WASTE MANAGEMENT AND RECOVERY OF FIBRES – THE IMPACT ON CLIMATE CHANGE

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I. Introduction

Integrated Solid Waste Management (ISWM) is a wide-ranging program for waste prevention, recycling, composting and disposal, since improperly managed solid waste poses risks to human health and the environment. Inappropriate waste management also increases greenhouse gas (GHG) emissions, which contribute to climate change (ISWA, 2009; USEPA, 2006). Diverse wastes and waste management actions can induce various impacts on energy consumption, methane emissions, and carbon storage, which, at their turn, have the potential to generate greenhouse gas emissions. The correlation between municipal solid waste management and greenhouse gases (GHG) emission can be made based on the amount and composition of waste (Chen and Lin, 2008). Waste management systems include temporary storage of waste in containers, collection and transport and treatment/elimination process such as recycling, composting, anaerobic digestion, incineration, landfilling.

Methods associated to solid waste treatment can significantly contribute to the emissions in atmosphere of greenhouse gasses, while each waste fraction has a different GHG emission potential, depending on the type of method applied (Calbro, 2009; Chen and Lin, 2008). When the waste management practices are analyzed, the following particular aspects can be found (Fig. 1): GHG emissions and especially CO_2 resulted from waste collection and transport are the consequence of the use of fuel by vehicle; recycling can offer substantial GHG emission savings; composting is an energy consuming aerobic process which implies CO_2 emission and carbon storage in the soil, because of the application of compost; anaerobic treatment of solid waste generates significant quantities of biogas, associated with CH_4 and N_2O emission; incineration, used to minimize the volume of solid waste to be disposed in landfills and to obtain energy is accompanied by the appearance of emissions containing nitrous oxide (N_2O) and carbon dioxide (CO_2) as main emission that contributes to climate changes; biogas produced from landfilling of solid waste contains mainly methane and carbon dioxide, relevant for the global warming phenomenon (Calbro, 2009; Chen and Lin, 2008; ISWA, 2009; USEPA, 2006).

In municipal solid waste systems a particular interest can be given to the separate collection of collection of waste paper and used cardboard, and reuse as raw material in the production of some categories of papers. This way, less energy is consumed, wood can be conserved and savings in term of GHG emission could be registered even during the manufacturing process (ISWA, 2009).

Based on the previous considerations, this paper analyses the relation between various scenarios for municipal solid waste management and waste paper recycling on the one hand, and the impacts generated in the environment by these scenarios, in terms of climate change, on the other hand. Aside from this goal, the impacts of paper manufacturing process based on waste paper (recovered paper, in fact) are assesses in terms of climate change, as well.

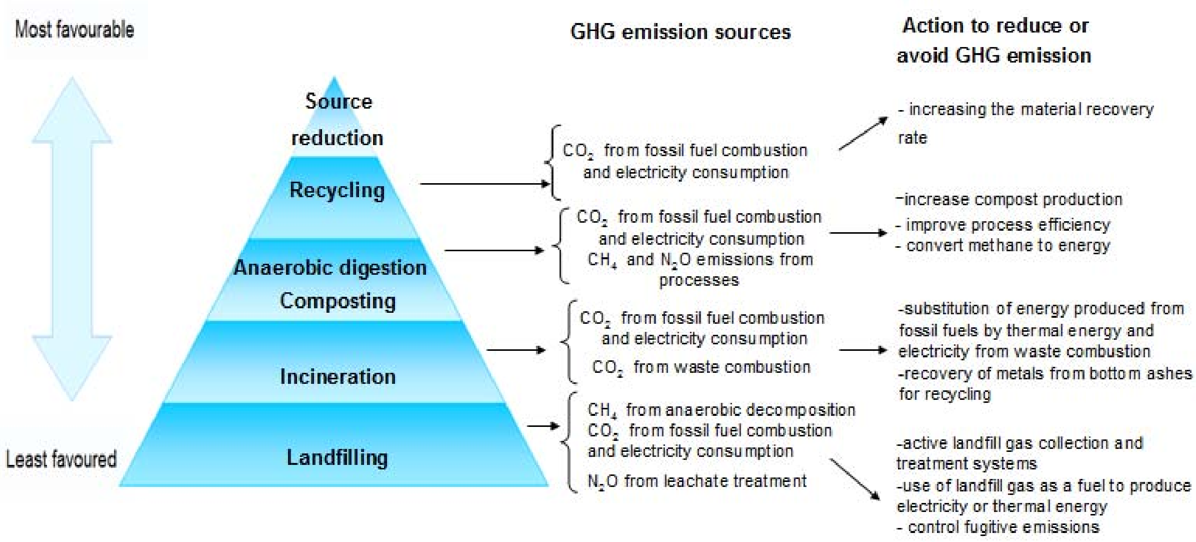

Fig. 1. Waste management and GHG

II. Life cycle assessment of municipal solid waste management scenarios

II.1. Description of the studied area

Municipal solid waste management scenarios were developed for Iasi city, located in the Nord East of Romania in the central zone of Moldavia, having the situation from 2008 as a reference.

In 2008 The city of Iasi had 391,654 inhabitants (Doba et al., 2008; INS, 2010). In the same year, 272,184 t of municipal solid waste were generated and collected in the city (Iasi County Council, 2009). Today, the municipal solid waste is collected by a public company of local interest, but the separate collection is still at the beginning, being carried out at some pilot projects levels and for materials with high market values, like paper and cardboard, and also PET (BALKWASTE, 2010; Doba et al., 2008; Ghinea and Gavrilescu, 2010a; Iasi County Council, 2009). In 2008, solid waste was collected and landfilled without collection and treatment of leachate and collection of biogas. After 2009, the situation of municipal waste treatment has been improved a little, because a new landfill provided with collection and treatment of leachate and landfill gas was put into operation. Also a composting station is under construction (Iasi County Council, 2009). Various alternatives to the actual system were proposed because the environmental impacts of the municipal solid waste management system are negative and the quantities of municipal solid waste will increase in time.

Negative environmental impacts that occur at three stages in the life cycle of paper, beginning with the harvesting of trees for fibres, continuing with the processing of wood fibres into pulp for making paper, and finishing with the disposal of paper products at the end of their useful life are assessed considering the paper manufacturing process based on recovered paper in a Romanian factory.

II.2. Methodology

Life cycle assessment (LCA) methodology was used to evaluate the environmental impacts of waste management systems and paper manufacturing process from recovered fibres. In recent years various tools were developed based on LCA methodology and applied to evaluate different systems (Ghinea and Gavrilescu, 2010b; Ghinea and Gavrilescu 2011; Ness et al., 2007; Winkler and Bilitewski, 2007). This work has been developed using GaBi4 software, which allows rapid simulation and modelling of complex systems and assessment of the potential environmental impacts based on various LCA methodologies such as CML 2001, CML 96, EDIP 1997, EDIP 2003, EI99 etc. (PE International, 2009). These methodologies can be divided in into theme oriented methods (problem oriented, mid-points approach) (CML, EDIP) and damage oriented methods (EI99, IMPACT 2002+), (PE International, 2009).

II.2.1. Functional unit and system boundaries

Seven different scenarios of municipal solid waste management that include temporary storage of waste in containers, collection and transport of waste and different treatment/disposal methods were developed and evaluated with Gabi4. The functional unit represents the amount of waste that will be generated in Iasi in 2018. This amount was forecasted with Waste Prognostic Tool based on the quantity of solid waste generated in 2008 in Iasi (Ghinea and Gavrilescu, 2010a). The system boundaries for solid waste management system include the main processes but also background system which comprises the secondary materials that enters and leave the waste management system.

II.2.2. Scenarios

Scenarios developed represents the past (first scenario), actual municipal solid waste management existent in Iasi (second scenario) and possible alternatives to the actual system (scenarios 3-7). All scenarios include temporary storage, collection and transport of municipal solid waste:

- the **first scenario** addresses **landfilling** a method for waste elimination, without collection and treatment of leachate and without collection of landfill gas;
- in the **second scenario** landfilling is the only method for elimination of waste, but with collection and treatment of leachate and capture of biogas;
- **scenarios 3-7** are processing methods for waste such as: recycling of materials, composting and anaerobic digestion of organic waste and also incineration and landfilling of residual waste:
    - scenario 3: composting and landfilling;
    - scenario 4: recycling, composting and landfilling
    - scenario 5: recycling, composting, incineration and landfilling;
    - scenario 6: recycling, composting, anaerobic digestion;
    - scenario 7: recycling, composting and incineration.

For a successful development of the study the waste management systems design must be adapted to the local conditions and needs (ISWA, 2009).

II.2.3. Inventory analysis

The data for life cycle inventory were taken from literature, statistics, documents from local environmental authorities, calculated and estimated. The necessary data for temporary storage of waste, such as the number of containers, the annual quantity of material required for containers fabrication, the emissions resulted from material manufacturing for bins were calculated based on den Boer et al. (2005) and on database from GaBi software. The number of vehicles and loading capacity (30 vehicles with total loading capacity of 1881 m^3) (Doba et al., 2008), transport distance, fuel consumption (30 L/100 km) (den Boer et al., 2005) and emissions from fuel consumption (calculated based on emission resulted from burning of 1 kg of diesel) (Recycled Organics Unit, 2003) are data taken in consideration for collection and transport of municipal solid waste. For the composting process the data were calculated using specific literature and software database. It was assumed that the total fuel consumption during composting operations is 5.53 L per tonne of waste (Recycled Organics Unit, 2003), electricity demand are 10 kWh/t, water demand are 2% from input mass; also the waste water represents 125 L/t input according to den Boer et al. (2005). Emission resulted from composting process are represented by emission to air which include CO_2 (95% from %C emission to air), CH_4 (3% from %C emission to air), NH_3 (96% from % N emission to air) and by emission to water: NH_3 (47% from % N emission to water), carbon organic (100% from % C emission to water) (den Boer et al., 2005). The amount of fresh compost obtained from composting represents 72.2% from the whole quantity of waste composted. After maturation of the fresh compost, it can be applied on soil and substituting the phosphorus and nitrogen synthetic fertilizer.

The inputs and outputs from landfilling of municipal solid waste were calculated emphasizing especially landfill gas and leachate. Gas volume was calculated and converted to weight, also the profile of biogas were also calculated according to Buning (2004). The emission in water and soil due to leachate were also calculated and estimated. Also the inputs and outputs for every stage of the processes like anaerobic digestion and incineration were calculated and estimated according to the literature and database of the Gabi software.

II.3. Calculated impacts of the proposed waste management scenarios

Althought the evaluation of impacts for the proposed scenarios with GaBi software can address different impact categories (acidification potential, eutrophication potential, global warming potential, human toxicity etc.) only the results associated to the climate change impact category are discussed. The global warming impact is presented in normalized values for EU 25+3 and EU (Fig. 2).

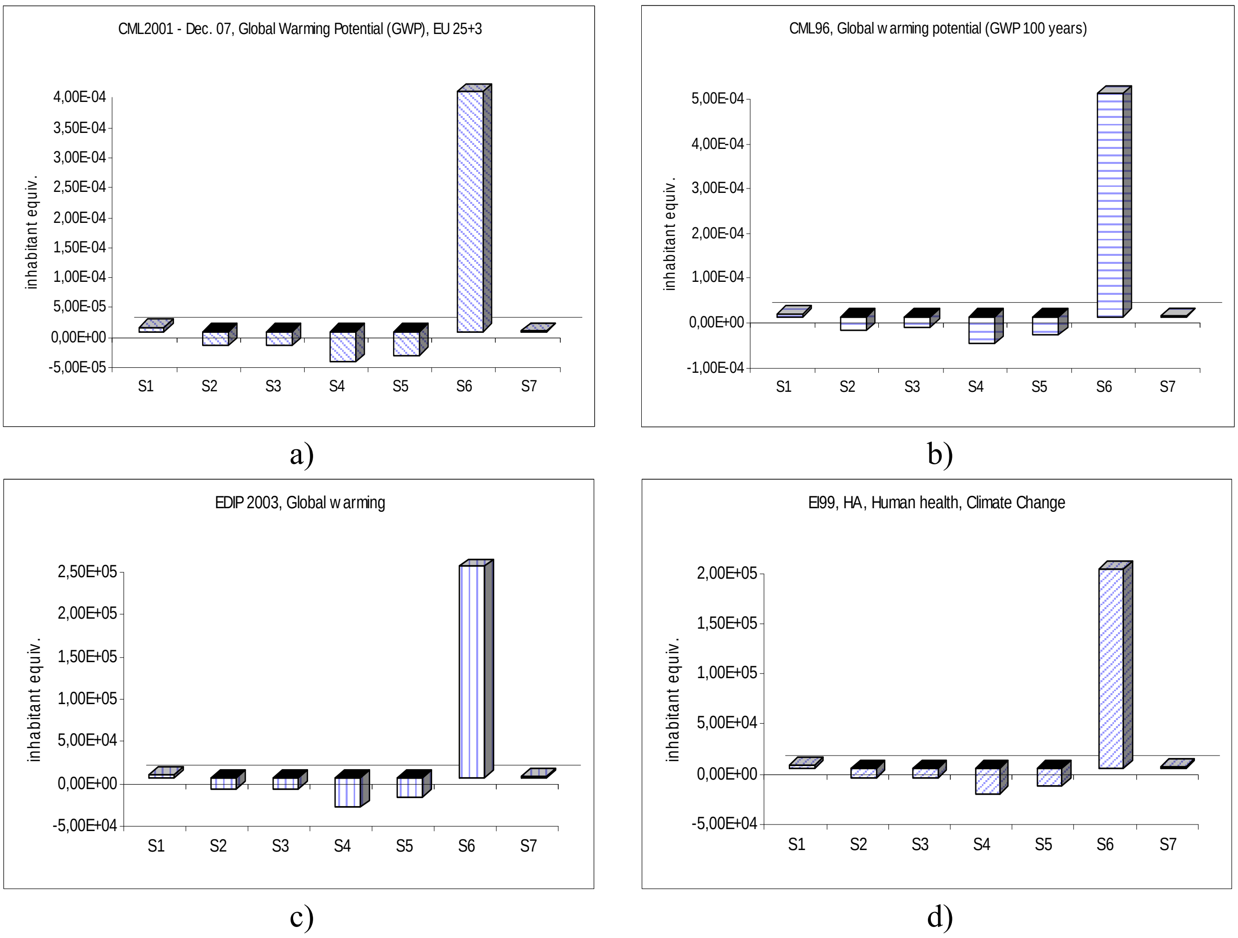

Fig. 2. Global warming potential for the analysed scenarios

In all methodologies analysed (CML 2001, CML 96, EDIP 2003, EI99) the scenarios 1, 6 and 7 represents scenarios with a negative impact for the climate change impact category, while scenarios 2, 3, 4 and 5 have positive impact. Scenario 6, which includes recycling of materials, composting and anaerobic digestion of organic waste, landfilling of residual waste was found to generate the most negative impact.

The most environmental friendly scenario from the climate change point of view is scenario 4, which includes: recycling of materials, composting of organic waste and landfilling of residual waste with treatment of leachate and use of biogas for electricity. Scenario 4 is followed closely by scenario 5, which consists of recycling of materials, composting of organic waste, incineration and landfilling of residual waste.

Using the results obtained for all amounts of waste processed in the scenarios presented above, it was calculated **kg CO_2 – equiv. for one ton of municipal solid waste**. One ton of municipal solid waste containing 9% biowaste, 3% garden waste, 15% paper and cardboard, 54% residual waste, 8% glass, 3% metals and 8% plastics contributes to the global emission of greenhouse gases with 18 kg CO_2 –equiv./ t of waste from collection and transport of this ton.

If one ton of municipal solid waste with the composition listed above is landfilled without collection and treatment of leachate and use of biogas for production of electricity, 94 kg CO_2 – equiv. will result. Also, when one ton of waste which contains 95% residual waste and 5% garden waste is incinerated, the calculated emission is of 303 kg CO_2 – equiv./t of waste. By composting one ton of biowaste, it results 247 kg CO_2 – equiv./t of waste, while 55 kg CO_2 – equiv./t of waste results from anaerobic digestion of the same quantity of biowaste.

By recycling waste, emissions are avoided, equivalent to (- 433 kg CO_2) – equiv./t plastic and (- 3277 kg CO_2) – equiv./t metals (sign minus means savings).

III. Life cycle assessment of recycled paper as raw material in the production of paper

III.1. Description of paper manufacturing based on recycled paper

The pulp and paper industry has always been considered a major user of natural resources (wood, water), energy (fossil fuels, electricity), and a significant polluter (Petraru and Gavrilescu, 2011). The characteristics of a sheet of paper depend mainly on the raw material used for pulp production, which might be wood, agricultural residues, waste paper, or other non-wood materials. Nowadays recovered paper is the most important source of fibre used in papermaking and provides about half of the total fibre used for papermaking in Europe (Stawicki and Read, 2010).

In the last years recovered fibre has become an indispensable raw material for the paper manufacturing industry due to the favourable price of recovered fibres in comparison with the market pulp (Petraru and Gavrilescu, 2010). The main environmental impacts from the pulping process originate from energy required for the process and the emissions to air and water from the pulping or bleaching processes (IPPC, 2001).

Recycling paper leads to efficient use of natural resources and supports sustainable development. Wood fibre can be recycled several times and paper can be made from recycled fibre alone (IPPC, 2001). In order to be recycled, papers and boards must be collected and sorted at source, to separate white papers from brown papers. It is very important that papers and board are not mixed with other wastes because the paper quality will decrease.

The statistics for 2005 show that EU‘s recovered paper collection rate was 62.5% with 55.6 million tons of paper and board collected for recycling. The EU exported about 7 million tons of recovered paper outside the region, mainly to Asia, and 48.7 million tons were utilized in paper manufacturing, but due to process losses and related factors about 85 to 90% of this volume ended up in the paper or board product (Stawicki and Read, 2010).

The recycled waste paper has to meet the quality criteria stipulated in the SR EN ISO 634:2003 (Vrancart, 2008). Waste paper must: not contain foreign elements (metals, wood, glass, rubber, celluloid, leather, textile strings, plastic, wax, polythene and other synthetic resins, waterproof paper, etc.); not contain dirt, earth, carbon black, toxic products packages; not be decayed or musty; be of maximum 10% moisture.

Some of the main environmental impacts of the paper industry are (Gavrilescu et al., 2008): accumulated toxic chemicals in rivers; toxic chemical pollution - many toxic chemicals are used in paper making; air pollution – with air pollutants such as carbon dioxide, nitrous oxides, sulfur dioxides, carbon monoxides, and particulates; energy consumption – paper making requires large amounts of electricity from public utilities or from own power plants, which are significant contributors to the air pollution; water consumption - paper making uses a large quantity of water; solid waste: paper making generally produces a large amount of solid waste.

III.2. Paper manufacturing scenarios using recovered paper as raw material

The recovery of waste paper and conversion into recycled fibres were modeled using three scenarios based on the environmental burden assigned to the first cycle of paper. As the number of uses will increase the burden from the paper's first life will decrease (Madesn, 2007). Considering these approaches paper were assessed three scenarios using the principle for allocating first life and assuming three uses with a burden of **80%, 60% and respectively 40% from products manufactured with virgin fibre.**

The tissue paper systems investigated include all stages of the manufacturing process of tissue products. For each stage of the life cycle were determined and calculated inputs, outputs and emissions reported to the functional unit. The functional unit for this study is 1000 kg of tissue product. Studies have proved that users of 100% virgin products have experienced greater absorbency for both oil and water than users of 100% recycled fibre products.

Fig. 3 details the main life cycle stages that were included in the life cycle of the tissue paper product system.

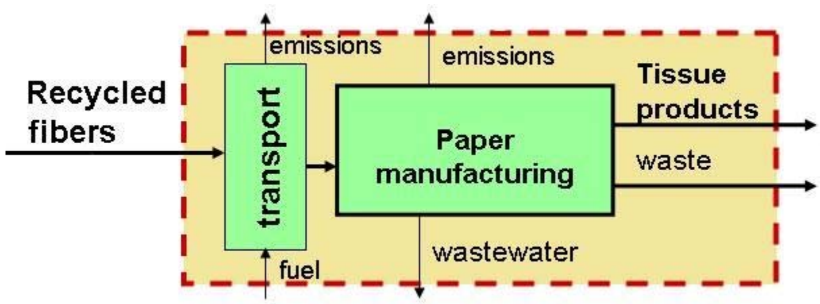

Fig. 3. Life cycle of tissue products from recovered fibre

For each of the tissue manufacturing systems, inventories of significant environmental flows to and from the environment, and internal material and energy flows, were produced. Inventory data were collected for the purpose of characterization the highlighted subsystems in the paper life cycle. For tissue paper the energy consumption varies between 400-500 kWh/t, chemicals demand in the manufacturing process consist of 0.0-1% H_2O_2 for repulping, 0.3-0.6 % soap for flotation, 1-2% H_2O_2, 0.5-1.2 % NaOH, 1-1.8% Na_2SiO_3, 0.4-1% dithionite for bleaching (IPPC, 2001).

The main environmental impacts from the pulping process originate from the production of the energy required for the process and the emissions to air (Table 1) and water from the pulping and bleaching processes (Madsen, 2007). The energy requirements for tissue production include de-inking and pulping operations, tissue machine (pulp to reel), converting (reel to dock) and heating. The energy consumption profiles for the different products have been established using technology-specific energy performance standard for tissue machines (Holik, 2006; IPPC, 2001; Madsen, 2007).

The water use for tissue operations was established using standard water quantity reflecting the expected water requirements per unit of tissue material production. The emissions level were taken from available sources, mills and reports and determined by reporting them to the functional unit (Abbassi and Abbassi, 2004; IPPC, 2001).

Table 1. Air emissions from the RCF process (IPPC, 2001; Recycled Organics Unit, 2003; Saarimaa et al., 2008)

Emissions from transport (diesel fuel use)	***Emissions from energy***	***Emissions from the process***
Carbon dioxide, CO_2	Sulphur dioxide, SO_2	Dust
Carbon monoxide, CO	Nitrogen oxides, NOx	Sulphur dioxide, SO_2
Nitrogen oxides, NOx	Carbon oxides, CO_2 and CO	Nitrogen oxides, NOx
Nitrous oxide, N_2O	Hydrogen chloride, HCl	Carbon monoxide, CO
Particulates, PM10	Dust	Hydrogen chloride, HCl
Methane, CH_4	Low concentrations of heavy metals	Low concentrations of heavy metals
Sulphur dioxide, SO_2		
Hydrocarbons		

III.3. Calculated impacts for paper manufacturing based on recovered paper

The methodologies CML 2001, CML 96, EDIP 2003, and EI 99 were used to analyze the contribution of the scenarios to climate change with GaBi software (Fig. 4).

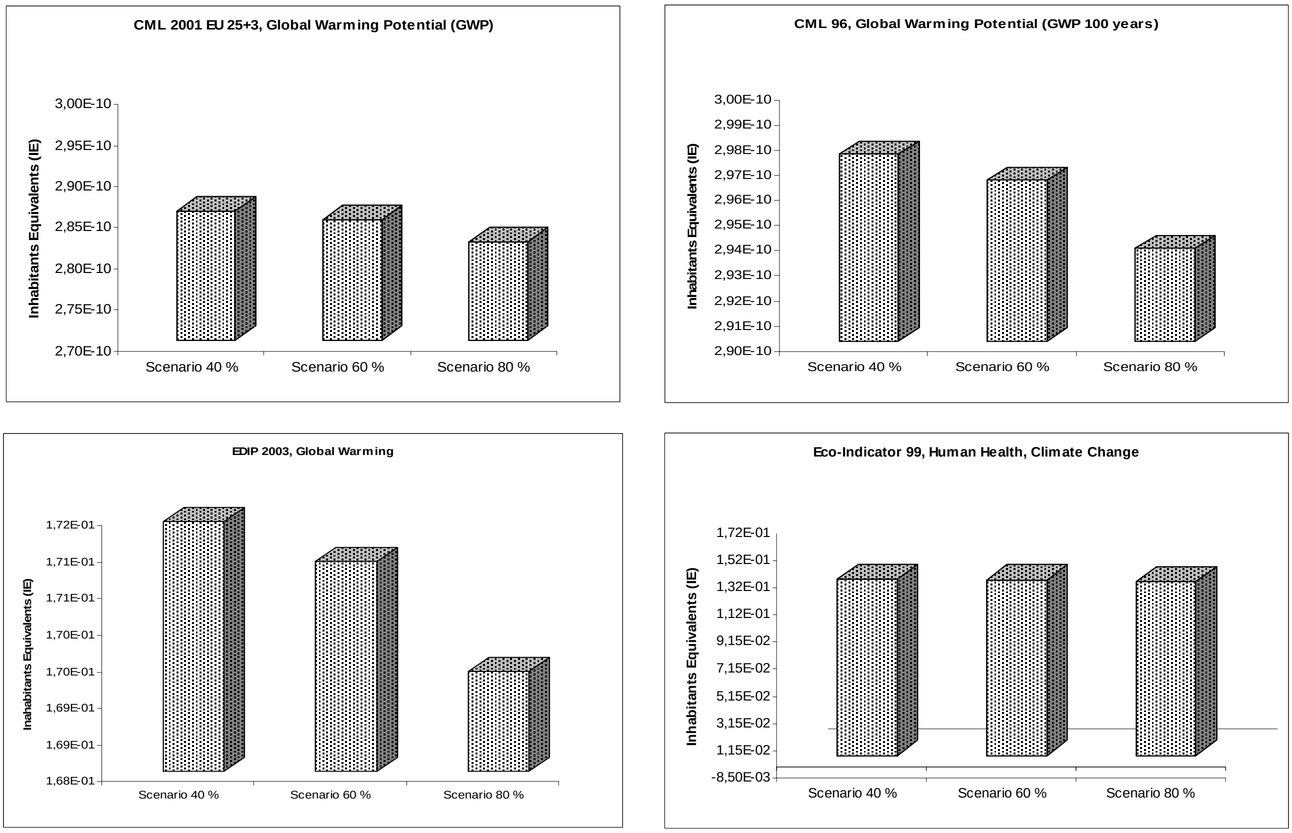

Fig. 4. Global warming potential for recovered paper scenarios analyzed

In all methodologies Scenario 40 % has the highest values of environmental impact due to the contribution of transport, energy demand and manufacturing process to the life cycle systems (Fig. 5). The energy consumption impact on global warming is dominant in all scenarios while other life cycle stages have a lower contribution.

The total contribution of scenario 80% to greenhouse emission results in 75.85% from energy consumption, 23% from manufacturing process and 0.83% from transportation stage.

Scenario 60% contributes in a higher percentage to the impact with 24% from manufacturing process and 0.94% from transport. Scenario 40% presents the highest environmental impact on climate change. The contribution to greenhouse emissions from the manufacturing process and transportation is higher for Scenario 40% because the demand of raw materials has increased in the last scenario. As the amount of raw material increases the emissions from the transportation and manufacturing process will also increase, the impact on the environment will be higher with the decrease of the impact allocated from previous cycle.

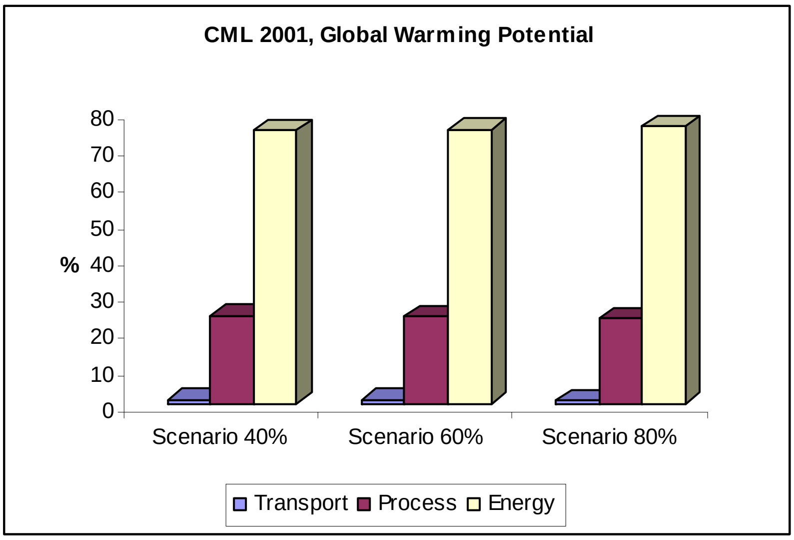

Fig. 5. Contribution of life cycle recovered paper systems to Global Warming Potential

From climate change perspective Scenario 80% is the most environmental friendly scenario. The scenario must be analyzed also from other impact categories such as acidification, eutrophication, ecotoxicity, photochemical ozone depletion because the results presented are evaluated only for climate change impact category. It is necessary to make a comparative analysis with the tissue products manufactured from virgin fibre to determine the most adequate scenario from economic and environmental point of view.

IV. Conclusions

Modeling in waste management area based on life cycle assessment can be used as a tool for the decisions making process, as to choose the most favourable waste management system from environmental point of view. Life cycle assessment was applied in the environmental impact quantification for different waste management systems and specific impact categories. In this paper the impacts of various waste management scenarios were presented and analysed from climate change point of view only. The results analysis showed that the scenario which includes recycling of materials, composting of organic waste and landfilling of residual waste with treatment of leachate and use of biogas for electricity proved to be the most suitable for waste management from climate change perspective. The contribution to GHG emissions is specific for each of the evaluated processes. Recycling of different materials can contribute to savings of GHG emission, a particular case being represented by paper recovery, which was also analysed

with LCA for different rates of recovery and modeled using three scenarios. The most favorable scenario was that where 80% of the environmental impact from paper's first cycle (products from virgin fibre) it was allocated to the first recycling iteration. The contribution of manufacturing process and transportation to greenhouse emissions induce the biggest influence on climate change impact category due to the increased demand of raw materials.
To establish the most suitable scenarios from environmental point of view, the other impact categories must also be taken into consideration in further studies.

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Abstract

Waste management options and natural fibres recovering have significant implications for CO_2 and CH_4 emissions, carbon sequestration and energy consumption. Quantities generated, composition of waste, destination of waste flows are key factors in establishing the influence of waste management and recovered fibres on climate change.

The greenhouse gas emissions can include both directly emitted carbon dioxide from waste combustion during incineration or methane from biodegradable waste in landfills and indirect emissions from fuel use in composting, sorting of recovered fibres. On the other hand, the energy demand and natural resources necessary for manufacturing of tissue paper exert a considerable pressure on the climate, which can change depending on the degree of recovered fibres use and the quality and purity of the recycled paper. Using recovered fibers can be a better alternative from a climate change point of view, since a lower impact from previous uses is allocated to them, comparative to virgin fibers. However, the use of recycled paper as a raw material could involve a more complex manufacturing process, with multiple stages for the treatment of the recovered fibre.

For this reason, an assessment of environmental impacts of waste management systems and paper manufacturing process from recovered fibres should be performed.
A valuable assessment method is life cycle analysis, which quantifies the impacts generated in the environment by the mentioned activities, based on material balances. For this purpose, Gabi software was applied and the results obtained on the basis of different methodologies include, besides climate change, other specific impact categories, such as: toxicity on humans, acidification, eutrophication etc. The indicator for climate change is global warming potential included in methodologies like CML 2001, CML 96, EDIP 1997, EDIP 2003, EI99, TRACI.
The results show that a sustainable waste management and recovery of valuable resources could contribute significantly to the global warming potential diminishing.

Keywords: climate change, life cycle assessment, recovered fibre, waste management