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Full Length Research Paper

Life cycle impact assessment (LCIA) of paper making process in Iran

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Forests play an important role on carbon concentration, unchecked harvesting could cause increase in carbon concentration. In this study, the environmental impact caused by paper production at Pars Paper Factory, Iran, was evaluated using life cycle assessment (LCA) approach. The ISO 14040 series were used as references. The functional unit considered was producing one metric tonne of paper for one year. The Centre of Environmental Science, Leiden University, NL, 2000 (CML2 Baseline2000) method was chosen for this LCA study. Ten impact categories were identified as follow: Abiotic depletion, acidification, eutrophication, global warming, ozone layer depletion, human toxicity, fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity and photochemical oxidation. From the results, using bagasse and electricity contributed the lowest impact value because both of these inputs used renewable sources. However, using heavy fuel oil (in this case mazut) gives the highest impact to global warming. Chlorine from bleaching sector contributes the impact for photochemical oxidation and ozone layer depletion. From the results obtained, the use of bagasse instead of wood in paper and pulp factory, has potential to reduce global warming impact. Hydroelectricity as the source of energy has less impact on the environment, while mazut may result in acidification, global warming and ozone layer depletion.

Key words: Life cycle assessment, Centre of. Environmental Science, Leiden University, NL, 2000 (CML2 Baseline 2000) bagasse, paper making process.

INTRODUCTION

World paper and paperboard demand is expected to grow to about 2.1% till year 2020 and the growth will be fastest in Eastern Europe, Asia (except Japan) and Latin America (Forsstrom et al., 2006). Paper and pulp sector are one of the main consumers of fibrous wood resources which has significant impact on the climate change by affecting forest resources. There are two kinds of paper production: (a) Using wood (virgin) as raw materials and (b) using non-virgin material like kanaf and bagasse (Honnold, 2009). There are several studies that applied Life Cycle Assessment (LCA) in pulp and paper products (Merrild et al., 2008; Murphy and Power, 2007; Schmidt et al., 2007; Holmgren and Hening, 2005; Dias et al., 2007; Wiegard, 2001; Fu et al., 2005 and Dias et al., 2002). In their research, they discovered that energy and water consumption, greenhouse gases (GHG), methane emissions, chlorine and raw materials used for non-virgin papers are less than virgin material. This study focused on LCA of non-virgin material (baggasse) in paper factory in Iran.

The Pars Paper Factory is a government owned factory located in Southwest Iran and is 500 m from Hafttapeh Sugarcane Factory. It was established in 1963 with a production capacity of 35,000 metric tonne per year. Nowadays, the production of this factory has reached 40,000 metric tonne per year. Hafttapeh Sugarcane Factory was supplying bagasse to the paper factory. Water for this process is provided from the Dez River which is also near the factory. Source of energy for this factory is hydroelectricity and mazut. Mazut is a

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Abbreviations: LCA, Life Cycle Assessment; **GHG,** greenhouse gases; **LCI,** life cycle inventory; **LCIA,** life cycle impact assessment; **IPCC,** Intergovernmental Panel on Climate Change; **OBA,** optical brightness agent; **EP,** eutrophication; **CFC,** chlorofluorocarbons.

Figure 1. Transported bagasse through the conveyer belts from the sugarcane factory to the paper factory.

brownish-black petroleum fraction consisting largely of distillation residues from asphaltic-type crude oils, with a relative density of about 0.95 which is used as the source of energy for heating and steam-raising for furnace, kilns and boilers. Bagasse is the fibrous residue remaining after sugarcane is crushed to extract its juice and is currently used as a renewable resource in the manufacture of pulp and paper products. The fibers are about 1.7 mm long and are well suited for tissue, corrugating medium, news print and writing paper. This factory has three production units as follows: (1) Preparation of bagasse (2) pulp mill and (3) paper mill.

Preparation of bagasse

Non-virgin material used in paper factory is from farmed trees. The farmed trees are supplied by supplier and cut into small pieces. The farmed tree is known as a bagasse. It is provided by the sugarcane factory which is 500 m from the paper factory. The materials are sent to the paper factory through pipes or conveyer belts and the energy used for this is electricity (Figure 1). Using agricultural crops rather than wood has the added advantage of reducing deforestation (Ekvall, 1999). Due to the fact that bagasse can be chemically pulped, bagasse requires less bleaching chemicals than wood pulp to achieve a bright, white sheet of paper (Kadam, 2002). Because of this, there are fewer impacts from the materials used in the bleaching section, such as chlorine, to the environment. The bagasse contains 65 to 68% fiber, 25 to 30% pith, 2% sugar and 1 to 2% minerals. It is passed through the process called depithing, where the fiber is separated from the pith. It is then, cleaned up and is ready to be used for pulp and paper milling processes.

Pulp mill

The aim of this process is to produce pulp that can be used for paper milling. During pulp milling, a few sub-processes such as cooking, washing, screening, ticking and bleaching are carried out (Figure 2 and 3). In the final stage (bleaching), Cl (chlorine gas) and NaOH are used to change the black liquor (black pulp) color to white color and the process is usually done three times.

Figure 2. Cooking process on pulp mill in Pars Paper Factory.

Figure 3. Pulp screening and cleaning in Pars Paper Factory.

Paper mill

Paper milling is the last process in producing paper. The pulp will go through several processes (stock preparation, wet end, draying section and cutting and wrapping) to finally become paper. Pulp is insufficient for making paper so in this section materials such as kraft are added to improve the pulp. The paper which is white in color is cut to A4 size. At this stage, the moisture in the paper is reduced to 55 to 60%.

Problem statement

Paper is made from plant fibers called cellulose which are found in wood. Cellulose must be converted into pulp before being used to manufacture paper. To begin the papermaking process, recovered fiber is shredded and mixed with water to make pulp. The pulp is washed, refined and cleaned then, turned to slush in a beater. Nowadays, by rapid economic development and population growth, the demand for paper has increased globally. More demand on paper needs more harvesting of woody materials. Uncontrolled harvesting of wood can caused deforestation, climate change, etc. However, producing one metric tonne of paper from non-virgin materials such as bagasse, kanaf and bamboo can save 17 trees, 3.3 cubic meter (m^3) of landfill space, 360 L of water, 100 L of gasoline, 60 pounds of air pollutants and 10401 kilowatt of electricity (Malaysian Newsprint Industries, 2007 and WasteCap, 2008). In addition, GHGs such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are critical components of the earth's atmosphere. These gases act like a blanket, trapping heat around the earth and temperatures necessary for human life. However, anthropogenic activities such as fossil fuel burning, land clearing and deforestation can thickened the greenhouse blanket which means, can have effect on climate changes. This paper is aimed to identify all impacts of paper making process in Iran, using LCA as a tool.

Objective of study

The objectives of this study are, to evaluate the environmental performance of paper manufacturing process and to identify inputs that have environmental potential from the paper manufacturing process for producing of one metric tonne of paper for one year.

MATERIALS AND METHODS

Life cycle assessment (LCA)

LCA is the assessment of the environmental impacts of a given product or process throughout its lifespan (Curran, 2006). LCA has its roots in the 1960s, when scientists concerned about the rapid depletion of fossil fuels and non-renewable resources, developed LCA as an approach to understand the impacts of energy consumption (Bathish, 2006). LCA is a phase-approach methodology. LCA can maintain consistency by using the ISO 14040 series of standards (ISO, 14040, 1997). Life cycle of a product include four main stages: Production stage, manufacturing stage, use stage and end-of-life stage. The environmental evaluation using the LCA approach is done by applying four steps: Defining the goal and scope of the study, establishing a life cycle inventory (LCI), life cycle impact assessment (LCIA) and finally, interpretation of environmental burden associated with the product (Murphy, 2004).

Goals and scope definition

The goals of the LCA study are to evaluate the environmental performance of paper manufacturing process and identify inputs that have environmental potential from the paper manufacturing process of one metric tonne of paper for one year.

Scopes of the LCA study

System boundary: In this study, the A4 size paper commonly used for writing, printing and copying a document was chosen as an assessing subject in the life cycle assessment. The life cycle of an A4 paper starts from the raw material extraction stage, production stage, use stage and end-up at the disposal stage (Figure 4). However, the system boundary of the study only focused on the paper production process stage (dotted line in Figure 4).

Functional unit: The functional unit was set as the production of one metric tonne of paper for one year.

LCIA method: Impact assessment is an important step in measuring the environmental impacts in LCA. SimaPro comes with a large number of standard impact assessment methods. The impact assessment methods are as follow: Eco-indicator99, Eco-indicator 95, CML 92, CML2 Baseline (2000), EDIP/UMIP, EPS 2000, Ecopoints 97, Impact 2002+, TRAC, EPD method, cumulative energy demand and the Intergovernmental Panel on Climate Change (IPCC) greenhouse gas emission. Each method contains a number (usually 10 to 20) of impact categories. The Centre of Environmental Science, Leiden University, NL, 2000 (CML2-Baseline 2000) method was chosen because this method elaborates the problem oriented (mid-point level). The CML guide provides a list of impact assessment categories grouped into: Obligatory impact categories, additional impact categories and other impact categories (SimaPro7 manuals, 2006).

In this study, CML2 Baseline 2000 method was used for LCIA (SimaPro7 manuals, 2006). The CML2 Baseline 2000 provides ten types of impact categories with its unit as follows: A biotic depletion (Kg Sb eq), acidification (kg SO_2eq), eutrophication (Kg PO_4---eq), global warming (kg CO_2 eq), ozone layer depletion (kg CFC-11eq), human toxicity (kg 1,4-DBeq), fresh water aquatic eco toxicity (kg 1,4-DBeq), marine aquatic eco toxicity (kg 1,4-DBeq), terrestrial eco toxicity (kg 1,4-DBeq) and photochemical oxidation (kg C_2H_4). The emissions inventory data are in terms of the mass released into the environment such as 1 kg per functional unit, it also means the impact of a unit mass (1 kg) of an emission to the environment (Pennington et al., 2004).

Assumption

In the LCA study, the following assumptions were made: There were no wastes or emissions to air and water nor by-products during paper production process because lack of data.

Table 1. Impact value for each type of impact during paper production process (SimaPro 7 Manuals, 2006).

No.	Impact category	Unit	Amount
1	A biotic depletion	Kg Sb eq	17.82
2	Acidification	Kg SO_2 eq	3.43
3	Eutrophication	Kg PO_{4---} eq	0.71
4	Global worming	Kg CO_2 eq	-729.81
5	Ozone layer depletion	Kg CFC^{-11}eq	0.00015
6	Human toxicity	Kg 1,4-DB eq	242.14
7	Fresh water aquatic toxicity	Kg 1,4-DB eq	57.31
8	Marine aquatic toxicity	Kg1,4-DB eq	81472.26
9	Terrestrial eco toxicity	Kg1,4-DB eq	7.34
10	Photochemical oxidation	Kg C_2H_4	0.37

RESULTS AND DISCUSSION

Life cycle Inventory

Data from paper making process in Iran

All the data in SimaPro are structured in such a way that the practitioner can recognize between data that is relevant to the particular LCA project and data that can be useful in other projects. There are a number of libraries in SimaPro software with all kinds of data regarding used materials, production process, transport, energy and disposal processes (Goedkoop et al., 2003).

In LCA, there are two kinds of data which are as follows: Background and foreground data. Background data is all data that can be provided from literature review, country reference or other database. These data are collected from second source. Foreground data is data from primary sources such as questionnaire, site visit, interview etc. In this study the background data used was from SimaPro 7 software and foreground data collected from the Pars Paper Factory (Table 2).

Life cycle impact assessment (LCIA)

CML2 Baseline 2000 was used to analyze the potential environmental impact using Simapro 7.0 database (SimaPro7 manuals, 2006). The graph is scaled to 100% per impact category in order to allow the description of widely dispersed values per impact category in one diagram (Figure 5). Colour difference of the graph is representing the different types of input. The negative value of the impact means benefit to the environment. The impact value for each impact was contributed from inputs that were used during the paper making process. In this factory, there were 12 types of inputs involved in the process and had been analyzed. They were bagasse (farmed tree 1), kraft (farmed tree 2), electricity, heavy fuel oil (Mazut), water, sodium hydroxide (NaOH), aluminum sulphate ($Al_2(SO_4)_3$), optical brightness agent (OBA), chlorine (Cl), clay, corn starch and resin.

Abiotic depletion, acidification and eutrophication contribute 17.82 kg Sbeq, 3.43 kg SO_2eq and 0.71 kg PO_4- eq, respectively, to each category of impact (Figure 7). For global warming, paper production process gives negative value, -729.81 kg CO_2eq, which means benefit to the environment. Ozone layer depletion and human toxicity on the other hand give the impact values of 0.00015 kg CFC-11eq and 242.14 kg1, 4-DB eq, respectively. Chlorofluorocarbons (CFC-11 and CFC-12) act as a GHG in the troposphere but also damage the ozone layer in the stratosphere. The study shows that, man-made chemicals can cause ozone layer depletion (Weigard, 2001). However, all inputs contribute 57.31kg 1, 4-DB eq to fresh water eco toxicity, marine aquatic eco toxicity by amount 81472.26 kg 1, 4-DB eq and terrestrial eco toxicity 7.34 kg 1, 4-DB eq to each category of impact. For photochemical oxidation, all inputs give impact value at 0.37 kg C_2H_4 (Table 1). From the LCIA results, assessment of paper making process showed inputs that gives the lowest impact value to all types of impact and its electricity except for global warming impact.

Global warming

The total impact of global warming is -729.81 kg CO_2 eq. For global warming impact, farmed tree 1 (bagasse) gave the lowest impact (negative impact) value with amount of -951.414 kg CO_2 eq from all types of input (Figure 6). Negative impact means environmental benefits. Electricity and bagasse contribute lowest impact value because both of these inputs were using renewable sources. Electricity is using hydroelectric sources, whereas, bagasse is a by-product of sugarcane factory. The consumption of renewable sources will reduce environmental degradation (Fress et al., 2005). According to Ekvall (1999), using agricultural crops in paper production has added advantage rather than wood. The consumption of bagasse as raw material for paper production

Table 2. Input from paper production process in Pars Paper Factory.

No.	Input	Item	Purpose
1	Non-virgin	Bagasse kraft	Raw material Improve the pulp
2	Energy	Electricity from river mazut	Steam, cutting
3	Water	Water from river	washing
4	Chemicals	Sodium hydroxide, NaOH; aluminum sulphate, $Al_2(SO_4)_3$; optical brightness agent, OBA; chlorine, Cl	All the chemical are used for bleaching
5	Others	Clay, corn starch and resin	Improve quality of paper

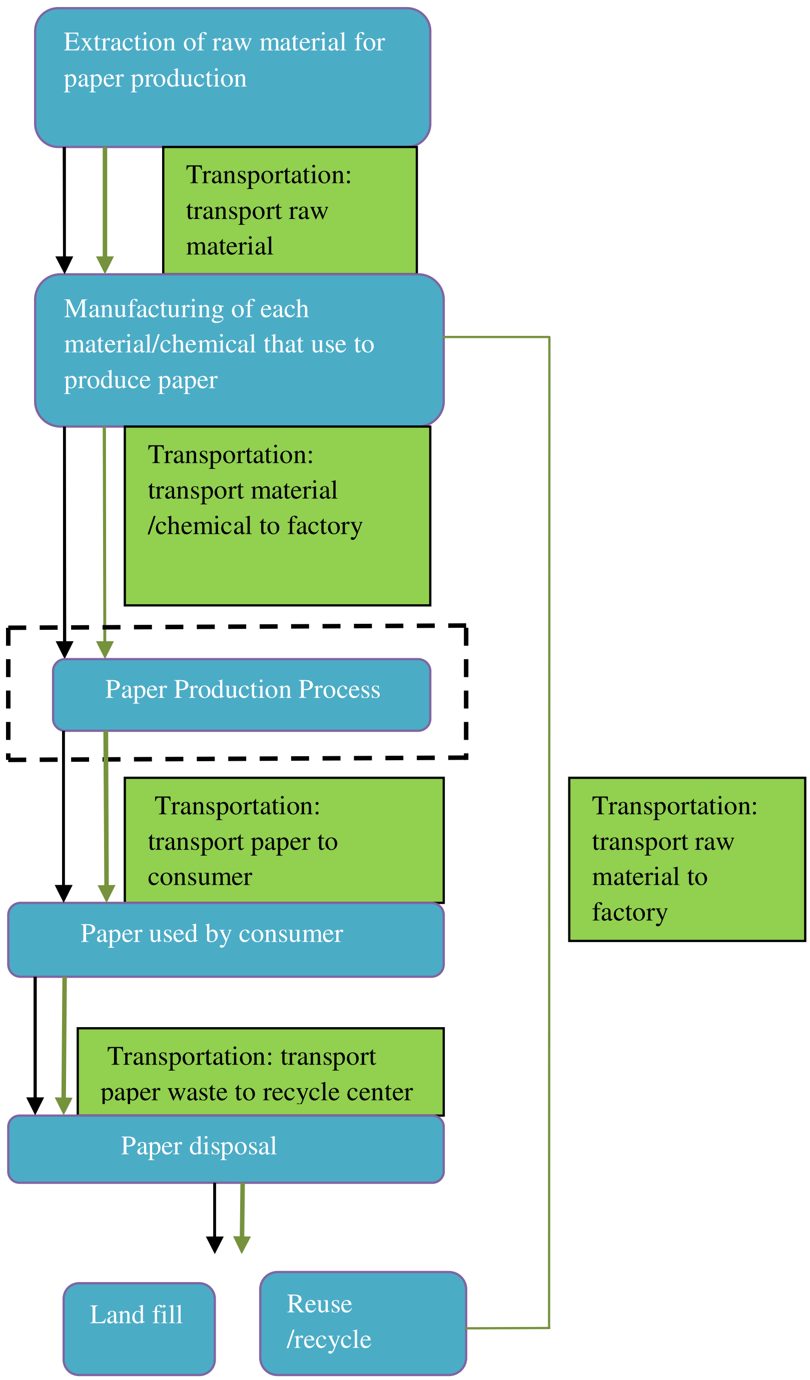

Figure 4. Life cycle of paper and system boundary of this study (dotted line).

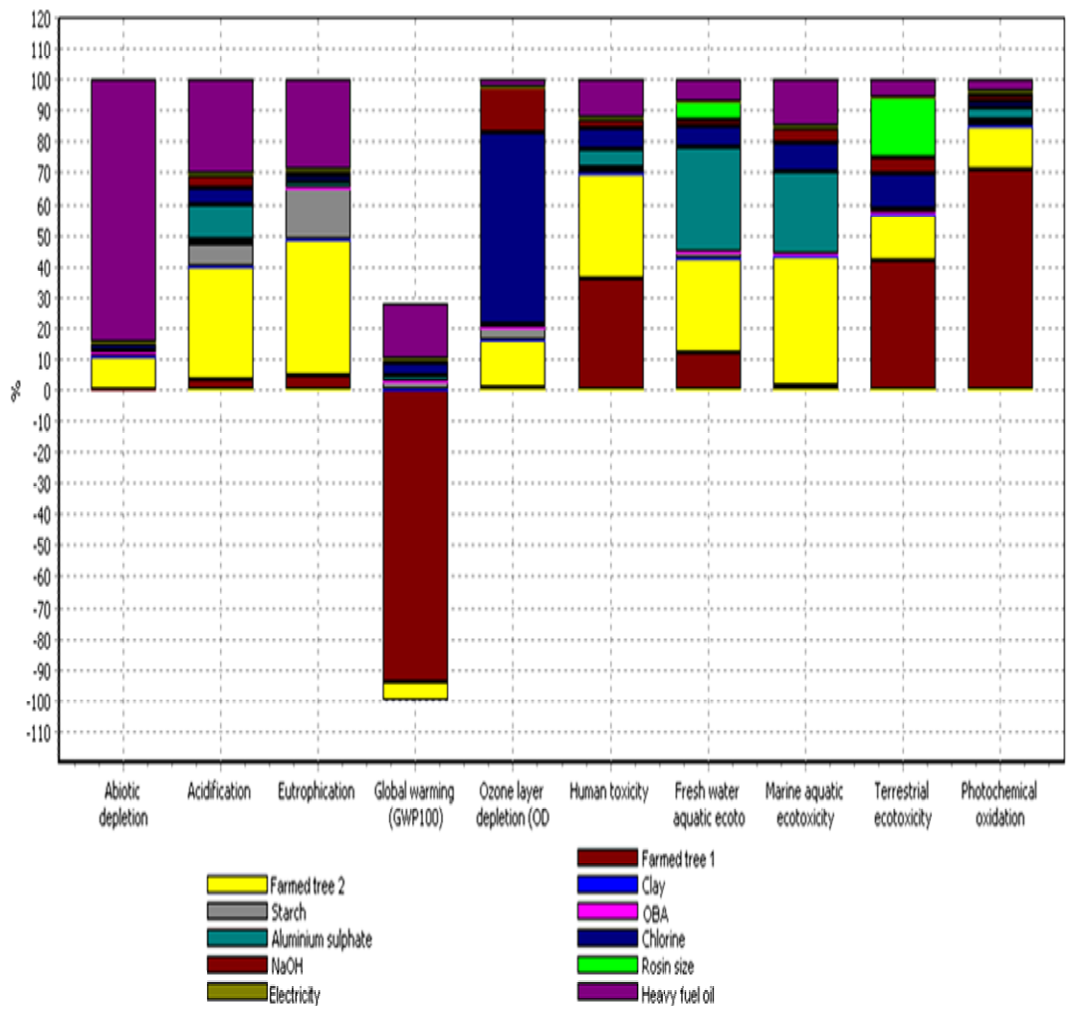

Figure 5. Impact of paper production process from all inputs for producing of one metric tonne of paper for one year.

(instead of virgin wood) may result in reduced deforestation and at the same time increased CO_2 absorption and has the potential to reduce global warming effect. Mazut on the other hand, gives higher impact value to global warming with 25% from the total impact value.

Normally in fuels, the amount of carbon per unit energy content varies significantly by fuel types. This means coal contains the highest amount of carbon per unit of energy, so it emits more greenhouse gases than the other fossil fuels. Burning fossil fuels can release 6.2 (GtC) into the atmosphere each year (Wiegard, 2001). So, using mazut as source of energy because of the high density of mazut, can contribute to global warming. Changing the land use like deforestation, can result in increased emission of carbon into atmosphere. During making kraft, forest will be cleared and deforestation will happen and it can affect global warming (Wiegard, 2001). However, using bagasse as raw material can avoid deforestation, which is the positive point of using bagasse.

Abiotic depletion, acidification and eutrophication

In abiotic depletion, acidification and eutrophication, mazut gives the highest impact for these impact categories and it was followed by kraft. For other impacts, kraft gave higher impact value for acidification (30%), eutrophication (44%) and toxicity (42%) whereas, chlorine and bagasse gave higher impact value with 62 and 71% for ozone layer depletion and photochemical oxidation, respectively, as shown in Figures 7 and 8.

Acidification

Acidic gases such as sulfur dioxide and nitrogen oxides (released during the burning of fossil fuels) contribute to the acidification of the soil and fresh water ecosystem. The category indicator for acidification was measured in kilograms of sulfur dioxide equivalent ($KgSO_2$ eq).

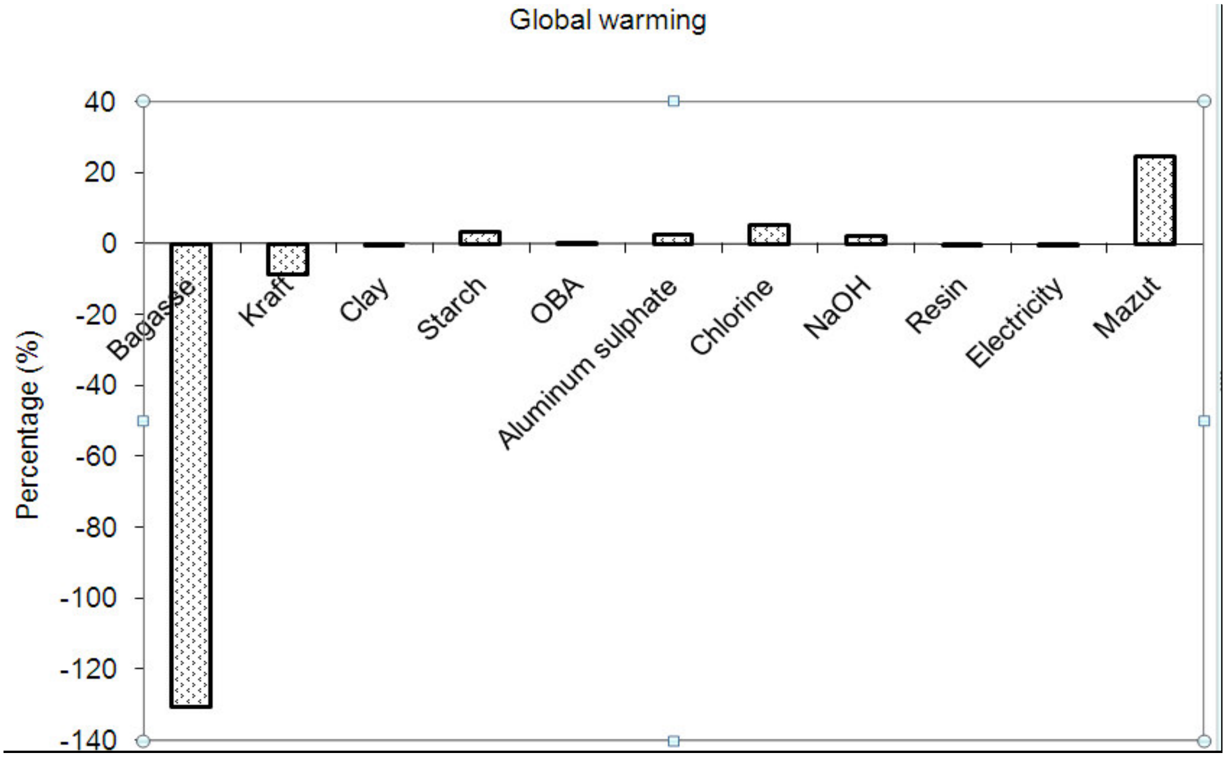

Figure 6. Input values in percentage for global warming impact for producing of one metric tonne of paper for one year.

Weigard (2001) indicated that, N_2O is produced naturally through human activities such as the burning of fossil fuels, deforestation, land-use changes and some industrial processes.

Eutrophication

The enrichment of soil and water by nutrients is measured by the eutrophication (EP) impact category. An increased EP could lead to algal blooms in lakes with reduction in sunlight penetration and other adverse consequences and similar undesirable effects on soil. Release of nitrates and phosphates continuously to fresh and marine water can cause increased nutrient buildup. During the combustion of fossil, fuels and fuel production, high NO_x is produced (Eriksson et al., 2007; Ally and Pryor, 2007). This can result in accumulation of nitrates, phosphates and dissolved oxygen content (Gordon, 2003). Mazut and kraft contribute the highest impact for eutrophication.

Ozone layer depletion

Ozone layer depletion was measured as CFC-11 equivalent. Chlorine contributed the first major impact (62%), Kraft was the second major contributor (16%) while, NaOH was the third (14%). Others made up a small range of impacts which was less than 5% each; starch (4%), mazut (2%), aluminum sulphate (1%), OBA (0.4%), bagasse (0.4%), resin (0.2%) and clay (0.01%). The total impact value contributed by the paper production process to ozone layer depletion was 0.00015 kg CFC-11 eq. Before the 1980s and early 1990s, free chlorine was used to bleach paper; however, nowadays, the use of free chlorine has ceased and chlorine-dioxide or other means of bleaching such as ozone have taken over (Villanueva and Wenzel, 2007). Chlorofluorocarbons (CFC-11 and CFC-12) were first manufactured in the 1930's but were not present in the atmosphere in any appreciable quantity before 1950. Until the 1990's, they were widely used as propellants, refrigerants and foaming agents. They act as a GHG in the troposphere but also damage the ozone layer in the stratosphere. The study shows that man-made chemicals can cause ozone layer depletion (Weigard, 2001).

Photochemical oxidation

The impact value of each input for photochemical oxidation is shown in Figure 8. Bagasse gave the highest impact value in photochemical oxidation with 71%. Kraft contributed 14%, aluminum sulphate and mazut 4% each, while chlorine and resin contributed 2% each, starch and NaOH 1% each. OBA, clay and electricity were at the lower and of the range at 0.2, 0.008 and

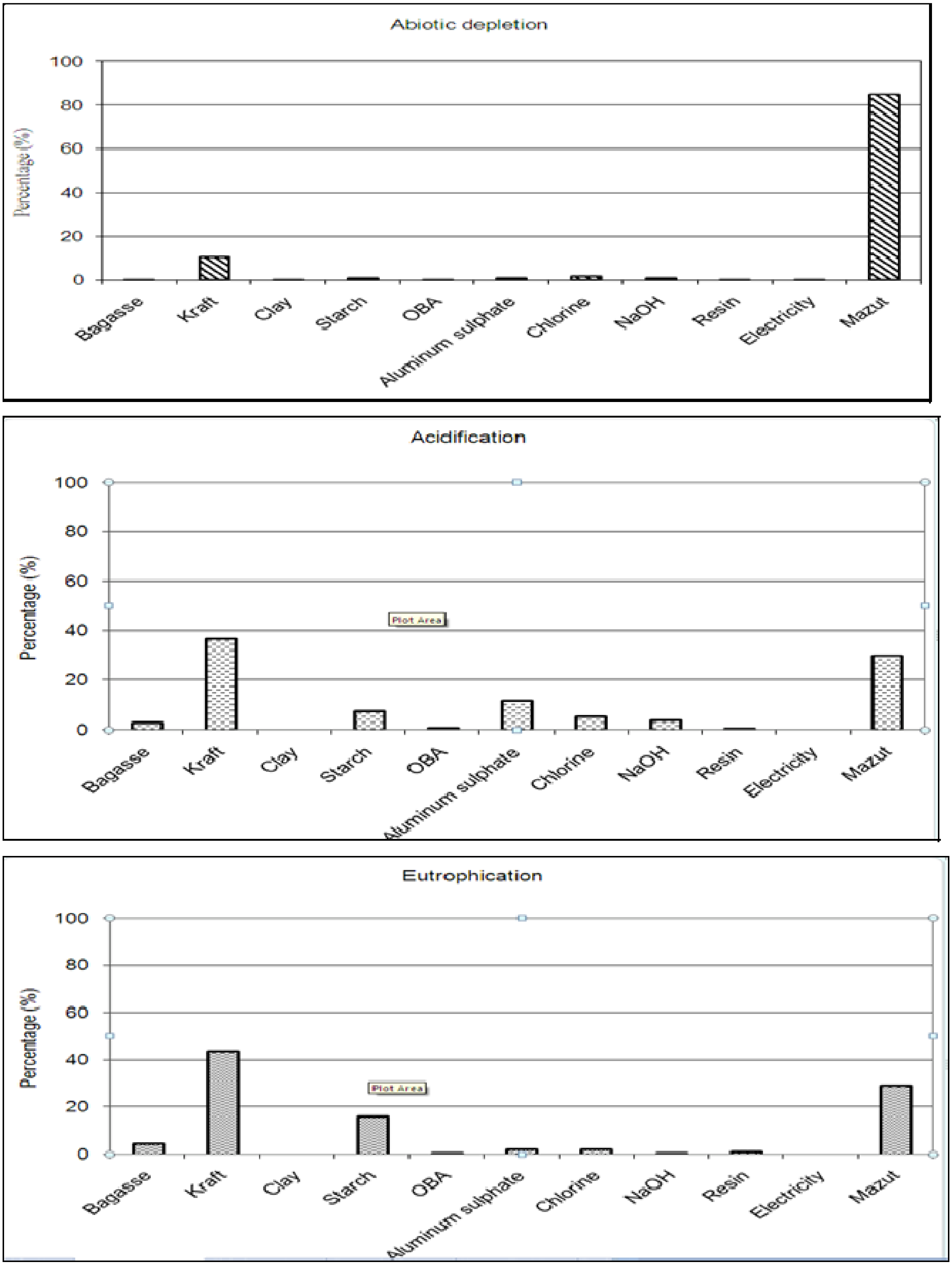

Figure 7. Input values in percentage for acidification, abiotic depletion and eutrophication for producing of one metric tonne of paper for one year.

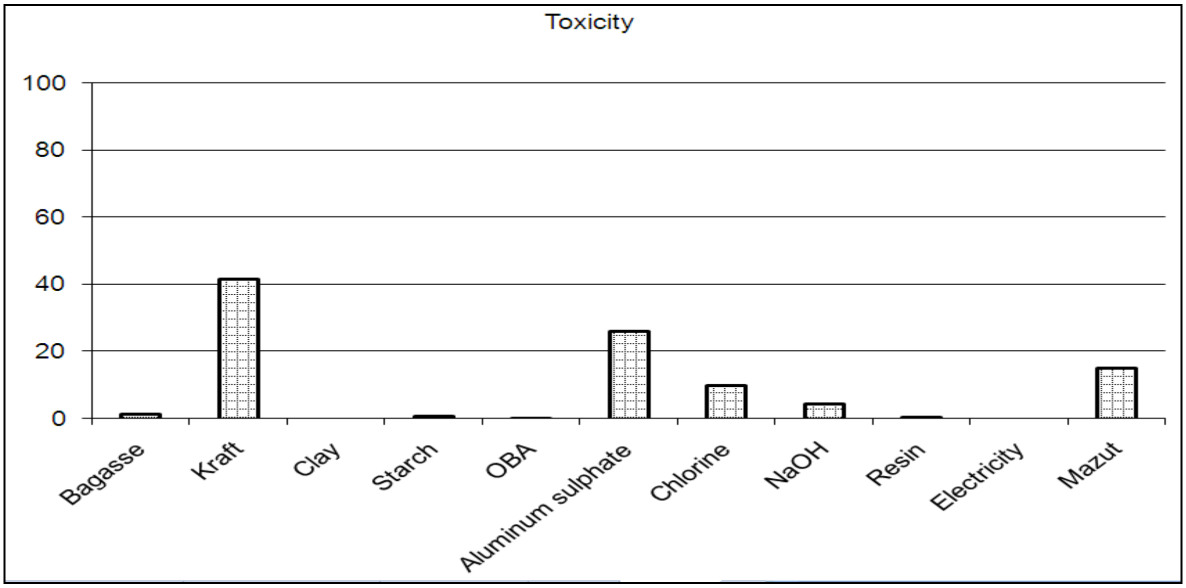

Figure 8. Input values in percentage for human, freshwater, marine and terrestrial ecotoxicity for producing of one metric tonne of paper for one year.

0.001%, respectively.

Toxicity

The toxicity impact was measured as 1, 4-dichloro-benzene equivalents per kg emission (Kg 1,4-DB eq). In the CML2Baseline2000 method for LCIA, toxicity to human environment, fresh water, marine and terrestrial ecosystem was considered. The toxicity impacts of the various materials or elements are shown in Figure 8. From the total impact, kraft contributed the highest impact of about 42%. Aluminum sulphate was in second place with 26% followed by mazut (15%), chlorine (10%), NaOH (4%), bagasse (1%), starch (1%), resin (1%), OBA (0.2%), clay (0.02%) and electricity (0.0005%).

Conclusions

From the paper making process, eleven inputs are recognized. They are bagasse, kraft, aluminum sulphate, OBA, clay, corn starch, chlorine, resin, mazut, NaOH and electricity. All the inputs were then assessed using CML2Baseline2000 method. The assessment method involves ten types of impacts: Abiotic depletion (17.82 Kg Sb eq), acidification (3.43kg SO_2 eq), eutrophication (0.71 Kg PO_4---eq), global warming (-729.81 kg CO_2 eq), ozone layer depletion (0.00015 kg CFC-11 eq), human toxicity (242.14 kg 1,4-DB eq), fresh water aquatic ecotoxicity (57.31 kg 1,4-DB eq), marine aquatic ecotoxicity (81472.26 kg 1,4-DB eq), terrestrial ecotoxicity (7.34 kg 1,4-DB eq) and photochemical oxidation (0.37 kg C_2H_4). Impact of human toxicity, fresh water aquatic ecotoxicity, marine aquatic ecotoxicity and terrestrial ecotoxicity were combined during the discussion because they have the same unit and are known as toxicity impact.

Assessment of inputs shows that, electricity gives the lowest impact value to all types except global warming. For global warming, bagasse gaves the lowest impact value from all types of input. In contrast, mazut contributes highest impact value to abiotic depletion and global warming with 85 and 25%, respectively, from the total impact value. On the other hand, kraft gives highest impact value to acidification (30%), eutrophication (44%) and toxicity (42%).

For ozone layer depletion and photochemical oxidation, chlorine and bagasse gives highest impact value with 62 and 71%, respectively.

Recommendations

Based on the results, this study makes several recommendations as follow:

Replacing the mazut with any friendly source of energy: Replacing mazut with nuclear energy, hydro-electricity or even using pith as source of energy for paper making.

Replacing the chemical: Replacing chlorine with more environmentally friendly material for bleaching.

Replacing paper recycling with the use of kraft: To reduce the amount of impact kraft can contribute to the environment or even try to use the ratio of paper recycling and kraft instead of just using kraft.

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