influence this part of the
waste is to include criteria for which waste should be allowed to be imported. According to
Profu AB (2013), the GHG emissions during the waste transportation are insignificant
compared to the reduction of GHG emissions due to the energy recovery when the landfill
disposal abroad is the alternative waste treatment. Therefore, when choosing which waste
should be imported, the criteria should be based on information about alternative waste
treatment and disposal in the exporting countries instead of the distance of the country from
Sweden. According to Profu AB (2013), when the waste is imported from UK and Italy
(where landfill disposal is the most usual waste treatment), the reductions of global GHG
emissions are approximately 250 kgCO₂eq/ton waste and 550 kgCO₂eq/ton waste, respectively.
When the waste is imported from Poland, the reduction is even higher at
1100 kgCO₂eq/ton waste (Profu AB, 2013). These numbers are based on assumptions that the
waste is used as a fuel for CHP production, and that the district heating and electricity
produced would replace fossil fuel-based district heating and electricity production.
Import of waste is often much debated in media. It seems that many people think that each country should take care of its own waste. However, these same people think it is perfectly alright to import oil, natural gas etc. leading to high emissions of CO₂. This is contradictory and confusing. From a more logical point of view it can however be questioned if export and import of waste is sustainable. In the short term the answer is “yes” given that the treatment method in the exporting country is less preferable than the treatment in the importing country (see above). But in the long term, exporting countries should develop their own waste treatment capacity in line with the waste hierarchy. If high quality waste treatment is present in most places, long distance transports to other countries will not be a preferable option. However, minor volumes may have to be transported across borders due to temporary insufficiencies in treatment capacity such as plant break-downs, etc.

### 3.1.4 Waste management system

*Municipalities* and *policy makers* (Figures 1 and 2) are also stakeholders which are included in the waste GM system.

In Sweden, *municipalities* have an active role in the long-term sustainable development of the waste management system. Most Swedish municipalities have their local plans for sustainable development of the waste management systems, which are based on the Swedish national plan. They are also responsible for collection and disposal of a part of the household waste (Avfall Sverige, 2015). The exceptions to this are some parts of the waste for which the producers are responsible, such as packaging, newspaper, office paper, agricultural plastics, tyres, end-of-life vehicles, waste from electrical and electronic equipment, and batteries (Naturvårdsverket, 2012; Stenmarck et al., 2014; Avfall Sverige, 2015).

*Policy makers* are very important stakeholders in the system surroundings, since through different policy measures they can influence all stakeholders in the waste GM system, and as such may play a decisive role for sustainable development. The policies that affect the waste
management system are not only the waste-related policies, such as e.g. ban on landfilling, landfill tax, and extended producer responsibility, but also the policies related to other sectors (e.g. district heating and transport sector). Swedish national legislation related to the waste management system is highly subordinate to the European energy and climate policy, which is governed by a number of international directives and protocols (Naturvårdsverket, 2012). While the Swedish national legislation tends to be more detailed and specific using different administrative and economic policies, the European energy and climate policy exerts moral rather than legal pressure, by presenting a number of broad statements of intent. A detailed discussions of the policies related to waste management can be found in Bisaillon (2009).

**Material recycling industry**

Material recycling is a process where the materials from the waste are resurrected by entering a second life as recycled content in new products. This process plays a decisive role for sustainable development of a society, since it leads to reduced use of finite resources and virgin materials, as well as lower energy use in the manufacturing companies (Avfall Sverige, 2015). According to Avfall Sverige (2015) the potential for material recycling of household waste is approximately 60% and 80% of the waste, depending on whether or not food is already sorted out from the waste. Of the total waste amount, excluding mining waste, in 2012 approximately 8 million tonnes of waste were material recycled. Approximately 4.5 million tonnes of this waste were used as construction material (e.g. for road construction), including the ash from the waste incineration in the plants that provide energy recovery (SCB, 2017b; Stenmarck et al., 2014).

**Biogas production industry**

In 2012, approximately 673 thousand tonnes of waste was biologically recycled in Sweden (Avfall Sverige, 2016). Development of the biogas market in the local transport sectors has a
decisive role for introduction and development of biogas production from solid waste in Sweden. Furthermore, cooperation between the local public transportation sectors (busses and taxis) and local biogas producers ensured the biogas market for the producers and increased security of biogas supply for the transport sectors; examples of this kind of cooperation can be found in some municipalities in Sweden, e.g. Linköping (Olsson and Fallde, 2015; Fallde, 2011).

**District heating companies**

Excess heat from incineration plants which provide waste treatment and energy recovery is used in several district heating systems in Swedish municipalities. In 2014 the total input capacity of these plants in Sweden was approximately 6.3 million tonnes of waste annually (Avfall Sverige, 2014; SEA, 2015), while the amount of domestic combustible waste was approximately 4.5 million tonnes. According to Profu AB (2013), until the year 2017 the total input capacity of these plants in Sweden is expected to increase to approximately 7 million tonnes of waste annually, which would increase the demand for waste import. Despite the fact that waste treatment is the primary process when the waste is incinerated, and that a large share of the waste treated in the plants would probably be incinerated anyway (e.g. non-recyclable waste, waste from hospitals), the International Energy Agency (IEA, 2005) defines the waste as a fuel. This has as a consequence the current recommendation from Pipatti et al. (2006) to allocate the total CO₂ emissions from waste treatment to the district heating producers.

**Cement, lime, and paper and pulp industry**

The cement, lime, and paper and pulp industry may also provide energy by using energy-rich waste as fuel. According to Stenmarck et al. (2014), in 2012 the largest amount of discarded tyres (approximately 35%) was used as fuel by the cement industry. The other types of waste
which may be used as fuel in the above-mentioned industries are plastic waste, meat and bone meal, and certain types of hazardous waste (e.g. waste oil and impregnated wood).

_Treatment of the hazardous waste_

During the year 2012, approximately 65 thousand tonnes of hazardous waste from was collected in Sweden (Avfall Sverige, 2015). The hazardous waste is usually the waste which includes paint, chemicals, oil and toxic substances, as well as carcinogenic and flammable waste. While private persons have a responsibility to sort this waste properly, the municipalities have a responsibility to transport it to special facilities for treatment. This facilities provide treatment (to alter the character or composition of hazardous wastes), temporary storage, or permanent containment of hazardous waste in specially constructed units designed to protect groundwater and surface water resources. During the year 2012, approximately 2.7 million tonnes of hazardous waste was generated in the industry sector in Sweden (SCB, 2017c). However, according to Avfall Sverige (2015), the information is insufficient.

_Landfill treatment organisations_

The amount of landfilled waste has significantly decreased during the last fifteen years (excluding waste from the mining sector). This happened because of the bans on landfill disposal of combustible and organic waste, which have been in effect since 2002 and 2005, respectively. In 2012 only 0.8% of household waste was landfilled (33 thousand tonnes) in Sweden. The total amount of waste landfilled, including industrial waste and ash from the district heating companies, was approximately 1.56 million tonnes (Avfall Sverige, 2015; SEA, 2015).
3.2 Problems of sustainability and solutions

Problems occur in different stages of the waste GM system. Some of the problems which occur at the beginning of the life cycles included in the system (called “primary problems” in section 2.3) are:

- increased use of products due to increased population and economic development (Hoornweg and Bhada-Tata, 2012);

- use of toxic materials – e.g. for electrical utilities (hydrogen fluoride, nitrogen dioxide and thallium) and for paper and paperboard mills (mercury, beryllium, and hydrogen fluoride) (Hertwich et al., 2010);

- use of finite resources as feedstocks for material production, especially in the case when the material is non-recyclable and as energy sources (e.g. during manufacturing);

The average household consumption in Sweden has increased 36% during the last ten years (calculated based on the indicators for household consumption for 2006 and 2016; SCB, 2017d), despite the fact that the number of inhabitants has increased by less than 10% (SCB, 2017e). This results in an increased waste generation as well. According to the Swedish Environmental Protection Agency (Naturvårdsverket, 2012) there is a prognosis that the amount of the waste may double by the year 2030. Although the Swedish Environmental Protection Agency has drawn up a new national waste management plan in the year 2012 (Naturvårdsverket, 2012) and supplemented it with a waste prevention programme in 2014 (Naturvårdsverket, 2014), later analysis have not showed any major impacts on the stakeholders (Naturvårdsverket, 2017). Reliable statistical data about the use of toxic materials, finite resources, and non-recyclable materials as feedstocks for material production is hard to find. Making statistical basis with this data should be a further step toward solving
the primary problems related to the sustainability of the waste. Another barrier related to the solution of these problems is that most of the documents which discuss responsibility of the product companies mostly refer to the responsibilities related to the waste disposal and providing information to the product users.

The primary problems related to the sustainability will in turn lead to a number of other problems which occur in the following stages of the life cycles (called “secondary problems” in section 2.3). Some of the most frequently mentioned secondary problems connected to waste generation and disposal are:

1. Fossil-based GHG emissions during incineration of the waste, which leads to global warming — violation of the first sustainability principle.

2. Emissions of heavy metals — violation of the first sustainability principle.

3. Emissions of synthetic substances such as halocarbons from discarded cooling systems — violation of the second sustainability principle.

4. Methane emissions from organic waste in open dumps and landfill disposals (Bogner et al., 2007) — violation of the second sustainability principle.

5. Environmental degradation and land occupation as a consequence of landfilling — violation of the third sustainability principle.

6. Human toxicity due to exposure of chemicals and hazardous particles from the waste (Giusti, 2009) — violation of the fourth sustainability principle.

Endpoints of the problems in the waste GM system are different damage categories: negative impacts on human health, impacts on ecosystem quality, climate change due to global warming, stratospheric ozone depletion, and shortage of natural resources (e.g. fresh water,
minerals). These damage categories are summarized and discussed in detail in Hertwich et al. (2010).

By solving the primary problems, the problems which occur in the following stages of the system may be prevented or reduced. Schöggel et al. (2017) and Shapira et al. (2017) argue that a comprehensive approach which use different sustainability criteria should be applied in the early phases of a product development. This would allow identification of opportunities for mutual benefits and exchange of knowledge between different stakeholders. The environmental impact which a product has over its life cycle is largely determined by decisions taken during the design process. This highlights the responsibility of the product development companies to design products with lower environmental impact. The choice of raw material is one of the characteristics which may have a decisive role from this viewpoint. Some of the other characteristics which may contribute to reduced environmental impact, according to the European Commission (2015), are to make the products more durable or easier to repair, upgrade or remanufacture. While Ashby (2013) argues that the starting point of a product design is actually a market need, Sundin et al. (2009) pointed out that even the manufacturing companies have a responsibility to adapt the products for product service system, maintenance, repairs and remanufacturing. This shows that even in this initial stage of the product life cycle, the product users can contribute to the sustainable development of the waste GM system by influencing the choices made by product designers (Figure 1).

The primary problems mentioned above can be solved by applying two basic mechanisms: dematerialization and substitution. By applying dematerialization the waste amount would be reduced, and by applying substitution the waste composition would be changed.

Actions related to dematerialization are: reduced product consumption, increased reuse of products and increased material recycling. Product users have an important role for
implementing these three actions. One way to introduce these actions is by introducing administrative or economic policies (e.g. by implementing weight-based billing in household waste collection). The other possible way, which according to some studies is even more efficient (Widegren, 1998; Hopper and Nielsen, 1991; Berglund, 2005), is to increase people’s awareness of the environmental problems which they cause. This would preferably lead to reduced waste generation due to lower product consumption and increased product reuse, as well as to increased material recycling due to better material sorting provided by product users. However, possibilities to perform these measures are highly dependent on the factors and product characteristics which are determined in the earlier phases of the product’s life cycles, such as the life length of the product and if the product is produced from a recyclable material. This means that the product development and manufacturing companies also have a decisive role for performing the measures mentioned above. They have also a responsibility to provide information which may further promote behaviour of the product users regarding waste disposal (Figure 1).

The second mechanism which can be applied in order to solve problems of sustainability in the system is substitution. One example of actions related to substitution is use of biologically based materials (e.g. plastics derived from renewable biomass sources) as an alternative to materials produced from non-renewable resources (Petersen et al., 1999). This measure is interesting when considering waste which originates from fossil-based materials and cannot be recycled (e.g. hospital waste, diapers). Furthermore, even with improved material recycling technology, it is not expected that all recyclable materials can be recycled endlessly. Other examples of substitution are use of renewable energy in the manufacturing companies instead of fossil fuel-based energy, use of recyclable materials as product feedstock instead of non-recyclable materials, and increased use of recycled content instead of virgin materials in new products (which would prevent rejecting properly sorted waste
from the recycling industry due to undeveloped market for the recycled materials). Use of recyclable materials as product feedstock and increased use of recycled content in new products are actions which are related to dematerialization as well, since these actions lead to an increased share of recyclable waste and to a larger market for recycled materials. Product designers (product development companies) have an important role in implementing the measures related to substitution, although their choices may be greatly influenced by market need and policy measures.

### 3.2.1 Possible trade-off situations related to the system

However, not all of the actions mentioned above would necessarily lead to sustainable development. A product design process should (but unfortunately in most cases does not) include LCA and evaluation of a number of impact categories related to all LC stages, such as resource use and emissions during product production, transport, use and disposal (e.g. resource depletion, global warming potential, acidification, human toxicity, ozone depletion). As a consequence, there are a number of different types of trade-off situations which may occur when sustainable development of the waste GM system is considered. These trade-offs are usually hard to detect and evaluate, but they have to be considered because sustainable development of the waste GM system is restrained by them.

Probably one of the most common types of trade-offs is between costs and benefits from an environmental perspective. Examples of these trade-offs are cases when materials with low environmental impact are more expensive than conventional materials, cases when waste is not material recycled because of high costs required to provide the recycling (e.g. the waste was properly sorted but rejected by the recycling industries), and cases when remanufacturing is not provided because of the costs related to the process. Policy makers can play a decisive role in overcoming these types of trade-offs, since that can be done by introducing
appropriate economic policy which would lead the development in the right direction by making the environmentally sound choice more economic.

However, there are other types of trade-offs which can be solved only by compromising and choosing the less bad solution after comparing a number of competing factors (Byggeth and Hochschorner, 2006). Some examples of these trade-offs related to environmental impact are contradictions between recyclability, energy efficiency (during production or transportation), use of bio-based raw material, reduced amount of packaging, and longer lifespan of the product. These trade-offs are usually reflected further on the product users as difficulties to decide which environmental aspects are most important when they need to choose which product to purchase (Commission for Environmental Cooperation, 1999).

There are a number of case studies which analysed the above-mentioned trade-off situations. In one of these studies Humbert et al. (2009) compared the environmental impacts associated with two packaging alternatives used for baby food by applying the LCA: plastic container and glass jar. The whole life cycle of the packaging alternatives was included in the study, starting with packaging production, and ending with packaging end-of-life. The food preservation is included in the analysis as well. The results show that using plastic instead of glass jars leads to a significant reduction in environmental burden, even if the plastic is fossil based (Humbert et al., 2009). However, although material recycling is environmentally more favourable than energy recovery, according to Kale et al. (2007), if packaging materials are soiled with foods or other biological substances, material recycling of these materials may be impractical. Therefore, after a fossil-based plastic is chosen as the packaging material, if the material recycling is impractical for some reason or if the product users do not sort the waste properly, the environmental burden is shifted from one life cycle stage to another and from one stakeholder to another. The last stakeholder in the life cycle, which in this case is probably the company that provides energy recovery, would take the whole responsibility for
the GHG emissions during the waste treatment (explained earlier in section 3.1.4), despite the fact that they have no possibility to contribute to a reduction of these emissions.

Applying the FSSD enable strategic management of the trade-offs (Broman and Robèrt, 2017). Broman and Robèrt (2017) pointed out that the trade-offs should be managed by evaluating the actions based on their capacities to serve as flexible platforms (stepping stones) towards the full scope of sustainability as defined by the sustainability principles. However, dealing with a trade-off on this way can be effective only in combination with appropriate “upstream” actions towards a situation where the trade-off dilemma does not exist anymore.

4. Conclusions

Based on our analysis the main stakeholders involved in the generation of the domestic waste from consumption are product development and manufacturing companies, product users, stakeholders involved in transportation of products, by-products and waste and finally the waste treatment companies. Stakeholder involvement is dependent on whether products are imported or not. In the case of Sweden and many other countries where free trade (meaning less restrictions on import and export of goods) is prevalent, stakeholders within the waste management system becomes relatively more important in terms of governance. The connection between product development and manufacturing companies on one side and waste treatment companies on the other is often weak which impose a need for improved policy instruments that support the development towards a circular economy.

The primary problems related to the sustainability of the waste generation and management system are problems at the beginning of the product life cycles. These problems are usually related to the type of energy sources and product design. The primary problems lead to secondary problems downstream in the product life cycle. A concrete example of this
“burden shifting” is when toxic or fossil-based materials are used as product feedstocks or as feedstocks for packaging materials. If not recycled, incineration of plastic can contribute to human toxicity and fossil based GHG emissions, while landfill disposal causes land occupation etc.

Sustainable development of the waste GM system requires continuous evaluation and analysis of numerous complex social, economic and environmental factors. Because of this, applying a system approach and LCA is extremely important. In order to prevent the “burden shifting” from one life cycle stage to another and from one stakeholder to another, policy measures and other actions which aim towards sustainable development of the waste generation and management system should be geared towards the stakeholders at the beginning of the life cycle. Thus it is important to integrate environmental aspects already into the product development stages.

Different trade-off situations make it even harder to allocate environmental burdens on different stakeholders in the life cycles and to find the suitable strategies towards sustainable development. When a trade-off is considered it may not be obvious which stakeholder should bear the burden of the problems. One example is material selection in packaging by using fossil-based plastic instead of glass in order to increase energy efficiency during the production or product transportation. Companies who provide the waste treatment in combination with energy recovering usually take the responsibility for these GHG emissions. This is despite the fact that the emissions are a consequence of the previously made compromise, and despite the fact that the waste treatment company lacks a possibility to reduce such emissions.

The main conclusion from this study is that when transforming the society towards a circular economy, the traditional view of separate systems for production and waste management
must be changed. In order to refer to all problems related to the sustainability of the system, LCA of waste management should include manufacturing and use of products which end up as waste. Waste entering the waste management system with “zero burden” (Finnveden, 1999; Ekvall et al., 2007; Gentil et al., 2010), by releasing the previous actors of the waste life cycle from any responsibility related to the environment, does not capture the problem with waste generation. In a circular economy there is ideally no waste, just by-products from the different phases of a products life cycle which are recycled and recovered in the same or other products life cycles. The waste hierarchy is still valid for these by-products. This in turn demands for a shift in nomenclature where waste (both non-hazardous and hazardous) always is a resource. All “waste” which is possible to make use of should be called “secondary resource” in contrast to virgin resources (crude oil used for plastic, wood from forestry for paper etc.) which are to be named as “primary resources”. This nomenclature is also in line with what is used in the energy sector (primary and secondary energy sources). The GM system in this paper would then more properly be called “material resources metabolism”.

As previously pointed out (see section 2.3.1), one of the limitations of the study is that the focus of the research is primary on the Swedish waste GM system. Different local conditions such as the characteristics of local energy systems, waste composition, waste quantity, different traditions related to the waste treatment and existing climate and energy strategies. (Vergara and Tchobanoglous, 2012; Christensen, 2011; Laurent et al., 2013b) can make the results from this study invalid for other countries. Furthermore, conditions presented in this study may change in the future. New materials and new waste treatment technologies may be discovered, as well as new problems related to the sustainability of the system.

Further research should be performed where the interactions between the stakeholders included in Swedish waste generation and management system should be analysed in more details. Particularly a review of the existing policies related to the system should be
performed in order to discover possible shortcomings. Furthermore, based on the theory presented by Ny et al. (2006), possibilities for potential multi-stakeholder cooperation should be analysed, in order to find possible strategies towards the defined goal of sustainability.

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