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ASSESSMENT OF ENVIRONMENTAL IMPACT OF FOOD WASTE: A CASE STUDY APPLE FRUITS

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Abstract. *The aim of this paper was to evaluate the environmental impacts (EI) of the apple supply chain from the NE region, Romania and to calculate the EI from apple waste landfilling. The evaluation was performed by applying Life Cycle Assessment (LCA) methodology. In the first phase the apple supply chain was investigated and the environmental impacts were calculated and interpreted, while in the second phase the evaluation of apple waste landfilling was performed. The results showed that the apple production phase has the highest contribution to all the impact categories studied (acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), human toxicity potential (HTP) and photochemical ozone creation potential (POCP) etc.). Transportation and storage stages contribute mainly to POCP and GWP, while landfilling contributes especially to AP, GWP and POCP.*

Keywords: apple, environment, food waste, landfilling, life cycle assessment

1. Introduction

The management of food loss and waste is a critical aspect for sustainable development and represents a sensitive issue at global level [1]. Food waste composition includes waste consisting of parts or entire products such as meat, dairy, cereal, vegetables, fruits and others (Fig. 1). These are the main products from consumer basket which can be wasted during different life cycle stage of these products. Apples represent 3% of the overall consumer basket in the EU which also includes dairy products (25%), meat (14%), cereal (7%), crop-based products (7%), vegetables (13%), beverages (32%), pre-prepared meals (0.5%) etc. [2].
The food can be loss (which is equal with food wastage) avoidable and unavoidable (such as seeds) during the primary production stage (edible products left in the field and others), transport and storage (for example product damaged by machineries, storage at a wrong temperature etc.), processing (food damaged by inappropriate packaging), distribution (expired food, unsold food, rejected food after quality controls etc.) and consumption (unavoidable loss, food not eaten or others) [2, 3].
The food waste hierarchy was developed in order to prioritize efforts to reduce food waste (from the last favorable to the most favorable option) (Fig. 2) [4, 5]. The environmental impacts of food waste disposal were evaluated and discussed in various studies, for example:
-Notarnicola et al. [2] investigated the environmental impacts of the most representative food types consumed in the EU-27 in 2010 and showed that food is

wasted in both the agricultural/industrial and domestic phases;

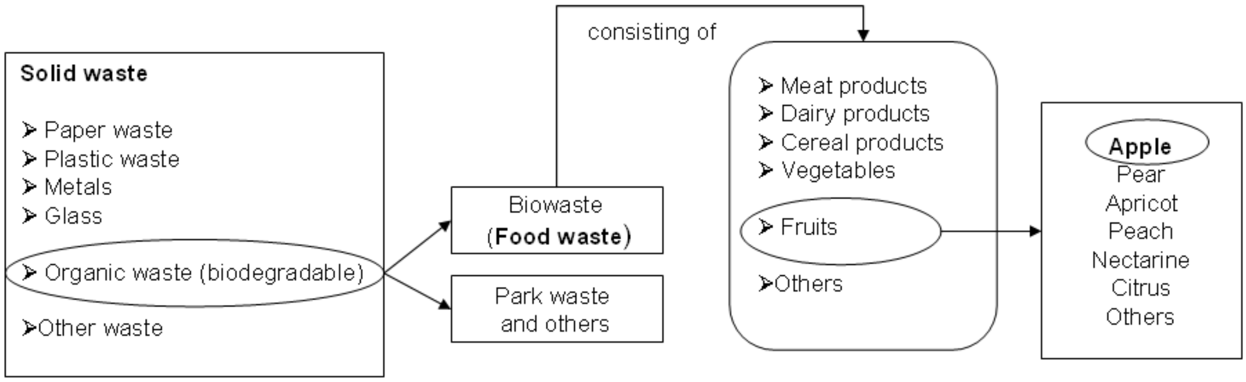

Fig. 1. Solid waste fractions

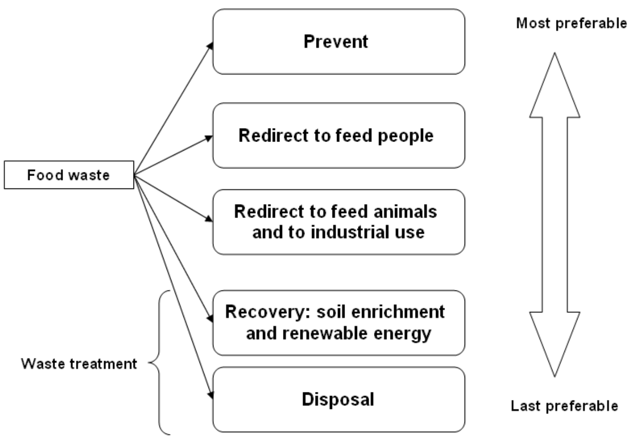

Fig. 2. Food wastage hierarchy

- Corrado et al. [3] provided a preliminary analysis of food loss by LCA modeling, and suggested a definition for food loss, discussed the strengths and weaknesses of various approaches for food loss in the supply chain and provided some recommendations for LCA practitioners;
- Salemdeeb et al. [5] studied food waste utilization for animal feed and compared the environmental and health impacts of different technologies such as composting, anaerobic digestion, dry pig feed and wet pig feed.

In this study the production, consumption and loss of apple fruits were investigated and evaluated from the environmental point of view. The method chosen for elimination of apple waste was landfilling.

2. Production, consumption and waste of apples

Apple tree is one of the most common fruit tree cultivated in Europe and covers 450000 ha. The area cultivated with apple in Romania represents 11% of the total production area of the EU [6, 7]. Total area planted with apple trees in 2012 in Romania was 51225.7 ha from which 6149.9 ha in NE region [8]. The apple production in EU is ranked differently from the area covered by apple trees: Poland harvested a quarter of the EU's apple production, followed by Italy (19.2 %), France (15.5 %), Germany (7.7 %) and Romania only 3.6 % [7]. The areas cultivated in Romania with apple orchards and apple productions in 2012 in NE region are illustrated in Fig. 3. Fruit cultivation has a long tradition in Romania and holds an important place in agriculture. The main species of fruit trees cultivated are: apple, pear, apricot, peach and nectarine. In our country about 100 varieties of apple grow, the most important ones being: Jonathan and Golden delicious (69.5%) followed by Starkrimson, Idared, Florina, Parmen gold, etc. [8]. Apple consumption values per capita in EU in 2015 were: Austria (53 kg), Slovenia (36 kg), Netherlands (34 kg), Hungary (31 kg), Luxembourg (26 kg), Croatia (25 kg), Portugal (24 kg) and Romania (23.5 kg) [9]. Fig. 4 illustrates the average annual consumption per capita in Romania for fruits and apples [10].

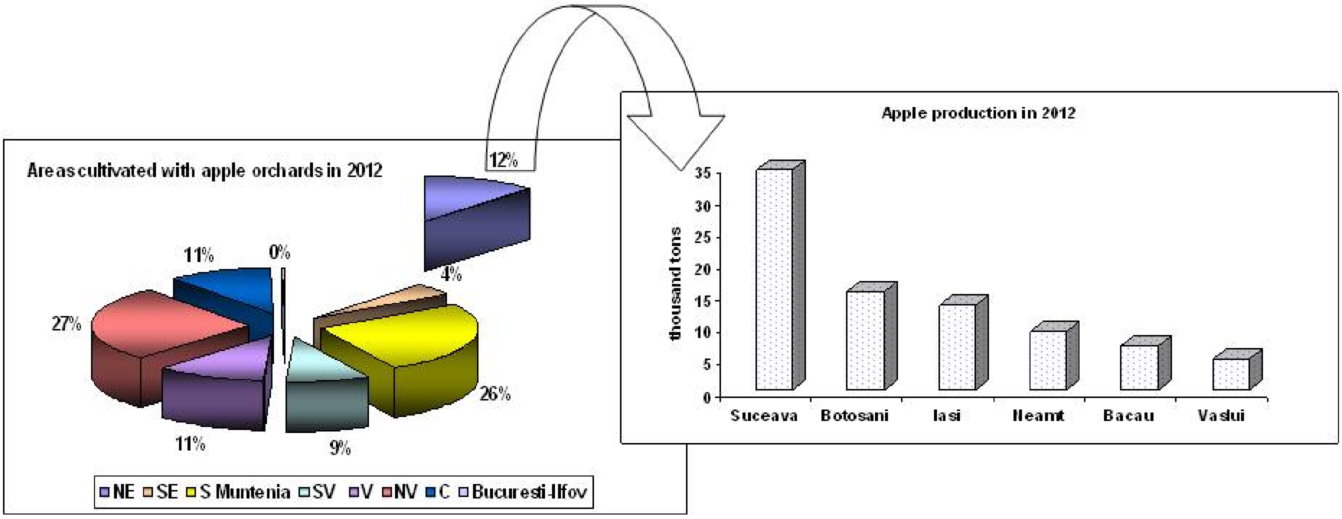

Fig. 3. Areas cultivated in Romania with apple orchards and apple production in 2012 in NE region

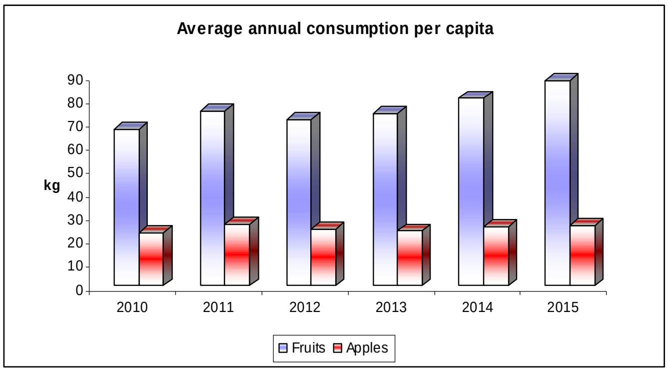

Fig. 4. Average annual consumption per capita

Fruits along with vegetables are recommended in daily consumption (400-800 g/day), in Europe average fruits consumption accounts for 166 g/day, but the consumption varies from a region to another [9].

According to [11] one medium apple with skin (192 g) provides 95 kcal, 19 g total sugars, 4 g dietary fiber and 195 mg K. [12] investigated various type of apples cultivated in Romania and established the following contents for Jonathan apple: 14.29% dry matter total content, 85.71 % water content, 9.84% sugar, 7.66% vitamin C/ 100 g fruit and ash content 2.38%. Apple loss and waste through the supply chain can be: field loss (5-25%), grading loss (5-25%), storage loss (3-4%), packing loss (3-8%) and retail waste (2-3%) [13].

3. Life cycle assessment

3.1. Methodology, system boundaries, functional unit

Life cycle assessment which is a standardized methodology was selected and applied to calculate and interpret the environmental impacts generated by apple fruit production, transport, processing, consumption and waste disposal.

The modeling was performed with GaBi software which is an instrument that includes LCA methodology and allows environmental impacts calculation of complex process [14, 15].

The system boundaries considered in this evaluation are illustrated in Fig. 5.

The functional units considered are the amount of apple produced in 2012 in the

NE region of Romania (for the supply chain, in the first part of the study) and the quantity of food waste resulted from distribution and consumption stages (for landfilling).

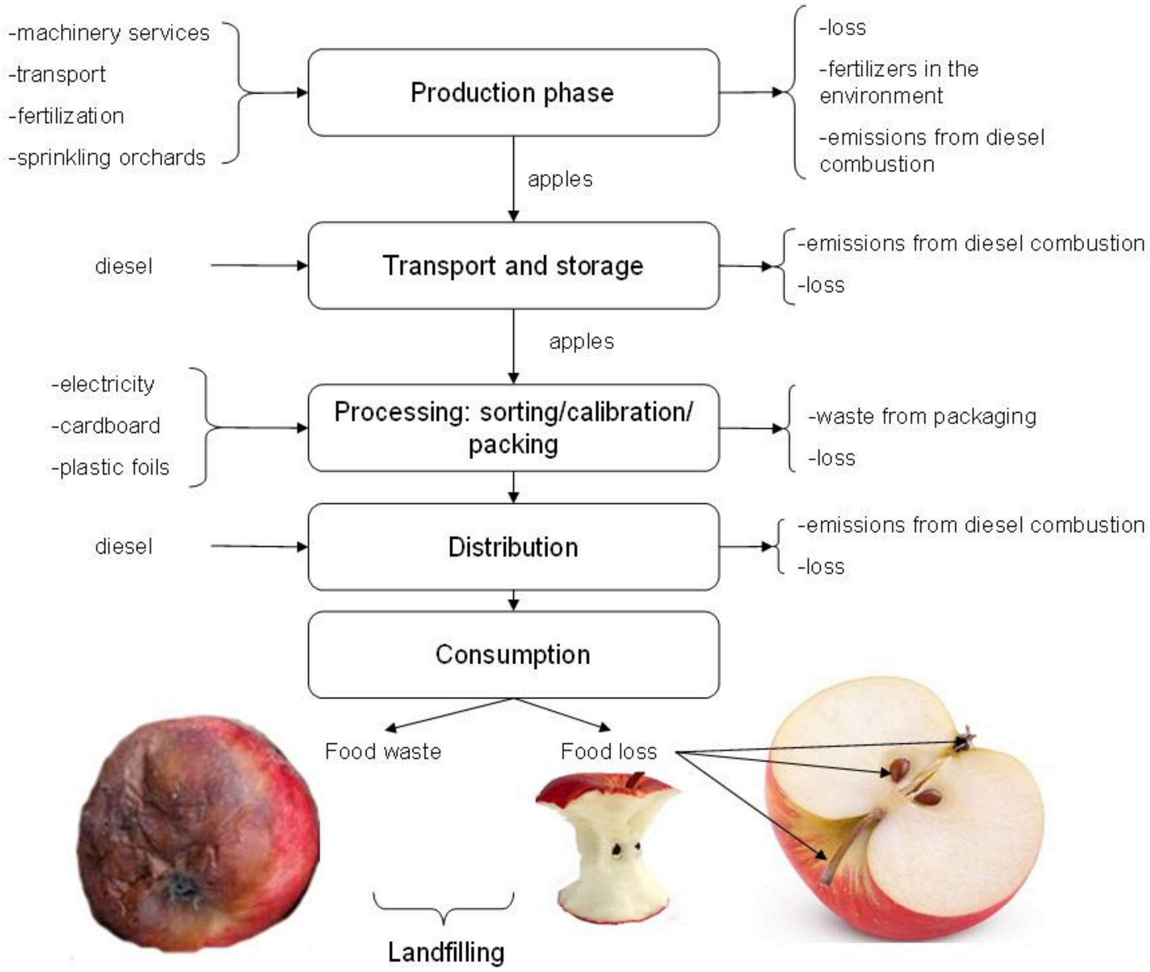

Fig. 5. System boundaries

3.2. Inventory analysis

In the inventory analysis phase the inputs and outputs for each stage included in the supply chain were established and calculated. The amount of apple produced in 2012 was of 84400 t. The apple losses considered are: the field loss 6%, transport loss 3%, processing loss 13% and consumption loss 6%. In 2012, 60876 t of apple were consumed in the NE region of Romania. Quantities of organic and mineral fertilizers were calculated based on the literature data. [2] considered the following amounts of fertilizers used in apple production: N 62 kg/ha, P_2O_5 4 kg/ha, K_2O 47 kg/ha, lime fertilizer 52 kg/ha.

Emissions to air can be N_2O (direct and indirect emissions from N fertilizers) 1 kg/ha, NH_3 from N fertilizers 7.5 kg/ha, CO_2 from fertilizers 43.3 kg/ha, while emissions to water NO_3 from N fertilizers 82.4 kg/ha, P from fertilizers 0.1 kg/ha and emissions to soil: pesticides (Chlorpyrifos 0.35 kg/ha, Glyphosate 0.28 kg/ha, Mancozeb 1.5 kg/ha, Mineral oil 1.6 kg/ha Sulfur 1.68 kg/ha) according to [2].

The total amount of diesel consumed for the production phase was calculated knowing the quantities of diesel used for plowing (4.3 L/ha), spraying herbicides

(1.6 L/ha), phytosanitary treatments (38.4 L/ha), orchard maintenance (70.8 L/ha), technological transport (44 L/ha) etc. [16]. Emissions in air (CO_2, CO, NO_x, N_2O, PM10, CH_4, SO_2 and hydrocarbons) from fuel consumption were calculated based on the emission resulted from burning 1 kg of diesel. The electricity consumed for apple sorting considered was 0.5 kWh/t [17]. Also, cardboard packaging and plastic films amounts were calculated.

3.3. Life cycle impact assessment, results and discussion

All the data obtained in the inventory step were introduced in GaBi software, where the potential environmental impacts are calculated based on plan, process and the inputs and outputs related to the system. Impact categories like acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), human toxicity potential (HTP) and photochemical ozone creation potential (POCP) can be analyzed and calculated with GaBi tool [14].

Emissions of nitrogen oxides (NOx), sulphur dioxide (SO_2) and ammonia (NH_3) contribute to acidification. In LCA the acidification potential (AP) is given in kg sulphur dioxide equivalents (SO_2-equivalents). Emissions of NOx, NH_3, P and N contribute to eutrophication potential which is expressed in kg PO_4^{3-} equivalents in LCA. The substances which may contribute to the GWP are: CO_2, CO, CH_4, N_2O, CFCs etc. In LCA the GWP is expressed in kg CO_2 equivalents. Human toxicity potential is related with VOC, particles, heavy metals, POPs, NO_x, SO_2 emissions and can be expressed in kg DCB - equivalents. Volatile organic compounds (VOCs) and carbon monoxide (CO) are degraded in reactions with nitrogen oxides (NOx) initiated by sunlight in the lower atmosphere which leads to photochemical ozone formation (POCP) expressed in LCA as kg C_2H_5- equivalents [18, 19].

After evaluation, the results were obtained by several impact assessment methods. This paper presents and focus on the results obtained with CML 2001-Jan. 2016, ReCiPe 1.08 and UBP (ecological scarcity) methods. The values obtained for each category of impact in different measurement units were normalized in order to compare and illustrate on a single graphic the environmental impact categories. Fig. 6 show the normalized values (in PE = person equivalents) obtained for the following impact categories AP, EP, GWP, HTP and POCP. It can be observed that all the impact categories have positive values which mean negative impacts on the environment.

AP has the highest value followed by POCP, EP and HTP, the lowest value being recorded for GWP. Acidifying substances such as SO_2 and NOx which contribute to the acidification potential come mainly from the burning of fossil fuels [20].

In this study the emission of substances which contribute to AP are due to diesel burning used for plowing, treatments, transport and distribution etc. Emissions with a slower contribution to AP come from N fertilizers application.

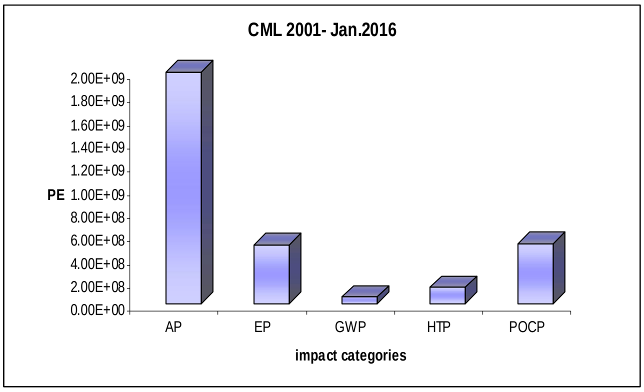

Fig. 6. Environmental impacts of apple fruit supply chain

Fig. 7 presents the contribution of production, distribution, transport and storage phases and also diesel and electricity consumption to the AP, EP, GWP, HTP and POCP. It can be observed that apple production phase has the highest contribution to the all impact categories (almost 90 % for AP and EP; 42% for HTP).

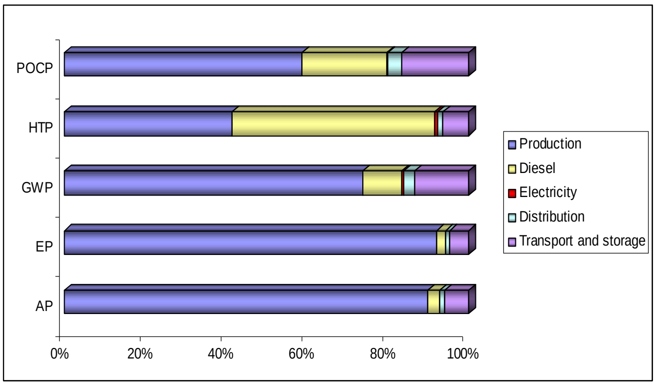

Fig. 7. Contribution to the environmental impacts of the production, distribution, transport and storage phases and diesel, electricity consumption

Diesel influence mainly the values of HTP (50%), POCP (21%) and in a lower degree GWP, AP and EP. Emission from transportation and storage contribute mainly to POCP (16.5%) and GWP (13.2%), having a lower contribution to the other impact categories.

Fig. 8 shows the normalized values obtained for climate change impact category with ReCiPe method, based on three cultural perspectives: egalitarian (E), hierarchist (H), individualist (I). Egalitarian principle considers long term aspects based on precautionary principle thinking, individualist principle is based on short term and is characterized by optimism aspects that technology can avoid many problems in future while hierarchist is based on consensus model often considered the default model [21].

From Fig. 8 it can be observed that all the values for climate change impact categories are positive which means negative impacts on the environment. The highest values are registered for climate change impact on human health. Also, Fig. 8 shows that the hierarchist perspective provides middle values compared with the other two perspectives.

Fig. 9 presents the contribution of phases from apple supply chain to the environmental impacts according to UBP ecological scarcity method.

Production and diesel contributes to water pollution, while the amount of pesticides that enter the soil is influenced entirely by the production phase. The main air pollutants come from production, transport and storage phases. Production phase contributes to the global warming in proportion of 75%, followed by transport and storage (13%).

Landfilling of apple waste amounts resulted mainly from distribution and consumption was also evaluated. The amount of leachate and biogas which may result from this type of food waste were calculated, also the emission in air, water and soil were estimated. After the calculation of environmental impacts was observed that the emissions from landfilling contribute mainly to AP, GWP and POCP (Fig. 10).

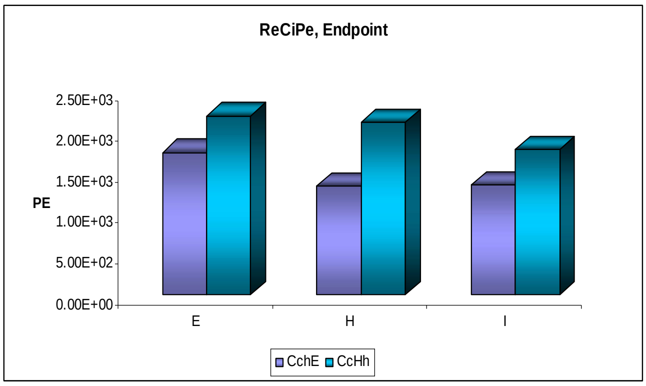

Fig. 8. Impact on climate change of apple fruit supply chain (CchE- Climate change Ecosystems; CcHh- Climate change Human Health)

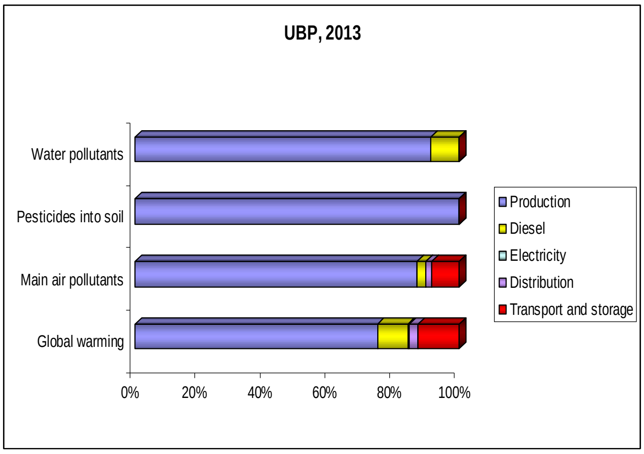

Fig. 9. Contribution of phases from apple supply chain to the environmental impacts according to UBP Ecological scarcity method

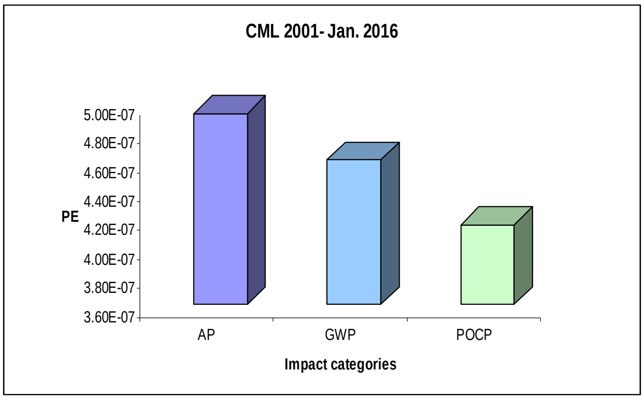

Fig. 10. Environmental impacts of food waste landfilling

4. Conclusions

In this paper the environmental impacts of apple supply chain were investigated. Life cycle assessment methodology was applied for environmental impacts calculation. The results obtained showed that the production phase has the highest impacts on the environment followed by transport and storage phases. Substance emission during the apple supply chain contributes mainly to acidification potential. The amounts of apple loss during the chain were also calculated. Landfilling was considered the elimination method for apple waste.

In the next study different scenarios for apple loss/waste treatment will be developed (considering that this type of waste can be used to feed animals, can be composted or disposed in landfills) and evaluated and compared from the environmental point of view.

5. Acknowledgments

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