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CARBON FOOTPRINT OF WASTE MANAGEMENT IN ROMANIA IN THE CONTEXT OF CIRCULAR ECONOMY

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Abstract

The shift from a linear economy to the circular economy emerges as a solution to save natural resources and to decrease the effects of the climate change on the environment. Understanding the role of the waste as secondary resource and recovering it can reduce the consumption of non-renewable primary resources, the consumption of energy in the production processes and can also lower the CO_2 emissions. The study aims at evaluating the environmental impact when applying the principles of the circular economy in the solid waste management and the possible savings in terms of global warming potential (CO_2 –eq.) in Romania. The evaluation is done with help of Life Cycle Assessment (LCA) approach on a case study in Timisoara. The study demonstrates that savings of over 40.000 t CO2 -eq. per year would be possible in a city with 300.000 inhabitants. The concept can be applied (with appropriate adjustments) also in other cities from Romania or from other countries, making possible the implementation of circular economy.

Key words: circular economy, CO_2 emission, LCA, secondary resource, waste management

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1. Introduction

The modern society is characterized by a continuously increasing consumption of goods, associated to an increased consumption of resources and higher waste generation. The economy functioned a very long time on the basic structure of linearity: take-make-waste. This model causes significant wastage of resources and money. Within this framework the English economist David W. Pearce introduced in the 90's the concept of circular economy as an alternative to the linear economy (so called throwaway economy) (Gavazzi et al., 2017; Pearce and Turner, 1990). Based on the thermodynamic laws, Pearce (1991) stated that the economic system cannot destroy anything, therefore whatever enters an economic system appears in same or transformed state somewhere else and "energy cannot be recycled at all, while many material uses are so dissipative that we cannot recycle the transformed product". In his opinion this adds up to the idea that the economy is rather a circular system than a linear one (Pearce, 1991). Recycling and reusing goods or materials are part of the circular economy but the focus lays on achieving resource recirculation through new product and new system design and Singh and Ordoñez (2017) noticed that the waste management hierarchy defined by EU (European Union) still focuses on post-consumer waste.

A package of documents on Circular Economy concerning an integrated revision of legislative proposals on waste management was issued in 2015 by the European Commission aiming at the stimulation of the transition towards a circular economy concept (Rada et al., 2017). Rada and Cioca (2017) draw the attention that the risk in keeping the

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conventional approach is to generate information that is not adequate for a correct design of the management system, either in terms of collection or in terms of treatment of residual municipal solid waste.

It is undoubtedly that incineration and other forms of energy recovery are helpful in reducing waste quantities and greenhouse gas emissions from landfill, but it should not be neglected that they also preclude recycling of materials such as paper or plastics (Tisserant et al., 2017). When the waste management policies are based on closing loops, as it happened in Germany during the last 20 years, and disposal responsibilities are assigned to manufacturers and distributors of products, the results are significant. People become more aware about the necessity of waste separations and their sorting behavior, together with the development of treatment technologies, make possible that 14 % of the raw materials used by the German industry originate from recovered waste (Nelles et al. 2016). According to Ragazzi et al. (2017) involvement of the population, correlated with the legislation, participation of municipalities and good coordinators of the afferent financial loop can lead to reliable waste management schemes.

Even if some authors (Ekvall et al., 2007; Ekvall, 2009; Finnveden et al., 2007; Morrissey and Browne, 2004) underline the limitations of applying Life Cycle Assessment (LCA) to waste management systems, such tools have been gaining greater acceptance in waste policy (Lazarevic et al., 2012; Ortiz-Rodriguez et al., 2018). Moreover, according to De los Rios and Charnley (2017) tools like LCA and carbon footprint can offer valuable information in decision process, provided that capable users are available for an effective application. Life Cycle Thinking is since many years a concept in the EU and now this concept is about to be transformed into legal requirements through the Circular Economy Package (Hughes, 2017).

According to Cobo et al. (2017) the shift from linear to circular waste management systems is one of the major lines of action to overcome the challenge of continuous depletion of natural resources related to our lifestyle. The implementation of the circular economy is not easy, and involves time and radical changes but the benefits are more and more recognized (Bica, 2017). Ciubota-Rosie et al. (2008) underline for example the beneficial effect of regenerating energies regarding not only the environment protection, but also from economic and social points of view and also Maina et al. (2017) consider that the circular economy promotes “sustainable and resource-efficient policies for long-term socio-economic and environmental benefits”.

Therefore the present paper aims at evaluating how a waste management system, based on circular economy principles, can contribute to savings of CO_2 emissions by valorizing the waste as secondary resources. The evaluation is conducted on a case study in Timisoara, a Romanian city situated at the western border. As first step a waste analysis is done to collect data on waste generation in Romania, where such data is generally missing. Afterwards, based on the LCA approach, a model is built with the help of the software GaBi and according to the principles of the circular economy (Berechet, 2017). In the end the results are evaluated and discussed.

2. Material and methods

As a member of the EU, Romania has to comply with the European environmental requirements and legislation. The chance of using the experience of western European countries in the field of solid waste management ought to be taken. Within a cooperation project between environment ministries from Romania and German state Baden-Württemberg, a waste analysis was set up to collect data on municipal waste generation in households from Timisoara. The German partners provided the technical support (throughout the University of Stuttgart), while the Romanian partners (University Politehnica Timisoara and waste operator Retim) provided the infrastructure and the facilities.

At that moment Timisoara was preparing the implementation of a selective collection system, switching from a single mixed waste bin, where all types of waste were collected together, to a system with two bins, where the recyclable materials were collected separated from the residual waste.

The waste analysis was done according to the guidelines of the German federal state Brandenburg. There were organized two sorting campaigns, one in summer and another one in autumn. Submitted to the investigation were the mixed bin from the old system and the residual bin from the new system. Out of logistic reasons it was not possible to investigate also the content of the bin dedicated to recyclable materials from the new system. The investigations did not allow the determination of the specific quantities of waste (waste quantity/person*year), but they offered valuable information on the percentage composition of waste. In Table 1 below there are summarized the results of the waste analysis, published in the project report (Kranert et al., 2008).

For the evaluation it was used the LCA tool. As recommended by Joint Research Centre (JRC; 2011) the precise definition of the system boundaries was important to ensure that all processes are actually included in the modeled system and that all relevant potential impacts on the environment are appropriately covered. LCA included the emissions and the consumption of resources from the moment of disposal. Production processes before the material become waste were considered in the present study as a ‘‘zero burden” to the waste material. The “zero burden” approach considers the waste to be managed by the system as a given (McDougall et al., 2001). Between consequential assessment, that describes changes of environmentally relevant flows as reaction to possible decisions and attributional LCA that concentrates on describing physical flows to and from a product/process that are relevant to environment (Finnveden et al., 2009) it was chosen the second one.

Table 1. Results of the waste analysis (Kranert et al., 2008)

		Timisoara	*Timisoara*
		2-container-system	*1-container-system*
Fine waste (< 40 mm)		21	20
	Organic fine waste (< 40 mm)	14	14
	Non- organic fine waste (< 40 mm)	6	6
Organic		36	34
	Kitchen waste	30	31
	Garden waste	6	2
	Wood (untreated)	0.2	0.4
Paper and board		9	10
	Paper (high quality)	2	2
	Paper (ordinary and medium quality)	4	5
	Cardboard, corrugated board	3	4
Plastic		12	12
	Plastic film	5	5
	PET bottles	3	4
	Plastic packaging	2	2
	Dense plastic	2	0.7
	Expanded polystyrene	0.7	0.3
Composites		2	2
	Composite packaging	2	2
	Composite mixed	0.1	0.7
Glass		5	6
	Mixed-glass(no flat glass)	5	6
Metals		2	1
	Scrap metals	0.9	0.1
	Tin plate, aluminum	1	1
Textiles and shoes		5	3
Building and demolition waste		6	6
Inert material (ex. ceramic)		0.4	0.3
Electronic scrap		0.6	0.3
Hazardous waste		0.4	2
	Battery	0.1	0.2
	Medical waste	0.1	0.2
	Hazardous waste	0.3	1
Nappies		3	4

Attributional LCA offers information on the mean unit of product and is useful for consumption-based carbon accounting (Brander et al., 2008; Zabeo et al., 2017). The methodology used is the system expansion, based on the ISO standard on inventory methodology. The inventory methodology recommends an order of priority for allocation procedures and gives priority to the prospective perspective, because system enlargement, done to describe the full effects of a change, is preferred over partitioning of environmental burdens (Tillman, 2000).

According to Christensen et al. (2009), the CO_2 formed during organic waste and biogas combustion as well as CO_2 emission associated with use on land of the digestate, i.e. CO_2 formed from the C that was not sequestered in soil, are considered as biogenic and so are assigned with zero GWP contribution. In this light, CO_2 avoided due to C sequestration is assigned with GWP factor of -1 kg CO_2 eq. per kg CO_2 not emitted. The functional unit is 1 t/year material treated and all inputs and outputs to the system are expressed per functional unit. At the end the results are scaled up to the entire quantity of waste (130 000 t waste/year).

The tool used for modeling is the LCA software GaBi (Ganzheitliche Bilanzierung) developed by Stuttgart Universität, as a tool commonly used for modeling solid waste management systems (Ghinea et al., 2014). The impact assessment method used in the study is CML 2001, which restricts quantitative modeling to early stages in the cause-effect chain to limit uncertainties.

As it can be observed in Table 1 there is low variation between waste composition in the mixed bin of the old system and in the residual bin of the new system. This is an indicator of a low participation of population to the separation of recyclable material. Therefore scenarios were modeled for a sorting performance of 50% and under the assumption that the sorting behavior of the population improves to 70%. This means that 70% of the recyclable material is correctly sorted by the population and disposed in the container for recyclable material (Berechet, 2017).

The models were tailored to fit the present collection system from Timisoara, with a wet bin for residual waste and a dry bin for recyclable waste, but they can be adjusted also to other selective collection systems. Following the principle of the circular economy, not only the fractions that can be recycled are indeed directed to recycling (this being the only alternative considered for the waste collected in dry bin), but also the residues are valorized (Berechet, 2017). The recycling plants are modeled according to actual state of the art, using examples from Germany.

Waste mixtures such as the content of the wet bin (50.2% organic waste and 49,8% residual waste) can be treated in mechanical biological plants, the treatment solutions considered for this mixture being the following: mechanical treatment combined with aerobic or anaerobic biological treatment. According to Montejo et al. (2013) the aim of these plants is to separate and stabilize the organic fraction of the waste as well as recovering recyclables from mixed waste streams. Mechanical biological treatment allows recuperation of valuable materials such as metals but also production of refused derived fuels from the high calorific fractions. Garg (2014) considers that a proper mechanical sorting can contribute to the effectiveness of the post-treatment (biological and thermal). Den Boer and Jędrczak (2017) consider that in a mechanical biological treatment plant that is processing mixed waste it is not possible to produce high quality compost.

Application of the digestate or stabilized material as compost in agriculture is not possible due to impurities and harmful substances contained in the input mixture, that are not removed during the mechanical biological treatment (Plavac et al., 2016). In agriculture can be applied only material resulting from composting of separated collected organic waste (which is not the case in this study). Moreover the legislation (law 211/2011, reviewed in 2017, § 21 Art. 31, point (3)) implies that it is forbidden to treat organic waste containing pollutants (as it is the case of the mixture from wet bin considered in this study) in compost plants. According to Trulli et al. (2018) through the mechanical biological treatment before landfilling the environmental impact and waste mass are reduced, up to 30%, since organic fractions are stabilized.

The waste disposed in the wet bin is collected from the source with appropriate refuse collection vehicles and transported to the proposed treatment plants. As mentioned above, the treatment options are aerobic and anaerobic. The flow diagram for scenario with aerobic treatment of residual waste is presented in Fig. 1. After collection the residual waste is transported to the aerobe mechanical treatment plant. The first step in the treatment is crushing the material and after that follows the sieving. Through air separation is removed the high calorific fraction (paper and plastic). The ferrous metals are sorted with magnets while for non-ferrous metals is used Eddy Current Separator. The ballistic separator is used to sort the heavy fraction. The high calorific fraction is utilized as refuse-derived fuel (RDF) in a cement plant. The recyclable materials (such as metal) are recycled. The organic fraction is submitted to aerobe degradation in the biological steps. The biological treatment consists of homogenization then intensive degradation inside closed tunnels. After that the material is stored in heaps, allowing a post degradation process. After the treatment the material, having reached the inert state, is transported to the landfill. Around 25% of the input represents the material loss during the degradation process (Cimatoribus, 2010).

Although RDF does not comply with CEN standards as municipal solid waste derived solid recovered fuel (SRF) does (Wagland et al., 2011), Hajinezhad et al. (2016) considers that RDF technology provides an alternative means for safe and eco-friendly disposal of municipal solid waste of the city and Chamurova et al. (2017) underline the technological, energetic, economic and ecological advantages of RDF utilization in the cement kilns.

The European Community issued technical standards that define and classify RDF, aiming to facilitate the marketing of these fuels, particularly referring to replacement of traditional fossil fuels in the production of electrical and thermal energy and in cement kilns (Massarini and Muraro, 2015). In Fig. 2 is represented the flow chart of scenario with the treatment of residual waste in an anaerobic mechanical biological treatment (MBT) plant. In this case the material is crushed and sieved. The high calorific fraction is sorted with air separation and used as RDF in cement plant. The metals are separated with magnets and Eddy Current Separator and submitted to recycling.

The organic fraction is submitted to anaerobe degradation in a wet fermentation process. After homogenization and watering the mixture is fermented in a mesophilic digester. The fermentation takes place at temperatures between 35° and 40° C for 3 weeks. The biogas earning represents around 6% of plant's input and has a content of about 60% methane. From biogas is produced energy, which is partly used by the plant itself and partly fed into the network. The energy efficiency is about 40% electric and 55% thermal. The fermentation rests are dewatered and submitted to aerobic degradation. The stabilized rests are transported at the landfill. Around 27% of the input represents material loss during the degradation process (Cimatoribus, 2010).

The fractions collected in the dry bin are sorted and then transported to recycling facilities. Recycled are materials such as metal, plastic, paper and glass. The sorting rests can be incinerated in a power plant to produce energy. This energy substitutes electricity from the grid mix. High calorific fraction that is not suitable for recycling (for example shoes) can be used as RDF in cement plants, replacing fossil fuels as shown in Fig. 3. At the moment in Timisoara the waste collected in dry bin is sorted in a sorting plant for the recyclable material. Another sorting station is plant to be built in the proximity of the landfill. At the aerobic waste treatment plant located at the landfill the valuable materials are sorted from wet residues. The organic fraction is stabilized and then transported to the landfill.

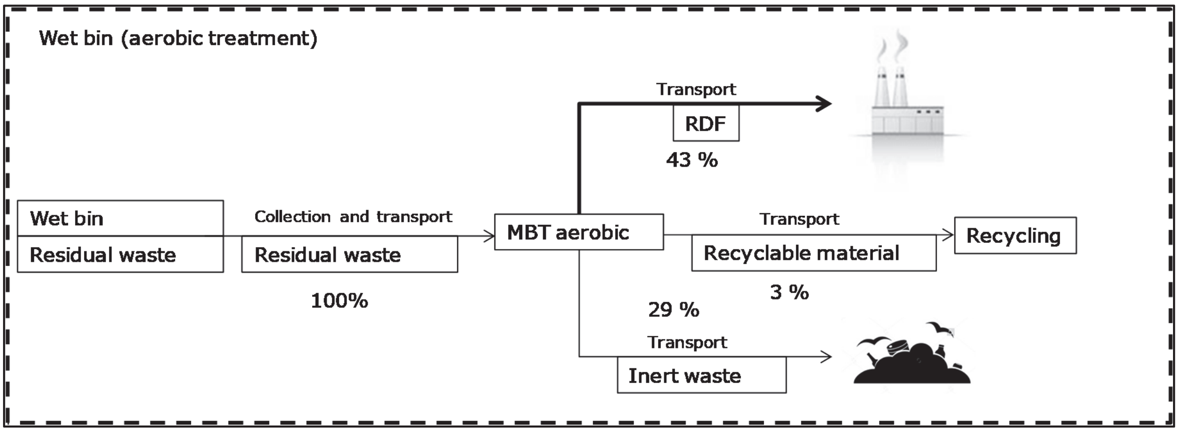

Fig. 1. Aerobic treatment of waste from wet bin (mean values) (Berechet, 2017)

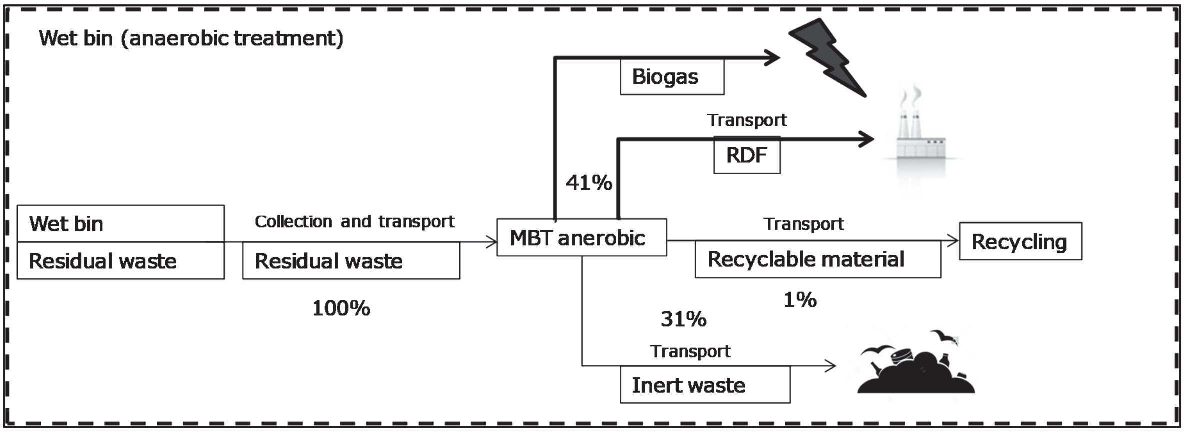

Fig. 2. Anaerobic treatment of waste from wet bin (mean values) (Berechet, 2017)

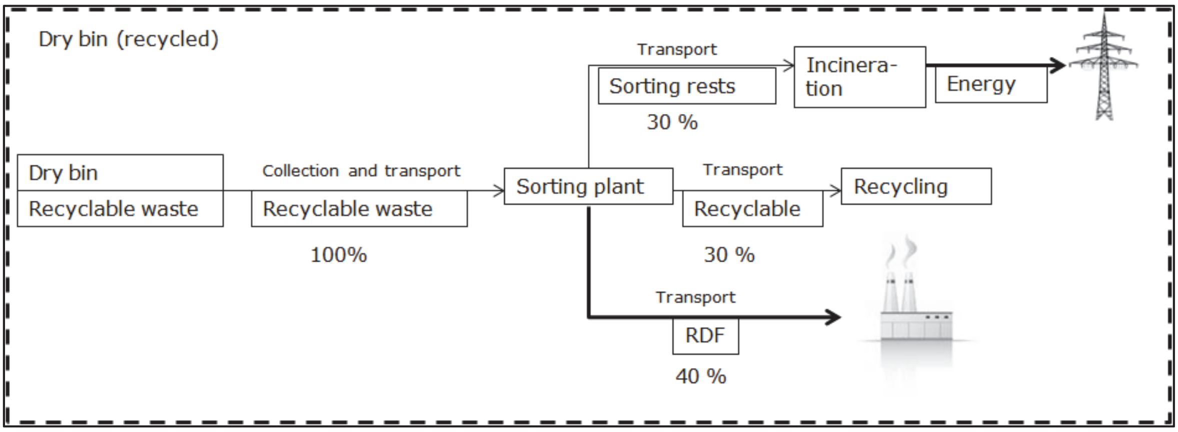

Fig. 3. Recycling of waste from dry bin (mean values) (Berechet, 2017)

3. Results and discussion

For the wet bin, in the case of a low sorting performance (50%), the most favorable solution is the anaerobic treatment in the mechanical biological treatment plant, the valorization of biogas representing an advantage. This leads to savings of over 18.000 t CO_2-eq. per year. The combination of anaerobic treatment of waste from wet bin with recycling of material from dry bin leads to savings of over 36.000 t CO2-eq per year.

An improved sorting behavior to a rate of 70% has a positive impact for the environment, making possible savings of over 23.000 t CO_2-eq. per year through the recycling of valuable material collected in the dry bin (Berechet, 2017). The combination with anaerobic treatment in mechanical biological treatment plant makes possible savings of over 40.000 t CO_2-eq. per year. The present solution in Timisoara with aerobic treatment in mechanical biological treatment plant leads to savings of around 10.000 t CO_2-eq. per year.

Montero et al. (2013) obtained in their comparative study of 8 mechanical biological treatment plants similar results, their savings values ranging between 6.400 and 53.000 t CO_2-eq. per year. Nevertheless it should be mentioned that such a solution like anaerobe treatment for residual waste can create difficulties in application due to the problems that the mixture, with a high content of inert material, causes to the fermentation process (Berechet, 2017).

The applied technologies, as well as the substitution of primary process, have a significant influence over the ecological evaluation of the scenarios. The primary processes cause emissions that can be avoided by recycling the waste. This happens especially in the case of metals and plastic material. Moreover, the RDF replaces the fossil fuels like coal or natural gas, the energy embodied in waste being recovered and used either in electrical or thermal form.

Processes like collection, sorting, transport or preparation lead to environmental pollution due among others to energy consumption. However, these are largely compensated by the substitution potentials of recycling and energy production. All these benefits can be credited in the waste management system. The value of crediting depends of course on the quality of the recyclable material. The secondary material replaces metals, plastic, paper and glass. When the secondary material can replace 1:1 the primary material than the allocated substitution factor equals 1 (Berechet, 2017). The substitution factors considered were 0,87 for glass, 0,87 for metal, 1 for plastic and 0,5 for paper (Scharpenberg, 2016).

4. Conclusions

On the case study of Timisoara it is demonstrated the positive impact on the environment – by saving global warming relevant emissions (CO_2 eq.) – that a waste management system can have when the principles of the circular economy are applied. It is time to acknowledge that waste is no longer a material to be eliminated but an important source for secondary resources. As it was shown above, separate collection of recyclable materials makes possible high quality secondary resources that could replace 1:1 primary resources. The sorting behavior of the population can influence the quality of these materials, therefore it is very important to educate, encourage and support it in the direction of recycling.

The modeling of the recovery scenarios by using the LCA approach showed the advantages of a modern waste management system, based on circular economy. Savings of over 40.000 t CO_2 -eq. per year would be possible in a city with 300.000 inhabitants. The model can be applied also to other cities provided the local conditions and frameworks are analyzed and all necessary adjustments are done. Further research should be done to analyze the opportunity of introducing the selective collection for the organic fraction. This would allow better valorization by producing high quality compost that can be used in agriculture. It is important that the EU focuses more on the significance of recycling and also in direction of the waste avoidance. The linear economy was based on consuming the natural resources and, since the resources available are limited, it is essential that we adopt solutions to protect them in order to allow also the next generations to benefit from them, while living in a healthy environment. The circular economy makes possible a sustainable development and it should be adopted as soon as possible.

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