Life cycle analysis in evaluation of household waste collection and transport in Cluj-Napoca, Romania

[1]Ioana N. Pop, [2]Gloria M. Sánchez de Ramírez, [1]Călin Baciu, [1]Nicoleta Bican-Brişan, [1]Octavian-Liviu Muntean, [1]Dan Costin

[1] Babeş-Bolyai University, Faculty of Environmental Science and Engineering, Cluj, Cluj-Napoca, Romania; [2] Federico Henríquez y Carvajal University, Santo Domingo, Dominican Republic. Corresponding author: I. N. Pop, nicoletapop612@yahoo.com

Abstract. Life Cycle Analysis (LCA) is widely used in studies related to improvement of waste management since it is the foundation for evidence based decision-making processes. However, few studies using LCA methodology have been performed on waste management in Cluj-Napoca, Romania, and there is a real need of improvement in this sector. Household waste management in Cluj-Napoca involves selective collection of waste at source on two fractions. Since a higher percent of the population lives in residential areas with block of flats and waste collection is organized for many families, it is difficult for waste selection to be performed properly on multiple waste fractions. Hence, the purposes of the study are: (1) to identify whether selective collection of waste at source on five fractions is more efficient in terms of environmental protection than collection of waste at source on only two fractions and (2) to identify the most appropriate solution for collection and transport of waste generated in Cluj-Napoca taking into consideration the environmental impact of the proposed scenarios. Several scenarios of collection and transport were taken in consideration and analyzed using SimaPro Software. CML IA baseline and ReCiPe Endpoint life cycle impact assessment methods were used. The lowest environmental impact in terms of transport and collection involved in waste management was identified to be for the scenario with collection and transport on two fractions. Since waste management in Cluj-Napoca is on the verge of being remodeled, this study could be a helpful planning tool in this process.

Key Words*:* LCA, SimaPro software, selective collection of waste, waste management.

Introduction. Life Cycle Analysis (LCA) is considered "the basis for a rational and evidence based decision-making process" (Pikoń 2015), therefore it is also used in analyzing waste management performance according to environmental requirements. There are many studies that applied LCA methodology as a tool in adopting the best waste management solution (e.g. Slagstad & Brattebo 2012; Di Maria et al 2014; Ghinea et al 2014; Leme et al 2014; Hossain et al 2016, etc).

Moreover, there are also studies that review the progress in this area of research, (Tascione & Raggi 2012; Abeliotis 2011). Generally, studies considered a number of scenarios from 2 to 24, and there are four main criteria commonly used to define scenarios: "standards and guidelines, good practice, focus on a specific waste management option and forecasts" as Tascione & Raggi (2012) concluded in their paper on the reviewed studies. Abeliotis (2011) identified the following aspects regarding to waste collection after reviewing 21 studies: „smaller volume containers have the greatest environmental impact; HDPE containers have greater impact compared to steel; the multi container collection system has the least environmental impact while the door-to-door system has the greatest; kerbside collection is environmentally better than collection in the bring system".

Furthermore, there is also an LCA study performed on waste management in Cluj County. Popita (2011) compared two scenarios: one that modelled commingled waste collection, transport and landfill of the whole quantity and a second one that added mechanical-biological treatment of organic fraction. The study indicated that second scenario is the best solution in terms of environmental impact. More scenarios of waste management in Cluj County were analysed in a study conducted by Popita (2012). However, the studies did not take into consideration more collection and transport options.

McDougall et al (2001) state that „collection is at the centre of an Integrated Waste Management system”. Therefore, the aim of the study is to identify the most appropriate solution for collection and transport of waste generated in Cluj-Napoca taking into consideration the environmental impact of the proposed scenarios.

The paper describes the waste management scenarios referring to the four stages that define Life Cycle Analysis according to McDougall et al (2001): Goal Definition, Inventory Analysis, Life Cycle Impact Assessment and Life Cycle Interpretation.

Household waste management in Cluj-Napoca. Cluj-Napoca is situated in the north-western part of Romania, in the centre of Cluj County, being also its main city, with an area of 179.5 km^2. It is an important university centre and the third Romanian city based on the number of inhabitants, with a population of 324.576 according to the 2011 census (www.cluj.insse.ro/).

Since the end of 2010, public administration of Cluj-Napoca delegated waste management according to Law 101 (2006) with amendments, for a period of at least 8 years. As a consequence, since then, two private operators have leased the service and they operate the collection, transport and treatment of household waste generated in Cluj-Napoca. Figure 1 presents household waste management system in Cluj-Napoca.

Figure 1. Household waste management system of Cluj-Napoca City (Pop et al 2014).

Local household waste management is based on the following elements that are also presented by Pop et al (2014):

1. Selective pre-collection of waste at source, by generators is performed on two fractions – humid fraction (organic waste and other residual waste) and dry fraction (recyclable waste – paper/cardboard, plastics, metals, glass) using containers or plastic bags received from the sanitation company; Local requirements allow household waste selection only on two fractions due to the lack of space needed for the five different waste containers on public places. However, even so, the selection degree is very low, especially in residential areas with block of flats; an increasing selective collection degree can be observed in residential areas with houses. To improve this aspect, in residential areas with block of flats coloured containers for different waste materials (blue – paper/cardboard, green – glass, yellow – plastics/metals) have been placed so that they can be used only by persons who select their waste.

2. Selective collection of waste by sanitation companies and transport is performed through a “Door to door” system on two fractions – humid and dry, in case of companies and population living in single houses and by surface containers in case of population living in block of flats. The collecting frequency is different according to generator type: (1) population that lives in single family houses: two or more collections per week; (2) population living in blocks of flats: daily collection; economic agents: depending on the generation rate (Pop et al 2014).

3. The *transport of waste* at the sorting facility and at the landfill is made with compactor trucks of different capacities. For the humid fraction of waste, compactor trucks with a capacity of 10 tones are used, while for recyclable waste, compactor trucks of 4 tones are used.

4. Sorting of the dry fraction of waste on different materials is performed at a manual sorting facility where waste is being treated (sorted and packed using a baling press) and then sent to final recyclers. However, there are low amounts of dry fraction as it is collected by the sanitation companies – about 20% of the humid fraction of waste and even a lower percent in residential areas with block of flats.

5. Landfilling of household waste on a local temporary deposit is still the most used waste treatment. However, waste pickers were also allowed to search for recyclable materials; since October 2015 when a new temporary deposit was built, according to data provided by the landfill operator, a 6% of recyclables are diverted from landfilling with the help of unqualified personnel.

6. The informal sector is also an active factor of waste management in Cluj-Napoca (Pop et al 2015a); there are also people known as “waste pickers” that sort waste from the bins of waste generators, from the landfill where waste is being deposited and also steal already sorted waste from the packaging waste bins (Pop el al 2015a). Strengths and weaknesses of this aspect are presented in a previous study by Pop el al (2015a).

In addition to the above presented processes there are also other authorized recyclable waste collectors that develop their activity within the city and collect waste randomly, based on contracts.

Composition of humid fraction of household waste and waste similar to household waste is presented in Figure 2 and represents the major fraction of waste since only a small percent of the population select their waste on two fractions and even a smaller percent of the population do that in residential areas with block of flats.

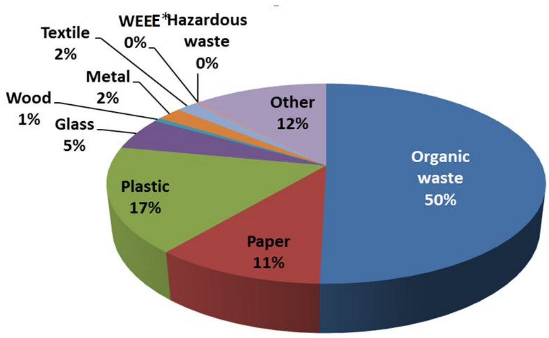

Figure 2. Composition of humid fraction of household waste and waste similar to household waste (Pop et al 2015b).

Nevertheless, an Integrated Waste Management System, funded by European Union is being prepared by the local authorities for the whole country. It includes a series of actions such as: (1) construction of an ecological landfill, sorting station and mechanical-biological transfer station; (2) implementing separate collection of waste on five fractions (plastics/metals, glass, paper/cardboard, biodegradable waste and residual waste); and (3) closing the current improper landfill from Pata Rat (Pop et al 2015b).

Goal definition and scope. The objectives of the study are the following: (1) to compare different alternatives for collection and transport of household waste generated in a specific area in Cluj-Napoca, Romania, (2) to analyze the environmental impact of the transportation in the proposed scenarios and (3) to identify the most suitable collection type in terms of environmental impact – collection and transport of mixed waste, on two fractions (humid fraction and dry fraction), or collection and transport of waste on five fractions (paper/cardboard, plastic/metals, glass, organics and residual waste).

Material and Method. The study refers mainly to household waste generated by population, and waste similar to household waste generated by economic agents and institutions.

The study area is represented by Manastur, one of the 11 major neighborhoods of the city and the largest one (aprox. 120,000 inhabitants), with 37% of the total number of Cluj-Napoca inhabitants (Figure 3). Manastur neighborhood is a residential area with block of flats and a higher population density. The reason for choosing this study area is the fact that the area is representative for the segment of population living in block of flats which predominantly do not collect their waste selectively.

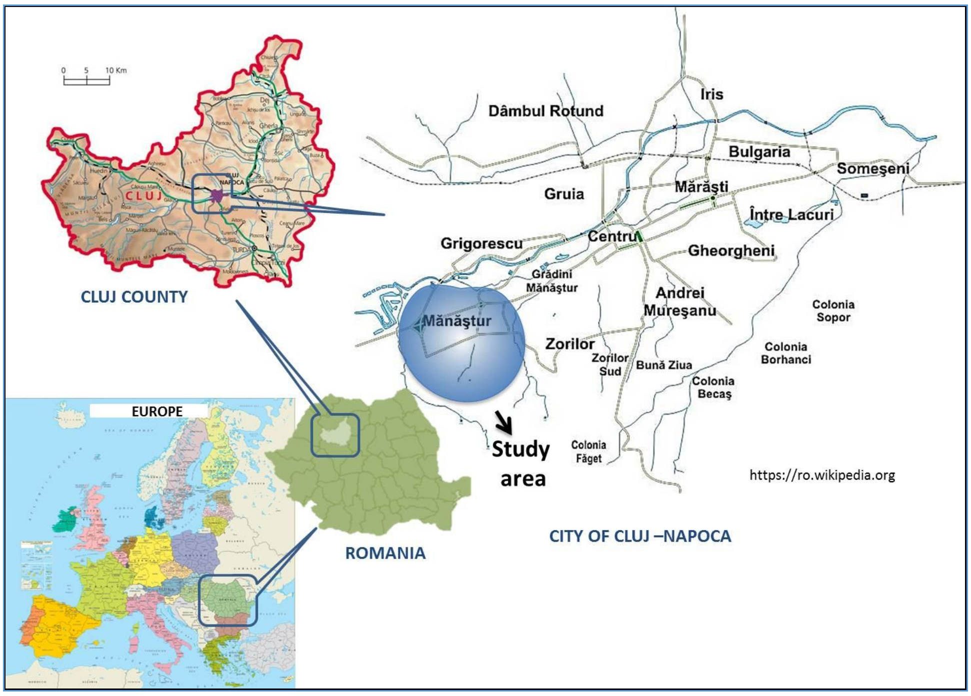

Figure 3. Location of the study – neighbourhoods of Cluj-Napoca.

The functional unit used for modelling the scenarios is 42.7 tonnes that is the total quantity of waste collected daily from the studied area.

Modelled scenarios. In order to accomplish the objectives of the study, 7 scenarios were taken into consideration and modelled using SimaPro Software. They focus mainly on a specific type of waste collection and transport on different forecasted collected recyclable waste. Waste treating options – landfilling and recycling were not analyzed in this study and were only considered from the perspective of waste quantity transported to the landfill or recycling facilities.

Scenario 0 describes the present situation for the selected area that is: transportation of waste on one fraction that is partly sorted at the temporary deposit and 6 % of that is diverted from landfilling and sent to recycling, according to the landfill operator registry. However, since the sorting facility is manual, the sorted materials are only paper/cardboard, plastics and metals. There it must be mentioned that, if the study area referred to the whole city, scenario 0 would include selective collection of waste on two fractions. Since the studied area is represented by Manastur neighborhood, collection and transportation of waste is made on one fraction because pre collection is made this way. This is mostly the reason for selecting this area for this study.

<u>Scenario 0B</u> assumes that collection and transport of waste is performed on one fraction and all the quantity is landfilled.

<u>Scenario 1</u> assumes that transportation of waste is performed on two fractions: dry fraction (paper, metal, plastic, and glass all together) and humid fractions (organics and other household waste); landfilling of humid fraction (65 %) and sorting and recycling of dry fraction (35 %) is considered in this scenario.

<u>Scenario 2</u> is similar to scenario 1 in terms of percent of deposited and recycled waste and transportation of on two fractions; the difference is that optimization of transport capacity was taken into consideration and a compression of transport routes was performed since the capacity of the vehicle transporting humid fraction is 10 t; therefore, a collection vehicle covered two areas instead of one; dry fraction is collected the same as in scenario 1 since the capacity of the vehicle is 4 tones;

<u>Scenario 2B</u> is similar to scenario 2 in terms of percent of deposited and recycling waste and transportation on two fractions; however, since there are no local recyclers in Cluj-Napoca, the rest of the scenarios used a transport distance for recyclable waste of 340-470 km, but for the modelling Scenario 2B a smaller distance until a local collector was used.

<u>Scenario 3</u> took into consideration collection and transportation of waste on 5 different fractions (organics, papers, plastic/metal, glass and residual), landfilling of 65% of the waste and recycling the rest of 35%.

<u>Scenario 4</u> is similar to scenario 3 in terms of collection and transport type, but it considered the fact that after sorting the 35% humid fraction, there could also be materials that cannot be recycled, so the recycled fraction is only 28% of the total collected waste.

Description of the modelled scenarios is summarized in Table 1.

Table 1

Description of modelled scenarios

Main characteristics/scenario	*SCN 0B*	*SCN 0*	*SCN 1*	*SCN 2*	*SCN 2B*	*SCN 3*	*SCN 4*
Collection & transport type (number of fractions)	1	1	2	2 (+transport optimization)	2 (+transport optimization)	5	5
Landfilled waste %	100	94	65	65	65	65	72
Recycled waste %	0	6	35	35	35	35	28
Distance to recycling/type of recycled material (Km)	0	340-470	340-470	340-470	30	340-470	340-470

Waste composition used in all scenarios, except Scenario 0, is determined by Pop et al (2015b) and presented in Figure 2.

Life cycle assessment methodology. The study was performed using SimaPro8 Software, version 8.1.1.16 Developer. As it can be seen in Table 2, SimaPro is the most widely used LCA software in modelling waste scenarios.

For the purpose of choosing the most suitable life cycle impact assessment (LCIA) method, a preliminary analysis was developed on similar peer-reviewed research articles. The results are synthesized in Table 2.

Table 2

Summary of software and LCIA methods used in several studies (Abeliotis 2011 modified)

Reference	*Software*	*LCIA method*
Chaya & Gweewala 2007	SimaPro5	Eco-Indicator
Iriarte et al 2009	SimaPro7	CML2 baseline 2000
Cherubini et al 2009	SimaPro7	Mid-point
Banar et al 2009	SimaPro7	CML
Rives et al 2010	SimaPro7	CML 2 baseline 2000
Merrild et al 2008	Easewaste	EDIP97
Toniolo et al 2013	None	IMPACT 2002+
Leme et al 2014	SimaPro7	CML 2000
Hossain et al 2016	SimaPro8	IMPACT 2002+
Di Maria et al 2014	None	CML
Slagstad & Brattebo 2012	Easewaste	EDIP97
Ghinea et al 2014	GaBi4	CML 2001
Bovea et al 2010	SimaPro7	CML
Rigamonti et al 2013	SimaPro7	CML 2001
Rigamonti et al 2009	SimaPro7	CML 2
Balaguer-Dátiz & Krishnan 2008	SimaPro7	Eco-Indicator 99
Di Maria & Micale 2014a	SimaPro7	CML 2

Therefore, the present study used two methods: (1) CML IA baseline method version 4.2, released by CML in April 2013, an update of the CML 2 baseline 2000 that uses a problem oriented mid-point approach and (2) ReCiPe Endpoint method, hierarchist version that uses a damage oriented endpoint approach (SimaPro8).

Hence, the environmental impact was analyzed using the two approaches mentioned above and, as described by Hossain et al (2016): (1) the problem oriented mid-points approach, that translates the environmental impact into the following phenomena: abiotic depletion (AP), abiotic depletion- fossil fuel, global warming potential (GWP), ozone layer depletion, human toxicity potential (HTP), fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestial ecotoxicity, photochemical oxidation, acidification potential (AP) and eutrophication potential (EP), using the CML method and (2) the damage oriented endpoint approach that models the impact upon: human health, ecosystems and resources using ReCiPe Endpoint method.

Life cycle inventory analysis. In the scenario modelling, databases were used as follows: Ecoinvent, Industry data 2.0, ELCD. Since the Inventory Analysis as it is extracted from SimaPro Software is a long one, Table 3 presents a summary of the input data used in the study.

The amount of energy used in recycling process was: 0.83 kw/h/kg of recycled paper, 3.16 kw/h/kg of recycled glass and 2288.88 kw/h/kg of recycled aluminium (Pikoń 2015) and 16.66 kw/h/kg of recycled PET (University of Cambridge 2005).

In addition, the study used waste generation and transportation data from Mănăștur neighborhood. Waste generated in the studied area is collected with auto compactor trucks – Euro 4 that can carry up to 10 tonnes of waste. There are six transportation routes, with daily frequency. The estimated characteristics of each transport route are presented in Table 4.

Table 3

Input data from databases existing on SimaPro used in LCIA (Source: SimaPro8)

Process/material used	*Database*	*Short description (source: SimaPro8)*
Transport, municipal waste collection, lorry 21 t/CH S (for humid fraction or unsorted waste)	Ecoinvent	"Included processes: Diesel fuel consumption, air emissions from fuel combustion for Stop&Go driving, tyre abrasion, brake lining abrasion, road abrasion and re-suspended road dust."
Small lorry transport, Euro 0, 1, 2, 3, 4 mix, 7,5 t total weight, 3,3 t max payload RER S (for recyclable waste)	ELCD	"Payload of the lorry is 3.3 t; its utilization ratio is 85%. The following combustion emissions (measured data) of the lorry are taken into account: ammonia, benzene, carbon dioxide, carbon monoxide, methane, nitrogen oxides, nitrous oxide, NMVOC, particulate PM 2.5, sulphur dioxide, toluene, and xylene. NMVOC, toluene and xylene emissions of the vehicle result from imperfect combustion and evaporation losses via diffusion through the tank. Lorry fuelled by diesel. Data set includes the whole fuel supply chain from exploration and extraction of crude oil over preparation to transportation to consumer. The background system is addressed as follows: Refinery products: Diesel, gasoline, technical gases, fuel oils, basic oils and residues such as bitumen are modelled via a country-specific, refinery parameterized model."
Sanitary landfill facility/CH/I S	Ecoinvent	"Included processes: infrastructure materials for landfill construction, operation and aftercare. Including access road. Remark: landfill for untreated municipal solid waste. 1.8 million m^3 volume. Construction phase is 5 years; use phase is 30 years; aftercare phase is 150 years. Average waste density 1000 kg/m^3. Geography: Specific to the technology encountered in Switzerland in 2000. Well applicable to modern landfilling practices in Europe, North America or Japan. Technology: Swiss municipal landfill for biogenic or untreated municipal waste ('reactive organic landfill'). Landfill gas and leachate collection system. Recultivation and monitoring for 150 years after closure."
Electricity, medium voltage, production RO, at grid/RO S (electricity for recycling)	Ecoinvent	"Included processes: electricity production in Romania, the transmission network and direct SF6-emissions to air; Electricity losses during medium-voltage transmission and transformation from high-voltage are accounted for. Technology: Average technology used to transmit and distribute electricity. Includes underground and overhead lines, as well as air- vacuum- and SF6-insulated high-to-medium voltage switching stations. Electricity production according to related datasets".
Aluminium scrap, old, at plant/RER U	Ecoinvent	"Included processes: Collecting, sorting and preparing (cleaning, pressing) of post-consumer aluminium scrap."
Waste paper, mixed, from public collection, for further treatment/RER S	Ecoinvent	"Included processes: transportation efforts for the collection as well as the further transportation to the next paper production site/paper sorting plant. No further efforts are included into this module. The collected waste paper has a biogenic C content of 40.4%;"

Process/material used	Database	Short description (source: SimaPro8)
PET bottles E	Industry data (Plastics Europe 2005)	www.plasticseurope.org
Glass, from public collection, unsorted/RER S	Ecoinvent	"Included processes: This module includes the transportation efforts for the collection as well as the further transportation to the next glass production site/glass sorting plant. No further efforts are included into this module. Technology: An average European situation with public collection points is assumed for this module."
Biowaste, at collection point/CH S	Ecoinvent	"Included processes: Transport processes required to collect the biowaste from households and deliver it to the treatment plant. In addition a credit entry accounting for the extraction of CO_2 from the atmosphere is accounted for. Technology: garbage truck for municipal waste collection."

Table 4

Input of transportation characteristics of the study area

Route code (area)	*Km/area (collection and transport to landfill)*	*Km/area (transport to landfill)*	*Km/area (collection)*	*Transported quantity of wast (t)/day*
1	56.95	30	26.95	6.8
2	58.35	30	28.35	6.7
3	66.44	30	36.44	8.0
4	64.7	30	34.7	6.6
5	58.97	30	28.97	7.0
6	50.11	30	20.11	7.7
Total	355.52	180	175.52	42.7

Results and Discussion

Life cycle impact assessment and life cycle interpretation. Life cycle impact assessment using CML method – normalisation, reveals that the highest impact of the scenarios is on the marine aquatic ecotoxicity followed by global warming and acidification; the lower impact of all scenarios is identified on abiotic depletion and on ozone layer depletion (Figure 4).

Moreover, the analysis indicates that the most favorable results for almost all impact categories in the transportation phase (CML method) is given by Scenario 1 that modelled selective collection and transport of waste on two fractions and a recycling degree of 35% of the generated waste (Figure 4 and Figure 5).

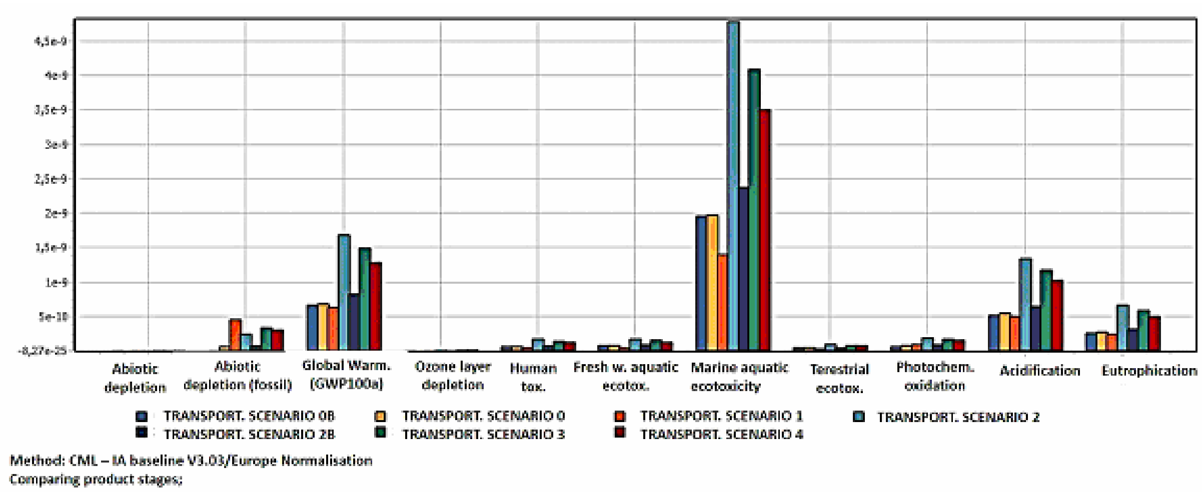

Figure 4. LCIA of transportation phase of all modelled scenarios – CML –Normalisation (SimaPro8).

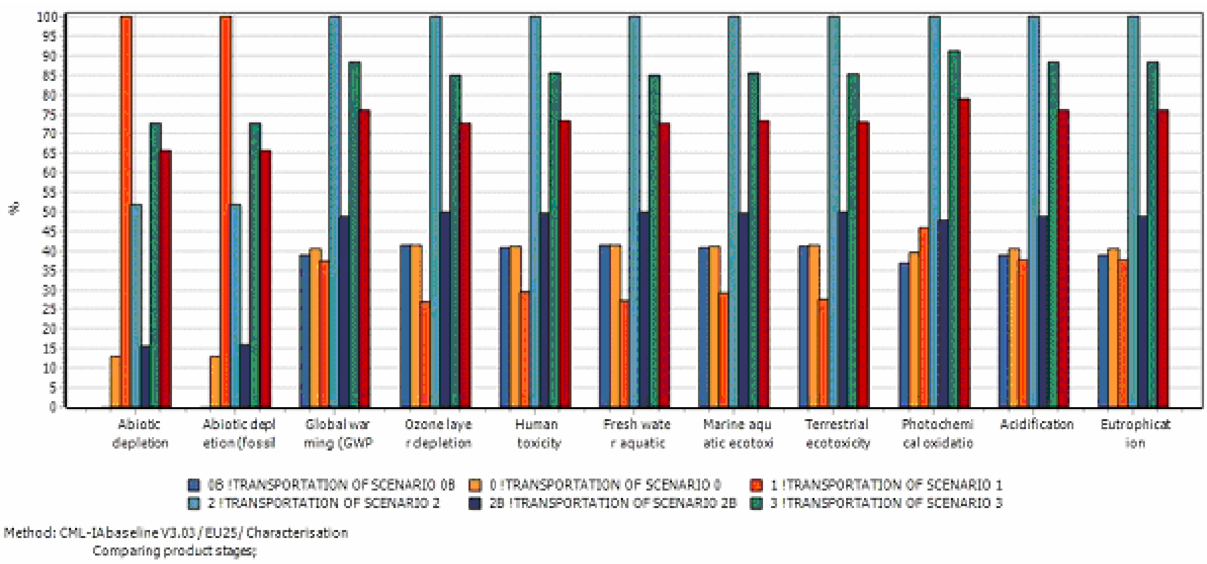

Figure 5. LCIA of transportation phase of all modelled scenarios – CML –Characterization (SimaPro8).

McDougall et al (2001) also agree that additional trucks involved in waste collection increase environmental impacts due to vehicle emissions, but also give solutions for that matter like (1) using a specially designed truck with multiple compartments – two for recyclables and one for organic waste, alternative introduced in Worthing, United Kingdom, or (2) co-mingled collection with one truck but in different colour bags that are afterwards sorted, alternative used in Omaha, Nebraska.

However, life cycle impact assessment using ReCiPe method – Single Score indicates that the impact of Scenario 1, the one with collection of waste on two fractions and transport of 35 % of waste to recycling and the rest to landfilling, is similar to the impact generated by Scenario 0B and Scenario 0 that imply waste collection on one fraction and transport of all waste to landfill respectively transport 6% of waste to recycling (Figure 6). That can be explained by the fact that considerable impact is given by transportation to recycling that represents between 340-470 km/waste material type. This explanation is also supported by the impact difference between Scenario 2 and Scenario 2B that are different only in terms of the distance to waste recyclers; Scenario 2B considers that recyclable fraction is transported to local recyclers (30 km/waste material type) while Scenario 2 considers that recyclable waste is transported to a distance of 340-470 km (Figure 6).

Efficiency in both economic and environmental terms means that waste management must be performed with the minimal use of transport (McDougall et al 2001). Therefore, one of the main measures for environmental impact minimization can be optimization of distance transportation to waste recyclers; local investors should be encouraged by the local authorities, so that facilities of waste treatment and recycling to be created.

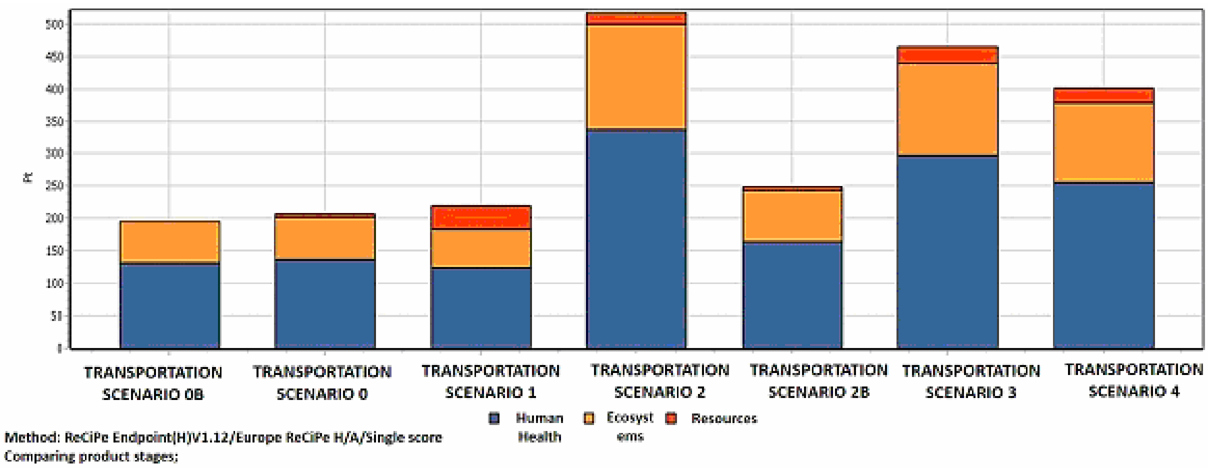

Figure 6. LCIA of transportation phase of all modelled scenarios – ReCiPe - Single Score (SimaPro8).

For a detailed analysis, Figure 7, Figure 8 and Figure 9 present the results of the LCIA of the collection phase and transport from waste generators of scenarios 0-4 performed with the ReCiPe Endpoint method.

In terms of transportation, Scenario 0, with collection of waste on one fraction and transport of the whole quantity to landfill has the biggest impact as indicated by Figure 7.

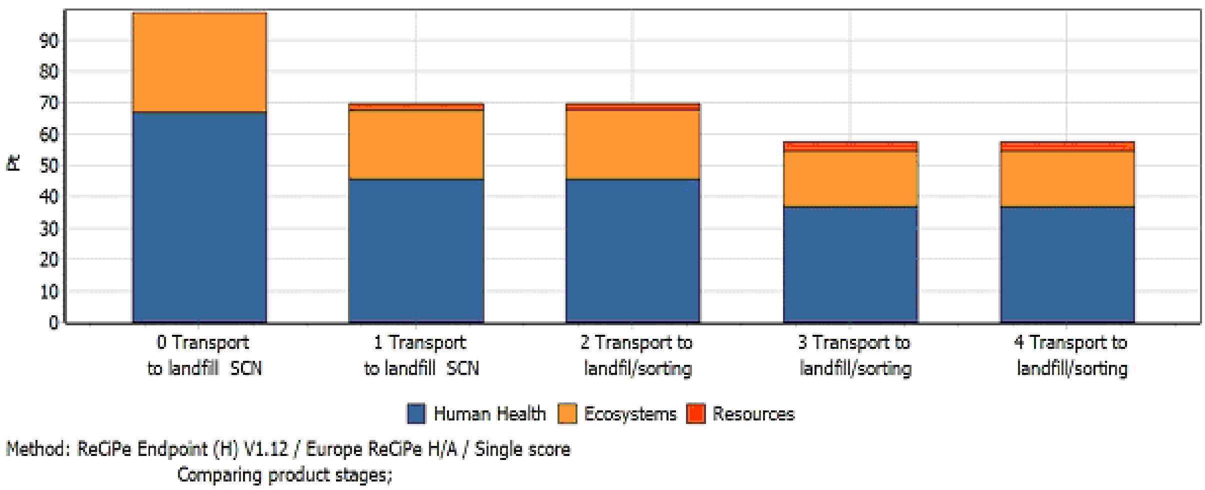

Figure 7. LCIA of transportation to landfill/sorting phase of Scenarios 0- 4– ReCiPe – Single Score (SimaPro8).

The fact that selective collection of waste on two fractions represented by Scenario 1 is the most environmental friendly is also underlined through ReCiPe method – Single Score represented in Figure 8 and by the analysis using ReCiPe method –Weighting represented in Figure 9. Moreover, there is no difference of impact upon any of the three components – human health, ecosystems and resources between scenarios 3 and 4 that both imply selective collection of waste on two fractions but differ in percent of recycled waste (Figure 8).

ReCiPe method indicates that the major impact reflects upon human health component (Figure 6, Figure 7, Figure 8 and Figure 9).

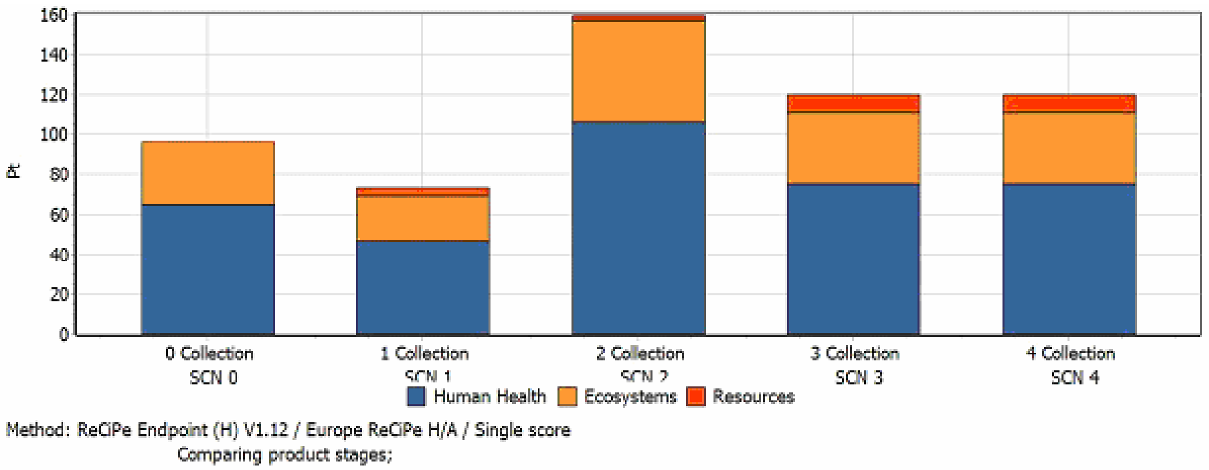

Figure 8. LCIA of Collection phase of Scenarios 0-4 – ReCiPe – Single Score (SimaPro8).

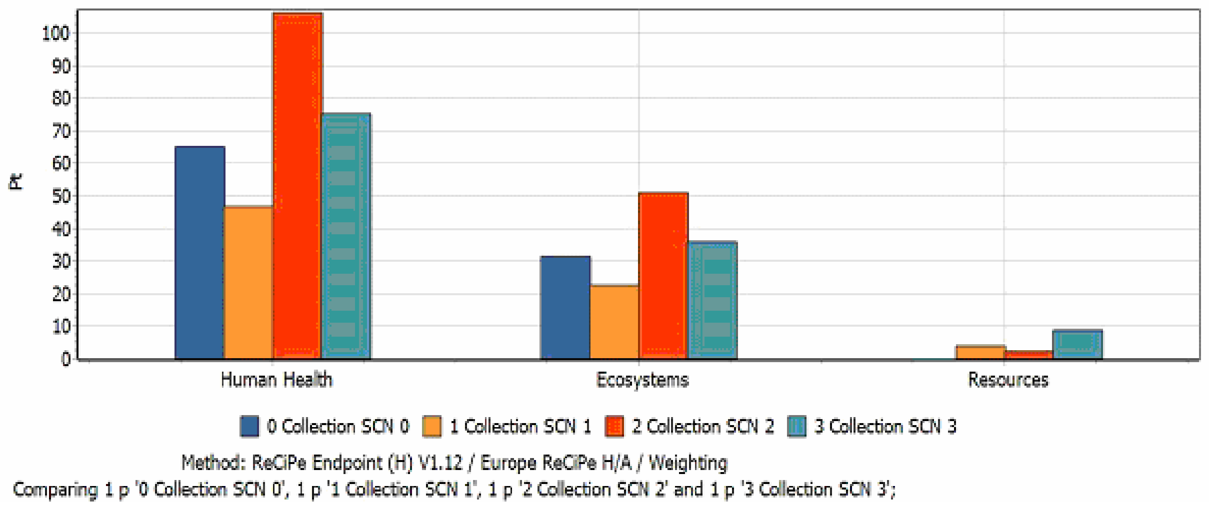

Figure 9. LCIA of Collection phase of Scenarios 0-4 – ReCiPe – Weighting (SimaPro8).

Conclusions. In conclusion, the lowest environmental impact in terms of waste collection and transport type is given by the scenario with separate collection of waste on two fractions and transport to recycling of a 35% of the generated waste. Moreover, transport to recycling ads extra impact to the scenarios considering the fact that recyclable waste is transported to 340–470 km from the generation site.

Therefore, according to the results of this study, in order to minimize the environmental impact of waste management in Cluj-Napoca, the following measures should be adopted: waste generated in Cluj-Napoca should be collected separately on two fractions; a sorting facility should be integrated in the process of waste management at local level; however, to reduce costs and environmental impact of the sorting facility, a split-compartment vehicle could be used; quantity of recyclable waste collected separately from the organic waste should be increased to the maximum capacity of 35% of the generated waste; a local recycling facility should be considered.

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Authors:

Ioana Nicoleta Pop, Babeş-Bolyai University, Faculty of Environmental Science and Engineering, Romania, Cluj, Cluj-Napoca, 400294, 30 Fantanele Street, e-mail: nicoletapop612@yahoo.com

Gloria Maria Sánchez de Ramírez, Federico Henríquez y Carvajal University, Technology and Innovation, Department of Science, Dominican Republic, Santo Domingo, 100 Isabel Aguilar Street, e-mail: gsanchez@ufhec.edu.do

Călin Baciu, Babeş-Bolyai University, Faculty of Environmental Science and Engineering, Romania, Cluj, Cluj-Napoca, 400294, e-mail: calin.baciu@ubbcluj.ro

Nicoleta Bican-Brişan, Babeş-Bolyai University, Faculty of Environmental Science and Engineering, Romania, Cluj, Cluj-Napoca, 400294, e-mail: nicoleta.brisan@ubbcluj.ro

Octavian-Liviu Muntean, Babeş-Bolyai University, Faculty of Environmental Science and Engineering, Romania, Cluj, Cluj-Napoca, 400294, e-mail: liviu.muntean@ubbcluj.ro

Dan Costin, Babeş-Bolyai University, Faculty of Environmental Science and Engineering, Romania, Cluj, Cluj-Napoca, 400294, e-mail: dan.costin@ubbcluj.ro

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