Chapter

Life Cycle Assessment as a Tool to Implement Sustainable Development in the Bioeconomy and Circular Economy

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Abstract

In this chapter, the life cycle assessment was presented as a tool to implement sustainable development in the bioeconomy and circular economy. Bulky waste includes large items such as furniture, doors, flooring and mattresses. The management of bulky waste is a serious problem for European countries. The URBANREC project proposed a solution to this problem through the use of new technologies for the bulky waste processing. The aim of the URBANREC project is to implement an eco-innovative, integrated system of bulky waste management and demonstrate its effectiveness in various regions of Europe. The project has received funding from the European Union. In this chapter, the LCA environmental analysis was performed for the technology of grinding bulky waste using a water jet by the Ecofrag company. The calculations were carried out using SimaPro 8.5.2.0. The LCA analysis shows that the reuse of foams and mattresses contributes to the avoidance of their targeted production, which is related with the reduction of greenhouse gas emission and consumption of fossil raw materials.

Keywords: LCA, sustainable development, bioeconomy, wastes, recycling

1. Introduction

Environmental life cycle assessment (LCA) is a technique designed to assess the environmental risks associated with the product system or activity either directly by identifying and quantifying the energy and materials used and the waste introduced into the environment or indirectly by evaluating the environmental impact of such materials, energy and waste. The assessment relates to the whole lifespan of the product or activity, from the mining and mineral material processing, product manufacturing process, distribution, use, reuse, maintenance, recycling up to the final disposal and transportation. LCA directs the study of environmental impact of the product system to the area of ecosystems, human health and the resources used.

In this chapter, the LCA method will be presented as a one of the tools to implement the principle of sustainable development in the bioeconomy and circular economy. In the economic model currently proposed in the European Union, resources are to be used more sustainably. Closing the life cycle of products by boosting the level of recycling and waste reuse will be highly beneficial, not only to the environment but also to the economy.

Taking into account the dynamically developing economies of the European Union Member Countries, and thus increased demand for raw materials and energy, the European Commission has adopted a new ambitious circular economy package. It is intended to help European businesses and consumers move to a stronger economy, where waste will be a valuable resource base for production processes. The proposals cover the whole life cycle of products: from production and consumption to waste management and the secondary market of raw materials. Implementation of the above strategies will allow for maximizing the use of all raw materials, products and waste and will be conducive to energy savings and reduction of greenhouse gas emission. In this chapter, the results of the life cycle analysis of a large-scale waste recycling, conducted as part of the URBANREC project, are presented as an example of the LCA method application.

2. Sustainable development in the economy

Since some years concerns have been raised about the economic development, the current rate of which can no longer be maintained that, in turn, may result in the incapacity to meet the demands of modern societies. Particular concerns are associated with the predatory use of natural resources, rooted in the incessantly growing consumerism and the lack of constraints on resource use. It is hoped that sustainable reconstruction of industrial society [1] may provide a remedy to mitigate the effects of human pressures. Within this context, the 'economy of sustainable development' has found its place in shaping a new social, economic and economic order.

Traditional economics itself is a social science characterized by a comprehensive spectrum of research problems of varying importance, from fundamental to detailed ones, from theoretical considerations to application recommendations [1]. Until recently, the economy was mainly interested in the pursuit of solutions that will enable the economic and social development. However, the newly emerging and hitherto unknown problems, with which the traditional economy is unable to cope, have led to the advent of new research projects that helped to single out the new types of economics, including the economy of sustainable development. They are collectively defined as sustainable science.

One of the main questions that the modern economy is trying to answer, is how to manage natural resources to ensure that all human needs are met and, at the same time, the regeneration of the natural environment and biosphere functioning are not affected? The economy of sustainable development also seeks to define conditions that would ensure a high ecological (environmental), economic and sociocultural standards, for both the present and future generations, within the limits of tolerance and regeneration of the nature, thus implementing the principle of intra- and intergenerational justice.

Economists dealing with sustainable development can see very clearly the relationship between the condition of the natural environment and the intensity of using its resources, as well as between the economics and the economy. The following major relationships and problem areas referring to the sustainable development economy can be enumerated:

- Climate warming → lack of economic stability

- Destruction of ecosystems → insufficient satisfaction of basic people's needs, increase in prices of goods

- Overexploitation of nonrenewable resources (mainly energy raw materials) → inflation, economic imbalance, dependence on raw material supply, economic development slowdown and increase in prices of goods and services

- Overpopulation → increase in prices of land and basic goods, insufficient satisfaction of basic needs of people (mainly water and food)

Numerous studies by environmental economists have proved the existence of socioeconomic factors that prevent the wise management of natural resources [1–6]. The following groups of determinants can be identified [1]:

1. Environmental costs, subject to externalization

2. Natural resources treated as public and openly accessible goods

3. Other socioeconomic factors, such as world population growth, continuous economic development, consumerism and, ultimately, psychological barriers

In order for the market self-steering mechanism to work, it is important that all costs associated with the production, use and disposal of a given good (including the costs of damage to the natural environment) are included in the final price of the product. If this is not the case, because part of the costs has been externalized or transferred to other entities (taxpayers, future generations or nature itself), then they are misallocated, and the goods are sold below their real price.

Reasons underlying cost externalization are numerous. The key ones include, first of all, the fact that environmental resources are treated as open access goods implying that anyone can use them unrestrictedly and shifted the responsibility for resulting damage onto others, in this case, onto the future generations. People are not willing to incur the costs of environmental impacts, in the hope that others will pay them.

Natural resources are often regarded as public goods, which can be used without major restrictions. We do not handle common goods rationally, economically and with due care as we deal with private property. This is, naturally, based on an erroneous assumption that has become evident particularly at present, when we have to deal with the overuse of nonrenewable raw materials, and consequently, with growing competition over access to these resources. Natural resources are slowly becoming rare goods that are already reflected in their market price. This price will gradually increase, and it is the future generations that will be hurt with a highest burden, being additionally charged with the follow-up costs. We are capable of predicting and estimating these costs; however, the prospect of the future for the present generations is so remote that we are far from long-term thinking and preventing future costs right now. Thus, one of the fundamental principles of sustainable development regarding the intergenerational justice is being violated.

In environmental economics, in addition to cost externalization and the problem of treating natural resources as public goods, there are the so-called other socioeconomic determinants, which include, among others, world population growth, continuous economic development, consumerism and, finally, psychological barriers.

The steady population growth globally entails a number of problems resulting mainly from the rapidly increasing demand for food, drinking water, energy resources, habitable land and advancing deterioration of the natural environment. In the fight against the ongoing degradation of the ecosphere, limiting the population growth seems to be indispensable. However, these are the radical actions that countries in the world are not yet ready for.

Another important determinant is the exponential increase rate of economic development and of related consumerism. Continual growth of needs of modern society translates into unimaginable resource exploitation and environmental burden. Developed countries are at the cutting edge of certain styles and trends that strongly affect developing countries. However, the desire to possess seems overwhelming at the moment, while demand and supply will continue to grow.

The so-called psychological barriers [1] constitute an interesting social phenomenon. This is a relatively new aspect, since the interest in the environment and its condition has also a short ancestry. People are reluctant to change their routines and habits, and fear of the unknown is often a limiting factor when introducing changes. Only a small percentage of people are willing to engage in new activities. A good example is entrepreneurs who, under the Environmental Protection Act, are obliged to incur the so-called fees for economic use of the environment (introduction of dust and gases into the air, water intake, waste generation, etc.).

In most cases, the entrepreneurs consider this obligation to be another legislator's invention, which was created to make their life more complicated. They are unaware that they are obliged by the statutory 'polluter pays' principle [7], while the environment is a public good, which does not mean that it is no one's good.

It should be clearly emphasized that the damage to the environment in the twenty-first century consists primarily in the predatory economy of fossil raw materials. This is due to the socioeconomic and economic factors mentioned above. One of the goals of the economics of sustainable development is to identify the most important economic and economic problems, define their causes and propose socially acceptable or necessary solutions. It is also important to undertake attempts at monetary evaluation of the environment and its resources as well as the goods produced. Thanks to the introduction of economic aspects into the idea of sustainable development, it is possible to lay new foundations of economic thinking, and to define economic conditions that will ensure appropriate economic, social and environmental standards.

3. Circular economy—contemporary economics of sustainable development

Circular economy (CE) is a concept that has forced its way into the dictionary of European business, at the same time increasingly displacing the term 'sustainable development', well-known for many years. CE is to be a response to the multiple challenges of the modern world, economic, environmental and social ones.

This new economic model is based on the assumption that the value of products, materials and resources in the economy is to be maintained for as long as possible to ultimately minimalize waste generation. Efficient use of resources is the priority of the circular economy. In this concept, raw materials are repeatedly recycled, often passing from one branch of industry to another. Therefore, it is about closing the product life cycle and transition from the linear economy model (raw material acquisition-production-use-waste use as raw material) to the closed circuit model (production-use-use of waste as raw material in the next production cycle).

Preventing and reducing food waste in households should be a key priority for both scientists and politicians. To achieve the goal of reducing global food wastage, a campaign should be implemented raising awareness on the gravity of food waste problem and the need for prevention. In Europe, the reduction of food waste is a key area of the circular economy [8, 9]. A huge challenge in this context is recycling of plastics. Equally important is the social acceptance of new products made of recycled plastic [10]. The concept of circular economy is now widely discussed within the

European Union (EU); however, the implementation of its assumptions in the Member Countries faces difficulties due to market and political barriers. The main legal barriers to the circular economy include regulatory provisions that hinder the implementation of the concept and the lack of global consequences. The main market barriers comprise low prices of primary materials on the market, limited standardization and high initial investment costs [11]. Companies do not tend to engage in activities for environmental protection as the latter have not been identified with increasing the company's profit and competitiveness [12]. Technological progress in the field of digitization may accelerate the transformation towards a more sustainable circular economy [13].

The response to the legislative needs of the above mentioned new management model was the set of proposals, announced by the European Commission (EC) in 2015, as the circular economy package. The proposals included in the package aimed at reconciling environmental and business interests. The package was a clear signal for business entities that using all available tools to fully implement the new ecological and raw materials policy was one of the European Union's priorities.

The package includes a strategy to make plastics and plastic products easier to recycle and biodegrade, as well as to reduce the presence of hazardous substances in plastics and to significantly reduce the amount of marine waste.

The package proposes also new rules on fertilizers to encourage nutrient recycling, while ensuring the protection of human health and the environment. A number of actions have also been foreseen for water reuse, as well as the review of legislation concerning ecolabelling (Ecolabel) and Eco-Management and Audit Scheme (EMAS).

The CE package includes also proposals to set new waste management targets to be achieved by 2030, aiming at a significant increase of the levels of waste recovery and recycling as well as a significant reduction of municipal waste landfill. Packaging waste, in addition to, among others, food waste, construction and demolition waste, biomass and bioproducts have been included in the priority areas requiring special attention of the EC.

The potential contained in waste is not only a great opportunity but also a challenge for attaining the vision of the European economy—sustainable, low emission and resource efficient, where raw materials are returned to circulation and waste generation is minimized. Unfortunately, still more than half of the waste generated in EU households ends in landfills or in waste incineration plants.

The EU waste legislation already provides a good foundation for building a circular economy model. The waste management hierarchy, which has been binding the EU countries for years, was formally defined by the Waste Framework Directive of November 19, 2008 (2008/98/EC). The directive instructs the order of implementing priorities, set in legal regulations and strategies, highlighting the importance of waste prevention and management. Only further priorities are assigned to waste recycling and recovery (including energy recovery) and finally neutralization, i.e., storage or thermal disposal (combustion without energy recovery) [14].

According to EU Directive 2018/851 of 30 May 2018 [15], Member Countries should introduce measures to promote the prevention and reduction of food waste. They should seek to achieve an indicative Union-wide target for reducing food waste by 30% by 2025 and by 50% by 2030. Those Member Countries that prepared for reuse and recycled less than 20% of municipal waste in 2013, or submitted landfill of more than 60% of municipal waste, should be able to decide whether to extend the periods to achieve targets for preparing for waste reuse and recycling set for 2025, 2030 and 2035. In the EU Directive of 2018, new targets were set for municipal waste preparation for reuse and recycling, a minimum of 55% by 2025, a minimum of 60% by 2030 and a minimum of 65% by 2035. Member Countries will implement a selective collection of at least paper, metal, plastics and glass, and from 1 January 2025—textiles.

According to official EU statistics, the aggregated amount of waste generated in the EU countries by all sectors of the economy as well as households amounted to 2.5 billion tonnes in 2014. It was the largest amount recorded in the years 2004–2014. Nearly 35% of the above was generated by the construction sector. The mining sector and mining activities are responsible for the next 28% of waste, while industrial production and wastewater treatment are responsible for 10% and 9% of waste mass, respectively. Household waste is only in the fifth position—with 8.3% of the total weight of waste generated in Europe.

One of the EC's priorities will be finding effective options to manage municipal waste. Unfortunately, as many as 54% of municipal waste in the EU is subject to landfilling or thermal transformation. Only about 28% is recycled and another 16% composted.

How the amount of waste generated in the EU countries has changed is shown in **Figure 1**.

Growing population numbers and increasing production of consumer goods make the life span of products shorter, thus causing an increasing problem with emerging waste. It can be assumed that the amount of waste generated

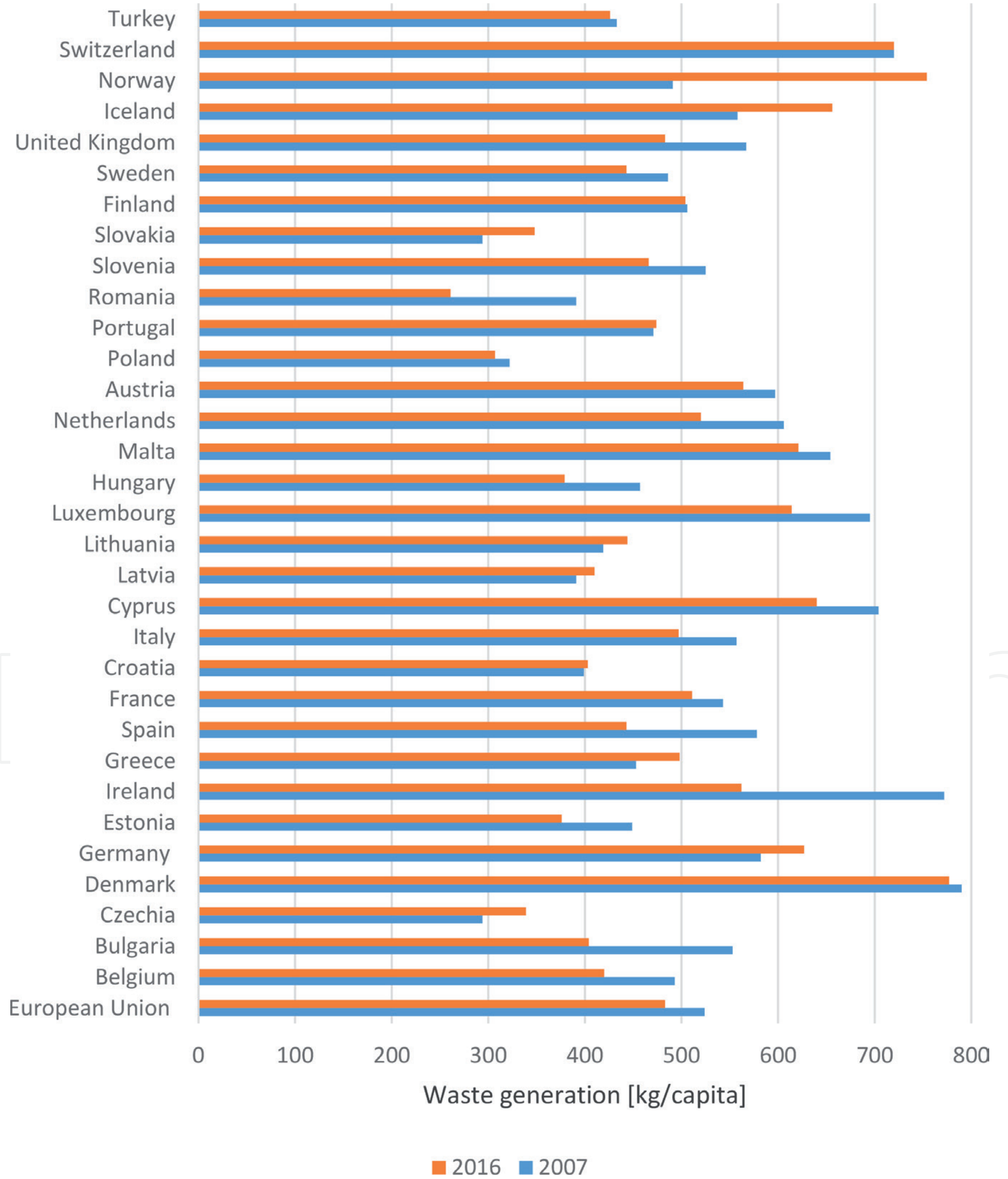

Figure 1.
Per capita waste generation by country, comparison between years 2007 and 2016 (data from Eurostat [16]). In the case of Ireland, data are for 2007 and 2016.

approximates, to certain extent, the gross national income per capita in a given country. In Poland, the per capita amount of waste in 2007 was 322 kg, while in 2016—307 kg, whereas in Denmark these amounts were by half higher, 790 and 777 kg, respectively (**Figure 1**) [16]. The lowest per capita amounts of waste, in 2007–2016, were recorded for Romania, Poland, the Czech Republic, Slovakia, Latvia and Estonia (**Figure 1**). The group of countries where waste generation is highest embraces the more developed countries, such as Denmark, Norway, Switzerland and Iceland. At the turn of 2007–2016, in most European countries, a reduction in the amount of waste generated per one inhabitant was observed, including in Belgium, Bulgaria, Poland and Ireland. In the same period, in other countries, there was an increase in the amount of waste generated (Norway, Iceland, Greece and Germany) [16].

The indicator (illustrated in **Figure 2**) measures man-made emissions of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, nitrogen trifluoride (NF_3) and

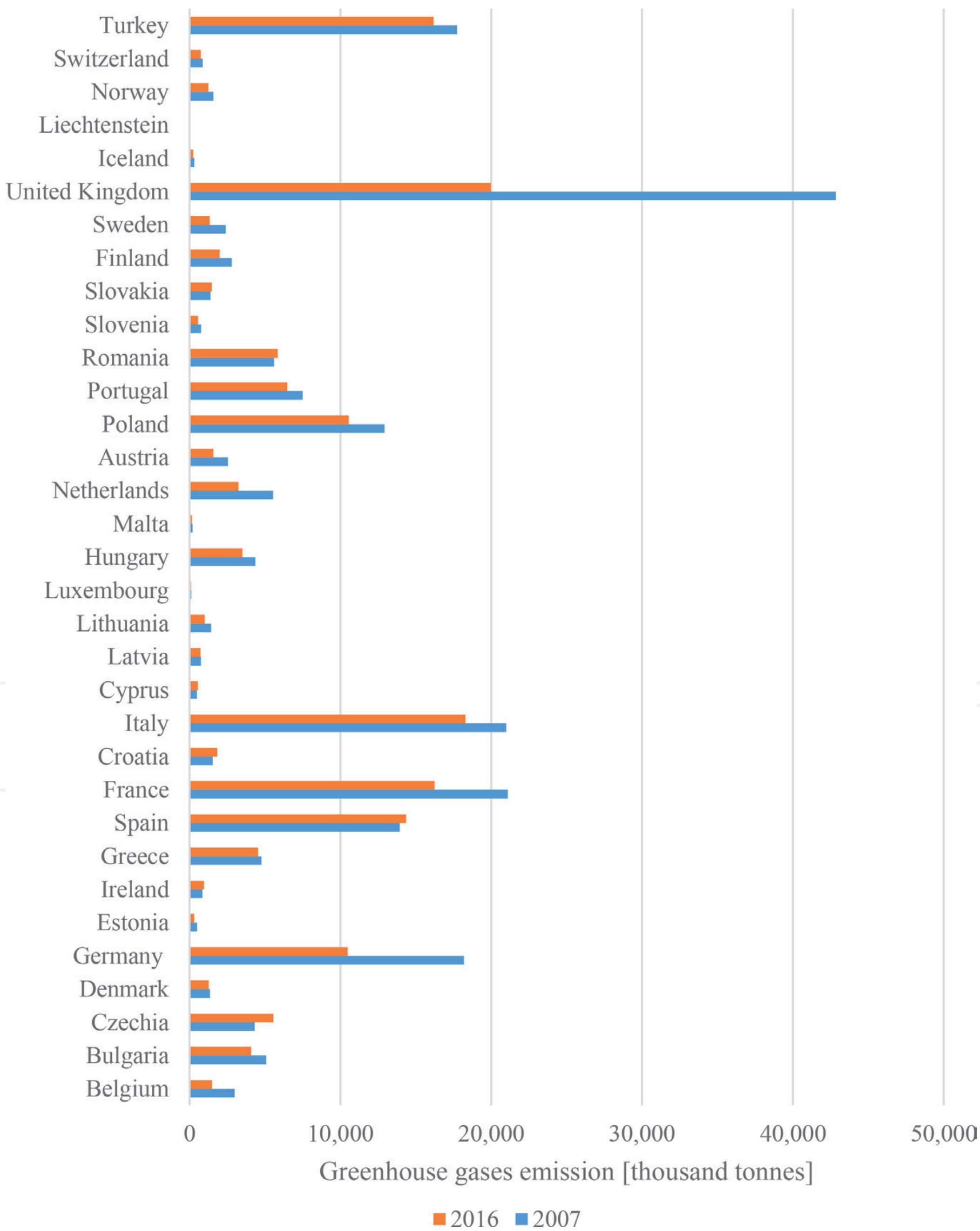

Figure 2.
Greenhouse gas emission from the waste management sector expressed in CO_2 equivalent (Source: Eurostat [16]).

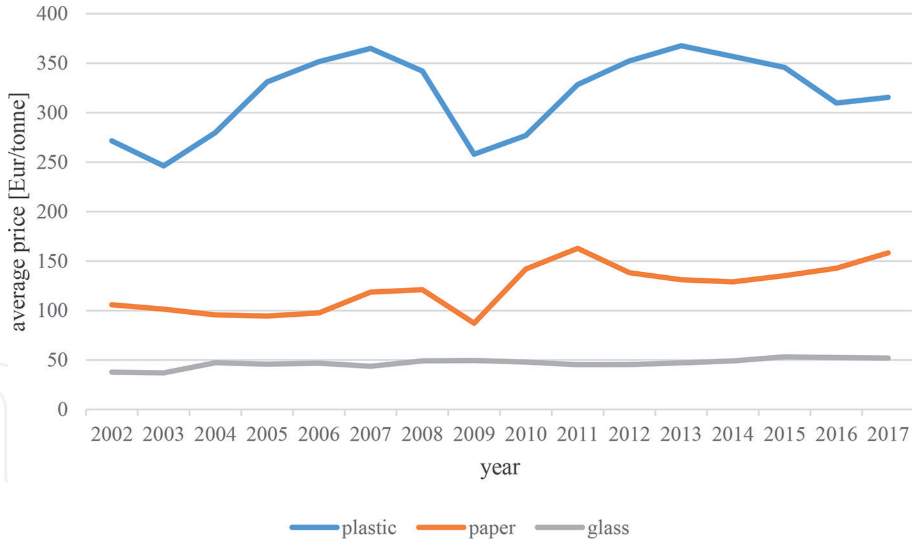

Figure 3.
Price changes of recyclates: plastic, paper and glass (data from Eurostat [17]).

sulphur hexafluoride (SF_6). The global warming potential (GWP) is for each gas individually integrated into a single indicator expressed in CO_2 equivalent units. This also indicates that, when there is a proper waste management, the greenhouse gas emission might be lower in the countries generating large amounts of waste, as compared to those producing low waste amounts, e.g., Denmark and Spain.

In the USA, the US Environmental Protection Agency noted that greenhouse gas emissions from waste landfills amounted to 115.7 Mt of carbon dioxide equivalent in 2015 [18].

The way to reduce greenhouse gas emission and to efficiently use raw materials is the closed circuit waste management. One of the waste management methods is recycling. Apart from being beneficial to the environment, recycling delivers financial profits to waste management companies. In **Figure 3,** the trends are shown for prices per ton of paper, plastic and glass over the past 15 years. Despite a significant drop in prices in 2009, one can notice an upward price trend per ton of recycled waste.

4. Environmental life cycle assessment in the circular economy

Environmental life cycle assessment (environmental LCA) is defined as a methodology to identify and assess potential environmental impacts associated with all the stages of a product's (good's) life. The life cycle should be holistically understood: from extraction of raw materials necessary for the production of a given good through the production process, transportation and distribution to the final management of the waste generated [19–23].

One of the most frequent definitions of environmental LCA, encountered in the subject literature, is the definition proposed by Fava et al. [24]; consistent with this definition, the environmental LCA is a method designed to assess environmental risks associated with the product system or activity, either directly, by identifying and quantifying the energy and materials used and the waste introduced into the environment, or indirectly, by evaluating the environmental impacts of such materials, energy and waste. The assessment embraces the whole lifespan of the product or activity, from the mining and mineral material processing, product manufacturing process, distribution, use, reuse, maintenance and recycling up to the final disposal and transportation. LCA directs the study of environmental impact of the product system to the area of the ecosystem, human health and the resources used [24].

The basic advantage of the above method is its versatility. LCA has typically been used to evaluate environmental technologies or production processes within boundaries of the 'from cradle to gate' or 'from cradle to grave' systems. The life cycle analyses within the framework of the circular economy concept shall embrace boundaries of the 'from cradle to cradle' system [25].

Depending on the adopted degree of detail of the analysis, it is possible to link all of the unit processes and to assess their impact on the environment, which is particularly important in the case of closing the circuits [26]. It is also possible to quantitatively identify all materials and energy used to produce the product, along with the release of dust and gas emission, noise and radiation emission, as well as the resulting waste, which allows for effective management of the production process and minimizing economic and environmental costs. The life cycle assessment allows for identifying the processes, which generate the largest environmental burden, and consequently, for modifying these processes in order to reduce environmental impacts. Moreover, LCA allows for reducing the economic costs by optimizing the consumption of raw materials (the so-called life cycle cost (LCC)) [27–29]. That is exactly why such a comprehensive and systematic approach to the production process as the LCA has gained wide attention and become a broadly used management method.

In Poland, LCA remains a rather novel method in the environmental management. It is used mainly for R&D purposes and has been developed by R&D centres. Considering the requirements imposed by the EU legislation, as regards minimization of adverse environmental impacts of the fuel industry, LCA seems to be a useful tool for meeting these requirements. The LCA may encompass the whole life cycle of fuel, from raw material mining, all the way through its manufacturing, use, to the processes involved in fuel handling [22].

In Turkey, the LCA analysis was used, for example, to demonstrate which waste management strategy is better from the viewpoint of environmental protection. The results obtained provided evidence that landfilling and incineration were the worst alternatives of waste disposal, while composting and material recovery showed a better performance [30]. Based on the LCA study carried out in Denmark, it was found that the assessment was a good tool for evaluating the household organic waste management system at the Danish-German border, where waste management systems were entirely different [31]. Helene Slagstad and Helge Brattebø demonstrated that waste composition constitutes an important uncertainty in the waste management LCA [23]. Waste composition can affect the total environmental impact of the system, taking into account, especially, the global warming, nutrient enrichment and human toxicity via water impact categories [32].

5. Bulky waste management in the circular economy—LCA results

Considering the constantly growing consumption, and hence the mass of post-consumer waste, there arises a significant problem of waste management. This chapter focuses on bulky waste considering the significant problem of its management.

Bulky waste is a term to describe waste that is too large to fit in ordinary containers. This includes, among other things, furniture, carpets and mattresses. Improper management of bulky waste can pose a large environmental and logistic problem. The waste is atypical since it is largely made of a variety of materials, which have different composition, and thus each may have different effect on the environment and should be treated differently. Considering the above, the main and preferred options for bulky waste management include recycling and energy recovery.

Material and energy recycling issues have been taken as subjects of the European URBANREC project. The project has received funding from the European Union's Horizon 2020. This project will demonstrate solutions for bulky waste management challenges. For the first step, technical solutions will be implemented in two representative European regions: Valencia (Spain) and Harelbeke-Flanders (Belgium). The results obtained will be spread out to other regions. In the first instance in Warsaw (Poland) and Izmir (Turkey), bulky waste management is evaluated in the course of the URBANREC project. The URBANREC project aims to develop and implement an eco-innovative and integral bulky waste management system and demonstrate its effectiveness in different regions. In URBANREC project, Northern, Mediterranean, Eastern and Southeastern areas in Europe are represented by Belgium, Spain, Poland and Turkey, which have very different urban waste recycling rates, from around a 60% in Belgium, 25–30% in Spain or 20% in Poland to less than 5% in Turkey. The URBANREC project aims to advance the separation and disassembling of bulky waste. The project will develop modern waste treatment technologies, such as fragmentation (3D cut). The waste treatments considered in the project include: rebounding and chemical glycolysis for the PUR materials, to prepare renewable adhesives, needle felt to obtain isolation panels from textiles, fibre reinforced composites from textiles, wood plastic composites and catalytic hydro-gasification with plasma for mixed hard plastics to obtain chemicals or fuel. Based on the results obtained, recommendations will be proposed for the new EU regulations as regards bulky waste.

The LCA focuses on demonstration of laminated cutting technology (fragmentation) for separated materials and products. The technology owner is the Ecofrag company.

In URBANREC project, a selection based on waste streams will be made in the civic amenity site located in Valencia to improve the quality of fractions obtained. Critical parameters for selection are defined depending on the waste stream. For mattresses, it is necessary to separate foams as latex, polyurethane or mixed foams. In textiles, different compositions can be obtained like cellulosic fibres—predominantly (cotton, viscose, flax and sisal) and thermoplastic material (PET, PP, PA, multicomponent PET with others, cellulose/thermoplastic blends). Hard plastics will be divided into polyolefin or non-polyolefin. Between the different technologies, laminated cutting technology for grinding will be selected and demonstrated in Valencia. This technique is developed by Ecofrag, and currently is employed as a novel system for fragmentation of PU foam, mixed textiles, mixed plastics, tyres and wood. The recovered fractions that cannot be reprocessed economically within an acceptable quality range (e.g. coated textiles, mix of different types of foams and wood) will be sent to the catalytic hydro-gasification process.

One of the main advantages of the fragmentation system includes lower CO_2 emission due to the reduction of energetic consumption (40–50% in energetic cost), in view of the use of high pressure water as a cutting system. Regarding the fractions obtained, this technology combines two major advantages:

- Clean and differentiated components
- Greater flexibility in sizes and textures that makes easy to recycle obtained fractions

The LCA analysis focuses on the environmental assessment of grinding technology for bulky waste treatment with the use of water stream. As a functional unit, 1 Mg of bulky waste of various types (e.g. PU foam, mixed textiles, mixed plastics or tyres) was adopted. The input data for analysis were provided by the project partner—Ecofrag enterprise.

As a generally applied and common tool, the programme SimaPro 8.5.2.0, developed by Dutch PRé Consultants, was used for the LCA analysis. Within the SimaPro programme, there is an option to select between several dedicated methods of the life cycle impact assessment. The methods vary from one to another, thus when selecting, it is necessary to specify priorities for a given LCA analysis. When selecting the life cycle impact assessment (LCIA) method and impact categories, it is important to take special account of the aim and extent of the analysis [19] and, additionally, of the following way of presenting the end results, way of weighting the individual impact categories, time frame indicated, geographical range, degree of accurateness of the method as well as impact categories included.

Bearing in mind the above, and after analysing the methods available in the SimaPro programme, the ReCiPe (mid-point and endpoint) method was considered to be the most appropriate.

ReCiPe is the most recent and harmonized indicator approach available in the life cycle impact assessment. The primary objective of the ReCiPe method is to transform the long list of life cycle inventory results into a limited number of indicator scores. These indicator scores express the relative severity on an environmental impact category. In ReCiPe we determine indicators at two levels:

- Eighteen mid-point indicators (focused on single environmental problems, for example, climate change or acidification)

- Three endpoint indicators (showing the environmental impact on three higher aggregation levels, being the (1) effect on human health, (2) biodiversity and (3) resource scarcity)

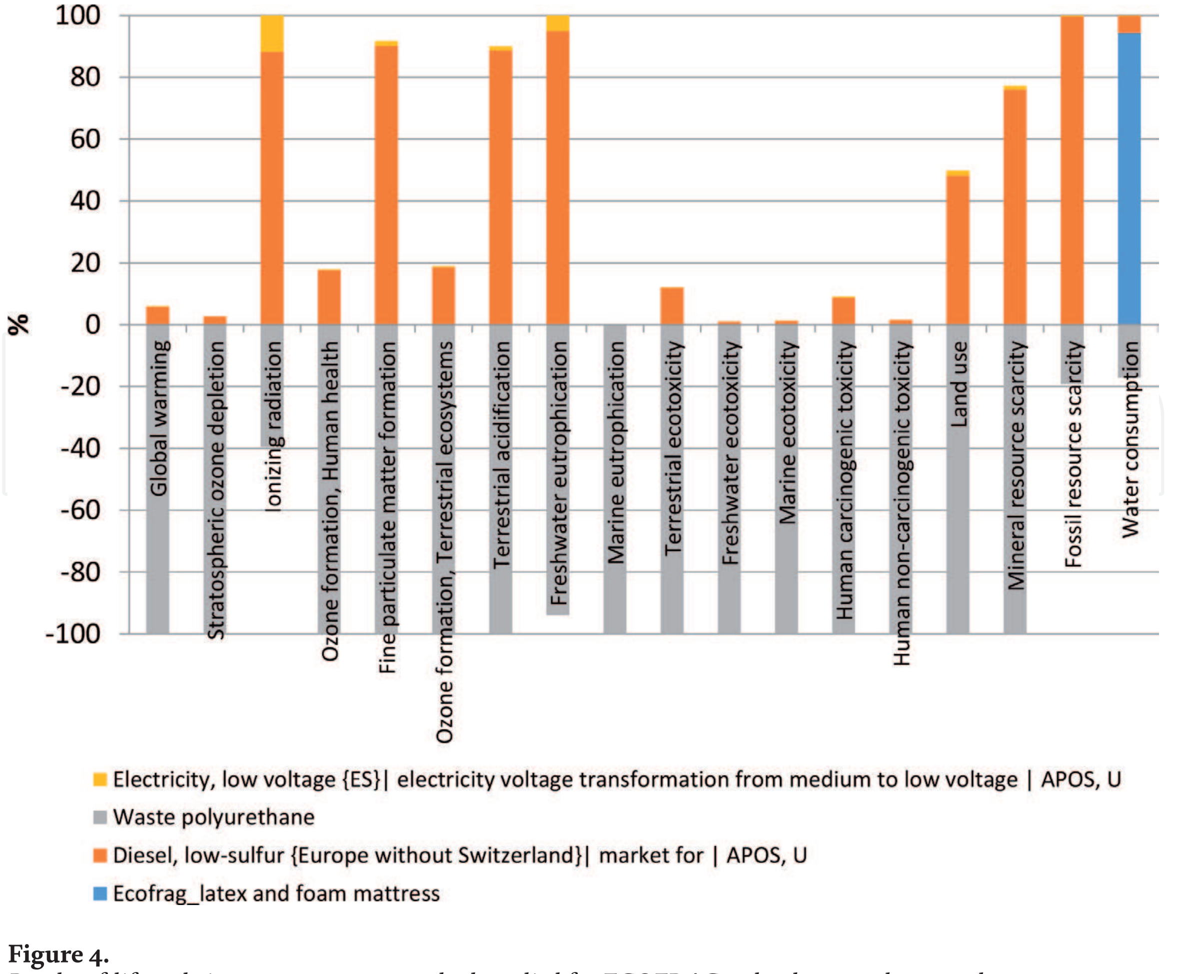

Figure 4.
Results of life cycle impact assessment method applied for ECOFRAG technology, used to treat latex mattresses and PU foam, for the individual impact categories within the framework of ReCiPe 2016 approach (characterization).

Each method (mid-point, endpoint) contains factors according to the three cultural perspectives. These perspectives represent a set of choices on issues like time or expectations that proper management or future technology development can avoid future damages.

- Individualist: short term, optimism that technology can avoid many problems in future.
- Hierarchist: consensus model, as often encountered in scientific models, this is often considered to be the default model.
- Egalitarian: long term based on precautionary principle thinking.

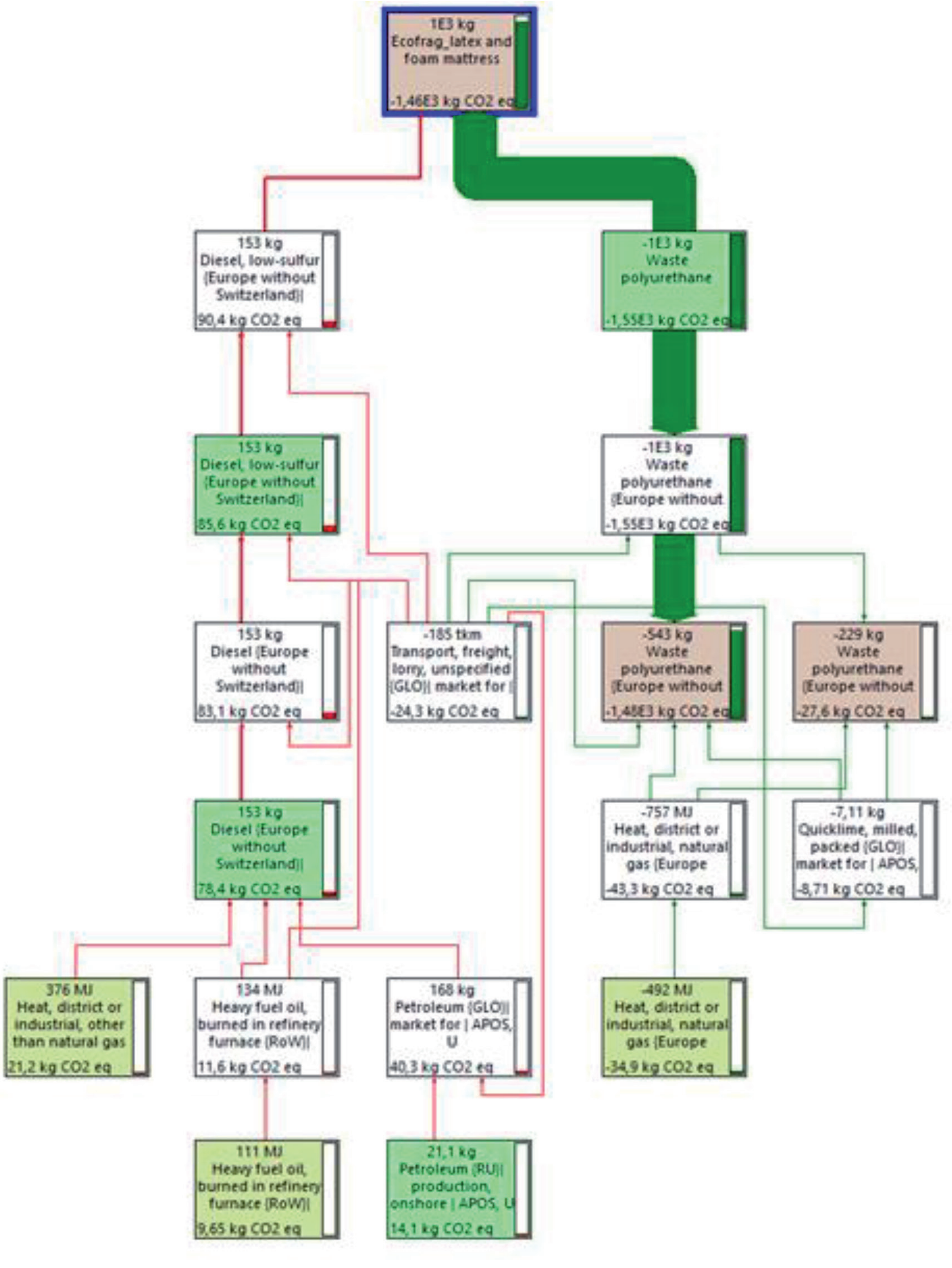

Figure 5.
A fragment of material-energy balance (the Sankey chart).

Considering the aim and extent of the analysis in question, the hierarchist variant was chosen, in view of the balanced time perspective, taking into account both long- and short-term perspectives.

The results of LCIA analysis are illustrated in **Figures 4** and **5**.

As it can be inferred from **Figure 4**, the largest environmental burden is linked with using diesel oil (DO) in electricity generators. Diesel oil combustion causes an increased emission of dust and greenhouse gases to the air that has consequences on increased global warming, ozone layer depletion, water eutrophication, acidification of the environment and increased dust pollution. The impact on water resources of Ecofrag technology is high, but the impact is reduced by the recirculation of water in the installation.

The use of net power generates a significantly lower environmental effect. It should be emphasized that the technology examined has a net positive effect on the environment owing to the application of waste materials as substrates. Recirculation of used PU foam and mattresses contributes to avoidance of emission and generation of waste involved with their target production. Such results have been confirmed by the fragment of the material-energy balance. The Sankey chart is presented taking into account processes/factors, whose impact is not lower than 0.56%.

In **Figure 6**, the results of LCA are given regarding the endpoints such as human health, ecosystem quality and depletion of natural resources, within the framework of the ReCiPe method applied. From the figure, it can be seen that the highest negative load is ascribed to the point 'nonrenewable resources'. This is closely related to the use of diesel oil (as a fossil energy carrier) for generating electricity necessary in the cutting process. On the other hand, a definitely positive impact is observed on human health and the quality of the ecosystem. This result is dictated by the application of Ecofrag technology for waste raw materials.

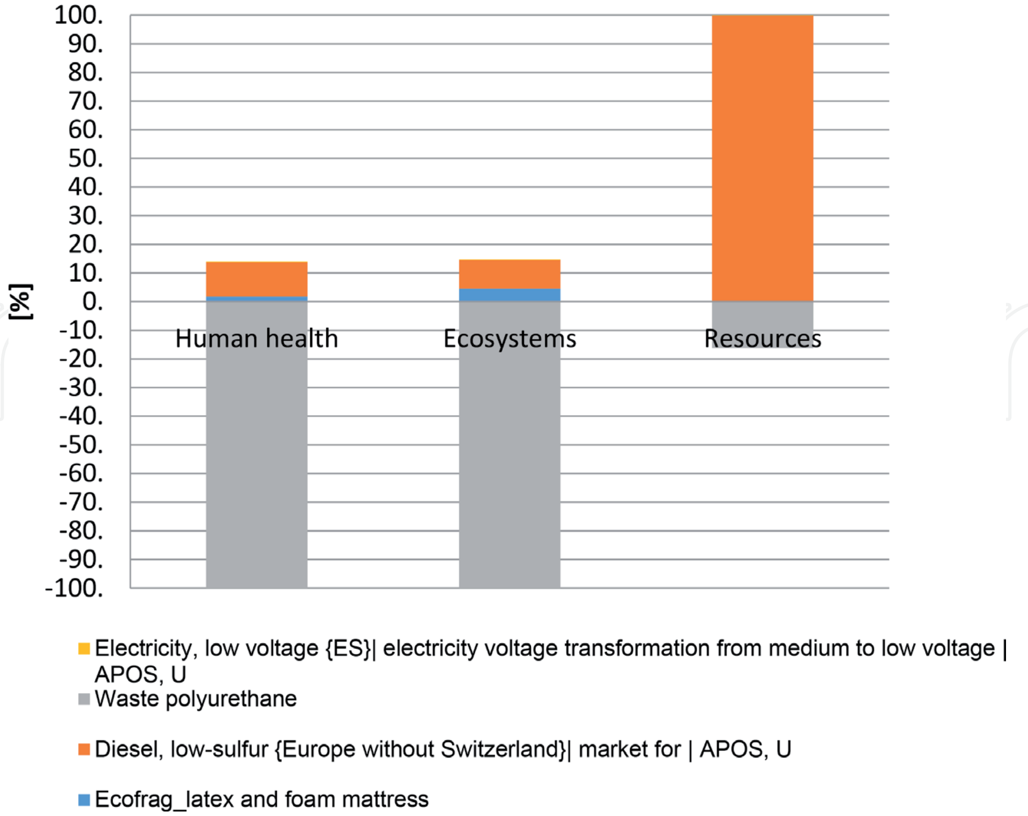

Figure 6.
The results of environmental life cycle assessment in relation to end-points within the framework of ReCiPe 2016 method.

Based on the results obtained, it has been demonstrated that material recycling brings numerous environmental benefits. This is mainly due to the reduction of environmental burdens associated with the intentional production of foam and mattresses, which has an impact on negative indicators of fossil raw materials consumption and reduction of greenhouse gas emissions.

6. Conclusions

The circular economy (CE) is a concept aiming to address activities that enable the reuse of products, focusing on positive society-wide benefits, among others. CE assumes development of a system in which the product does not end up in a landfill and is reused in the same or different form or is recycled. The remodelled hierarchy of waste management is to indicate the order of priorities in the policy and regulations regarding waste prevention and management. Prevention is of crucial importance; it applies to both product producers and consumers. It aims to reduce waste by reusing products or extending their lifespan. Another advantage of such an economy is the reduction of the waste adverse impact on the environment and human health. The circular economy is regulated by the European Directive, which sets specific goals to be achieved by Member Countries in the given years.

The management of bulky waste poses a significant problem for European countries. Under the URBANREC project, a solution to this problem was proposed through the use of new technologies for the bulky waste processing.

In this chapter, the LCA environmental analysis was carried out for the technology of grinding bulky waste using a water jet by the Ecofrag company. The analyses have shown that the reuse of used foams and mattresses contribute to the avoidance of their targeted production, which is associated with the reduction of greenhouse gas emission and consumption of fossil raw materials. The next step under execution of the URBANREC project is to perform the life cycle cost analysis, for the purpose of optimizing economic costs.

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URBAN Rec BULKY WASTE MANAGEMENT

Conflict of interest

Authors declare that they do not have 'conflict of interest'.

Acronyms and Abbreviations

CE	circular economy
DO	diesel oil
EC	European Commission

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EU	European Union (EU)
LCA	life cycle assessment
EMAS	Eco-Management and Audit Scheme
R&D	Research and Development
LCC	life cycle cost
LCIA	life cycle impact assessment

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