An Exploratory Comparative Study on Eco-Impact of Paper and Plastic Bags

Subramanian Senthilkannan Muthu, Yi Li*, Jun-Yan Hu, Pik-Yin Mok

Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong

Abstract: Today there are varieties of comments prevailing among people who use Plastic and Paper bags for their shopping needs. A few people support Plastic bags with their own justifications and others support Paper bags. This is a hot topic of today and arguments are going up and down to deduce which one is better in terms of environmental impact, but some people abstain from this issue by choosing the other option of going with reusable bags. This exploratory study is attempted to infer the environmental concerns made by these bags. The two common grocery bags of today – Paper & Plastic bags are compared in this study. Two imperative measures – total amount of energy used by a bag to get it manufactured and the amount of pollutants emitted during the manufacturing phase of a bag - are chosen as data for Life Cycle Inventory (LCI). To arrive at a clear state of conclusion with respect to environmental impact made by these two bags, life cycle impact assessment (LCIA) study was accomplished. Evolvement of Life Cycle Assessment (LCA) study from the data available on this context is the crux of this study. The Eco-indicator 99, damage oriented method for LCIA in SIMAPRO 7.1 tool is used to assess the environmental impact made by these two grocery bags. The single score values calculated by the Eco-indicator 99 is considered as a directive to compare the environmental impact made by these and a detailed explanation of results is also dealt with in this paper. As far as the Life cycle energy analysis and amount of pollutants produced from these two bags are concerned, a plastic bag simply scores out a paper bag. The impact assessment results are also in line to support the plastic bags over paper bags. However, this conclusion has been drawn on the basis of the secondary data chosen for LCI and the results provided by the software which also has certain hypotheses and assumptions.

Keywords: plastic bags, paper bags, life cycle impact assessment, SIMAPRO, eco-indicator 99

1. Introduction

There are many types of bags available today to cater the shopping needs of people. An endless variety of raw materials and technologies are employed to manufacture them. Out of them the most popular ones are Plastic and Paper bags, since many years. Also one should accept that they are the ones which are being subjected to a lot of constructive criticisms as well. Due to the highly demanding environmental needs, many alternatives are found to be superior to them in many platforms, especially in terms of environmental friendliness have come to the market now and become familiar among common people. Even then it is worthwhile to infer the Eco-Impact made by them. Numerous perplexing arguments [1-19] can be seen in many discussions from different web pages on which bag is better amongst Paper and Plastic ones? Notwithstanding these references present different sorts of justification for the arguments, a scientific evaluation to quantify the environmental impacts is very much needed. This paper serves as an exploratory study on the quantification of environmental impacts of these bags to facilitate the investigation on the piled up issues associated with these bags. This present study sheds light on the eco-impact made by plastic and paper bags by using Life Cycle Analysis study.

2. Production Processes of Paper and Plastic Bags

Plastic bags are made from non-renewable resources, where the key ingredients are petroleum and natural

* Corresponding author's email: tcliyi@polyu.edu.hk

gas. Polyethylene - High Density, Low Density, linear low-density polyethylene [LLDPE] are the raw materials widely used for the manufacture of plastic bags [20]. The shopping bags used by super markets would be ideally produced out of LLDPE to get the desired thickness and glossy look. And if one needs very thin and filmy bags then LDPE would be an ideal choice [21]. The oil used for manufacturing plastic bags figures out to 4% of the world's total oil production [12, 13]. The production outline of plastic bags in general is depicted in Figure 1, which shows the generalised picture of manufacture of plastic products and plastic shopping bags [22]. People feel plastic bags are light and easy to carry. Their shape and structure aid people to have such a feeling about them. Also they are found to be cheaper in cost when compared to paper bags. Also they have the capability to be reused and recycled. Such recycling activities can be found in a number of supermarkets and one can see many slogans in this perspective in supermarkets in most of the countries. Their rate of decomposition is much slower which can even last up to 1000 years [23] and most of the plastic bags, say up to 96% are being thrown into landfills [24].

Switching over the discussion track to Paper bags, they are made out of Pulpwood from trees, which is a renewable source. However, we get paper bags by cutting of trees which on the other way blemishes both plants and animals. It is also produced by energy created by coal or natural gas. Thus created pulp will be converted into a paper bag by different processes and machines after consuming tremendous amounts of energy from fossil fuels, electricity, various chemicals, etc. [13]. An outline of manufacturing process of paper shopping bags is given in Figure 2. And also they are biodegradable and can be recycled to create corrugated cardboards majorly.

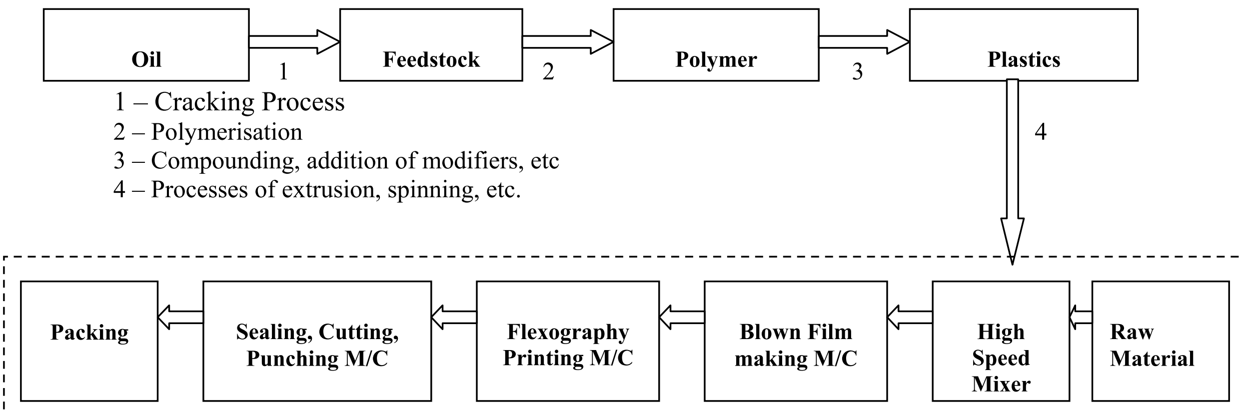

Figure1 General outline of plastic bags manufacturing process.

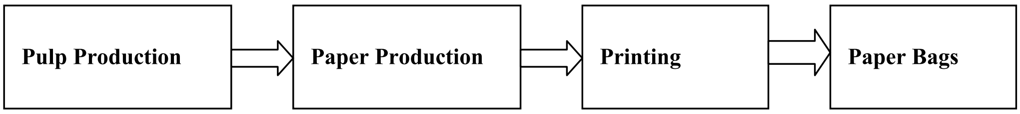

Figure2 Process outline for paper shopping bags manufacture.

3. Technology of Life Cycle Assessment

A life-cycle assessment [LCA] is an analytical tool which can help in understanding the environmental impacts from the state of acquisition of raw materials to final disposal [25]. In accordance to the definition given by The Society of Environmental Toxicology and Chemistry [SETAC], LCA is an iterative process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and material uses and releases to the environment; and to identify and evaluate opportunities to effect environmental improvement. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation and distribution; use, reuse, maintenance, recycling and final disposal [26].

According to ISO 14040 an LCA study essentially consists of four interconnected steps/phases [27] [see Figure 3]:

- Goal and scope definition
- Inventory analysis
- Impact Assessment
- Interpretation

In the first step Goal and scope definition, the definition of goal is intended to specify the application of study, the very purpose of pursuing the study and also to state to whom the study is targeted at. The definition of scope aims at prescribing the breadth, the depth and the complete details of study. It is mandatory to define a functional unit, which is an object of the assessment in a life cycle assessment study and the boundaries of the system under study with clear specification of data quality requirements. This step and the following step Inventory analysis are corresponding to ISO 14041 [28].

The second step – Inventory analysis, [LCI – Life cycle Inventory] focuses on analyzing the different flows of material and energy corresponding to the production of the product and the environment. And the data pertaining to the flows of input and output are collected in this phase [28], as shown in Figure 4. Input flows refer to the various resources like raw materials, energy or land or any sort of thing connected to the production of the product. Output flows mean any sort of emissions to air, water or to land. The next step - Impact assessment [LCIA -Life Cycle Impact Assessment], which corresponds to ISO 14042 [29] deals with the exploration of the implication of impacts made on the environment derived from the outcome of the inventory analysis. In other words, in this phase, the results of the inventory analysis step are interpreted in terms of the environmental impacts. Various effects deduced at this step can be compared to arrive at the overall assessment of the products under investigation. The impact assessment phase - LCIA consists of both mandatory and optional elements in accordance with ISO 14042, which is diagrammatically represented in Figure 5.

In a nutshell, this phase consists of selection and definition of impact categories such as Global Warming, Acidification, Eutrophication, Human Toxicity, Ozone depletion, Photo-oxidant formation, Depletion of abiotic resources, Aquatic and terrestrial toxicity measures, etc and classifies them by assigning the results from the Impact Assessment to the relevant impact categories. Then characterizing by aggregating the inventory results in terms of adequate factors called as, “Characterization factors” of different types of substances within the impact categories; therefore a common unit is defined for each category [30].

The last but not least step – Interpretation of LCA which is in accordance to ISO 14043 [31], primarily aims at drawing conclusions out of the study and also advising suitable recommendations to chuck out major impacts encountered if any. The entire process of Life cycle assessment is iterative [32].

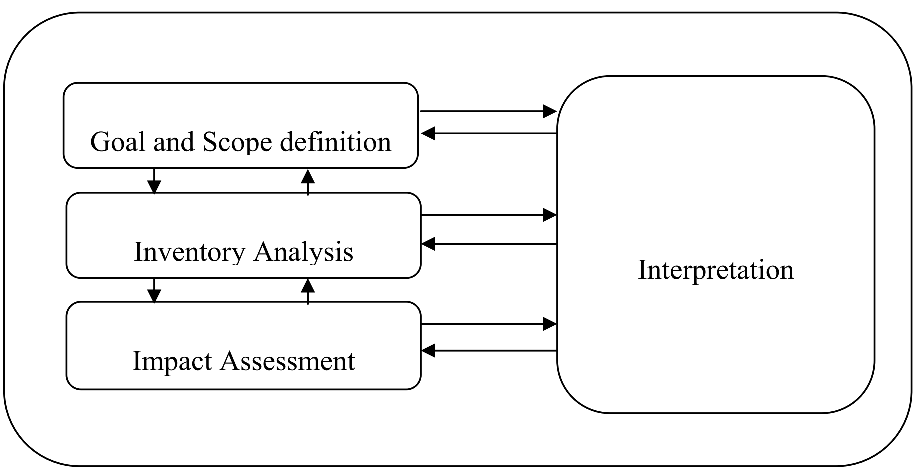

Figure 3 Phases of an LCA.

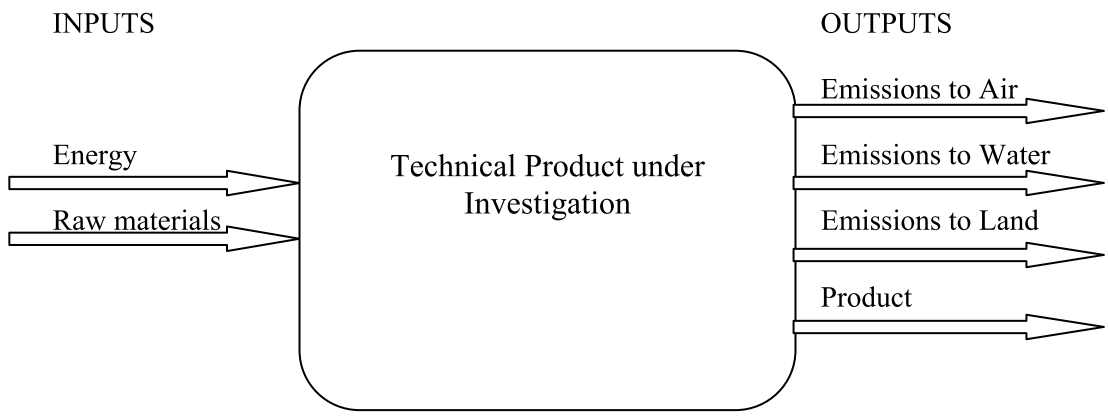

Figure 4 Data to be collected in LCI.

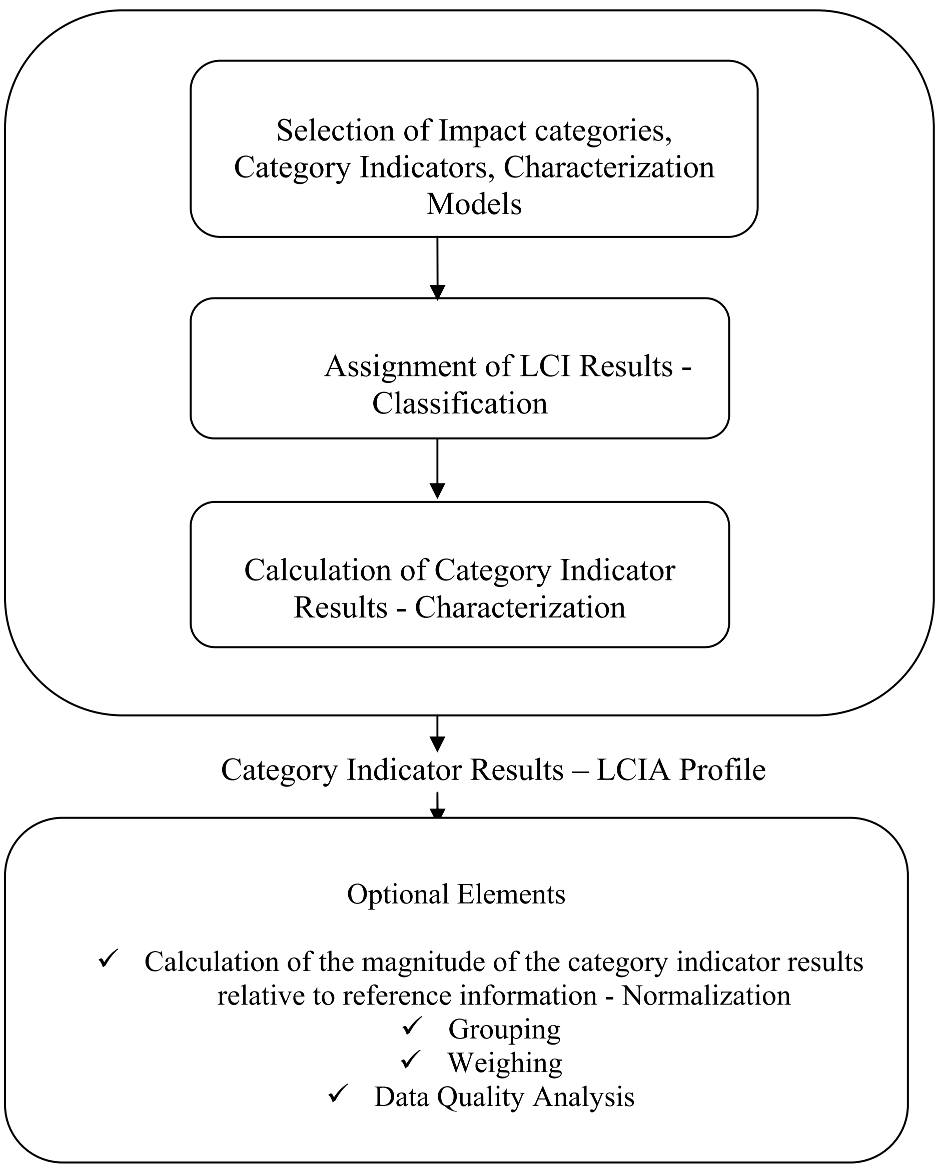

Figure 5 Mandatory and optional elements of LCIA.

4. Exploratory Study of LCIA of Plastic and Paper Bags

As stated earlier, this study revolves around the Life Cycle Impact Assessment of plastic and paper bags. The functional unit is 1 unit of paper and 2 units of plastic bags. The initial step of this study is the secondary data for LCI which was obtained from the study on life-cycle energy analysis comparison on plastic and paper bags done by Institute for Life Cycle Environmental Assessment; this in turn is based on the basic study performed on by Franklin Associates, Ltd. [33]. This same set of secondary data has been widely used in various studies [1, 19, 21, 34-38].

Data pertaining to this study focuses on two main issues: first and foremost is the total energy consumed by a bag to get it manufactured, where total energy represents process and feedstock energies. The second criterion is the quantity of pollutants emitted during the process of manufacture. Having considered the carrying-capacity of two carrier bags under investigation, to be conservative on volume & weight, two plastic bags is compared to one paper bag. Also it should be noted that they also assume current recycling rates, hence the functional unit is chosen as 1 unit of paper and 2 units of plastic bags.

4.1 Energy Data

Energy related data are collected from the elements of:

- Transportation
- Electricity
- Fuel extraction and processing
- Energy within the feedstock

Energy equivalents collected from the above said elements are all converted into energy units, say kilojoules [kJ].

Table 1 Energy Data

Category	Feedstock	Petroleum	Process Energy	Total energy
Paper	550 kJ	500 kJ	350 kJ [Coal]	1,680 kJ
Plastic	990kJ [Natural Gas]	240 kJ [Feed Stock]	160 kJ	1, 470 kJ

Table 2 Pollutants Data

Category	Solid Waste	Air Emissions	Water-borne waste
Paper	50 g	2.6 Kg	1.5 g
Plastic	14 g	1.1.Kg	0.1 g

Table 1 enumerates the energy data [33]. From the table 1, one can understand that 2 plastic bags consume less energy than one paper bag does. Almost it accounts to 87% of the amount of energy used by one paper. The same point of less energy consumption of plastic bags compared to paper bags has been mentioned in some other studies as well [39-42].

4.2. Emissions Data

Under this topic, major emissions such as amount of solid waste produced, atmospheric waste, water-borne wastes are calculated. The following table 2. gives a glimpse on the amount of pollutants produced by plastic and paper bags [33].

The above said data also portrays a clear picture on the quantity of emissions by paper and plastic bags, out of which one can understand that plastic bags emit less amount of pollutants in different categories than paper bags. The same sort of conclusion has been derived by many other studies as well [39-42].

4.3. Life Cycle Assessment Analysis & Results

Thus the above mentioned data are processed by using one of the commercial LCA softwares – SIMAPRO 7.1. The Eco-indicator 99, damage oriented method for LCIA is employed to assess the environmental impact. A good number of LCA studies used this method to assess the LCIA; some references are [43-48]. The main impact categories to be investigated under this exploratory study are: carcinogens, respiratory organic and inorganic, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals and fossil fuels. Single score values are calculated by this method and the results are given below. The following figures 8-12 illustrate the results of Life Cycle Impact Assessment made by plastic and paper bags.

4.4. Comparative Environmental Impacts

4.4.1. Description of Computational Structure of Eco-indicator'99 Methodology

Eco-indicator 99 [E] v2.06/ EI99 H/A version used in the analysis characterizes the impacts into the following impact categories: carcinogens, respiratory organic, respiratory inorganic, climate change, radiation, ozone layer, ecotoxicity, acidification/ eutrophication, land use, minerals and fossil fuels. The working principle of Ecoindicator'99 method [49] is explained in the Figure 6 given below.

The general framework of Ecoindictor'99 lies in modelling the life cycle analysis in three main spheres namely Technosphere, Ecosphere and Valuesphere. The three fields of scientific knowledge and reasoning has to be necessarily dealt with in LCA methodology [50], which is termed here, as "spheres":

[1] Technosphere, the description of the life cycle, the emissions from processes, the allocation procedures as far as they are based on causal relations.

[2] Ecosphere, the modelling of changes [damages] that are inflicted on the "environment".

[3] Valuesphere: the modelling of the perceived seriousness of such changes [damages], as well as the management of modelling choices that are made in Techno- and Ecospheres.

With the above mentioned three spheres as foundation, a basic three-stage approach of the Eco-indicator method has been evolved:

- The life cycle model is constructed in Technosphere. The result is the inventory table.
- Ecosphere modelling is used to link the inventory table to the three damage categories or "endpoints".
- Valuesphere modelling is used to weigh the three endpoints to a single indicator, and to model the value choices in the Ecosphere.

This three-stage method is represented in the Figure 7 below[50].

JFBI Vol.1 No. 4 2009 doi:10.3993/jfbi03200909

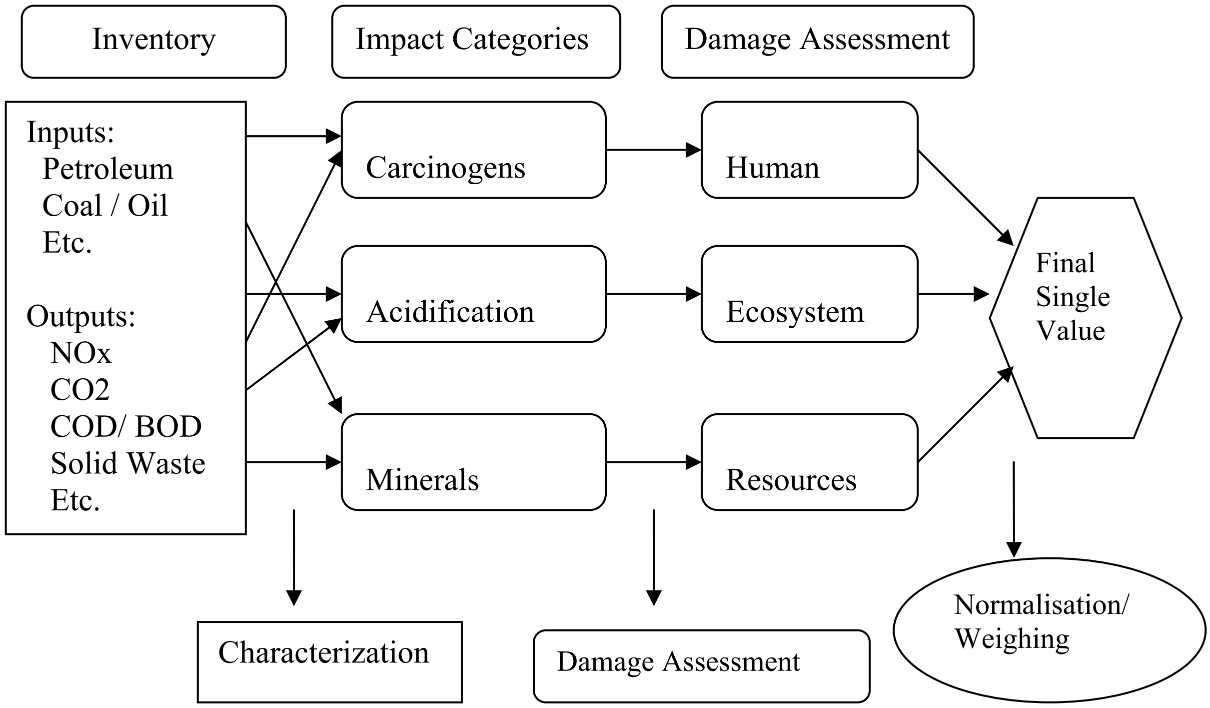

Figure 6 Working principle of Ecoindicator'99.

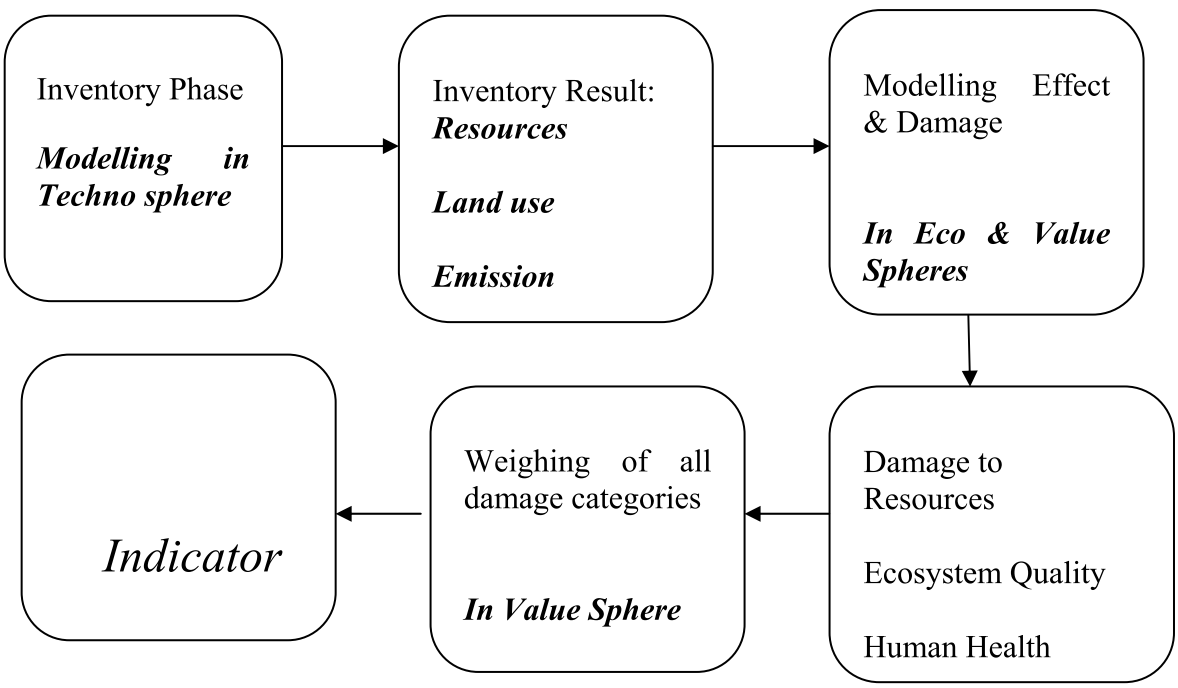

Figure 7 Core concept of the Eco-indicator 99 methodology.

During the first step i.e., classification and characterisation stage, considerations are given to three major conditions, which are Human Health [HH], Ecosystem Quality [EQ] and Resources [R] [51]. The corresponding impact categories [52] for the above said three conditions and their respective units can be viewed from the following Table 3.

Table 3 Units of different Impact Categories in Damage Assessment

Damage Assessment	Unit	Impact Category
Human Health	DALY	Carcinogens, Radiation, Respiratory organic and inorganic, Climate change, Ozone layer
Ecosystem	PDF*m2yr	Ecotoxicity, Acidification/ Eutrophication, Land Use
Resources	MJ surplus	Minerals & Fossil Fuels.

Damages to HH are expressed in unit of "Disability Adjusted Life Years" [DALY]. Damages to EQ are expressed in terms of "Potentially Disappeared Fraction" [PDF] and "Potentially Affected Fraction" [PAF] of species due to an environmental impact. The PDF and PAF values are then multiplied by the area size and the time period necessary for the damage to occur. Damage to Resources is often expressed by means of the surplus energy needed for the future mining of resources [51]. The detailed explanation of ecoindicator'99 is explained elsewhere [53-59].

4.4.2. Analysis Results

Characterisation Values

Figure 8 shows the characterization results in the form of a bar chart. From this figure one can see the characterisation of impacts into different categories as mentioned earlier. The result of the comparison shows that plastic bags found to be little better in terms of lesser environmental impact compared to paper bags. In a closer perspective, impacts of paper bags characterized to 100% on Carcinogens, Respiratory organics, Inorganics, Climate Change, Ecotoxicity, Acidification/Eutrophication, land use and around 49% on Radiation, 47% on Ozone layer depletion, 29% on minerals and 46% on Fossil fuels. On the other hand, the impact of plastic bags characterized to 100% on Radiation, Ozone Layer, Minerals and Fossil Fuels categories and 53% on carcinogens, 90% on respiratory organics, 63% on Inorganics, 45% on climate change, 52% on eco toxicity, 85% on acidification/eutrophication and 75% on land use.

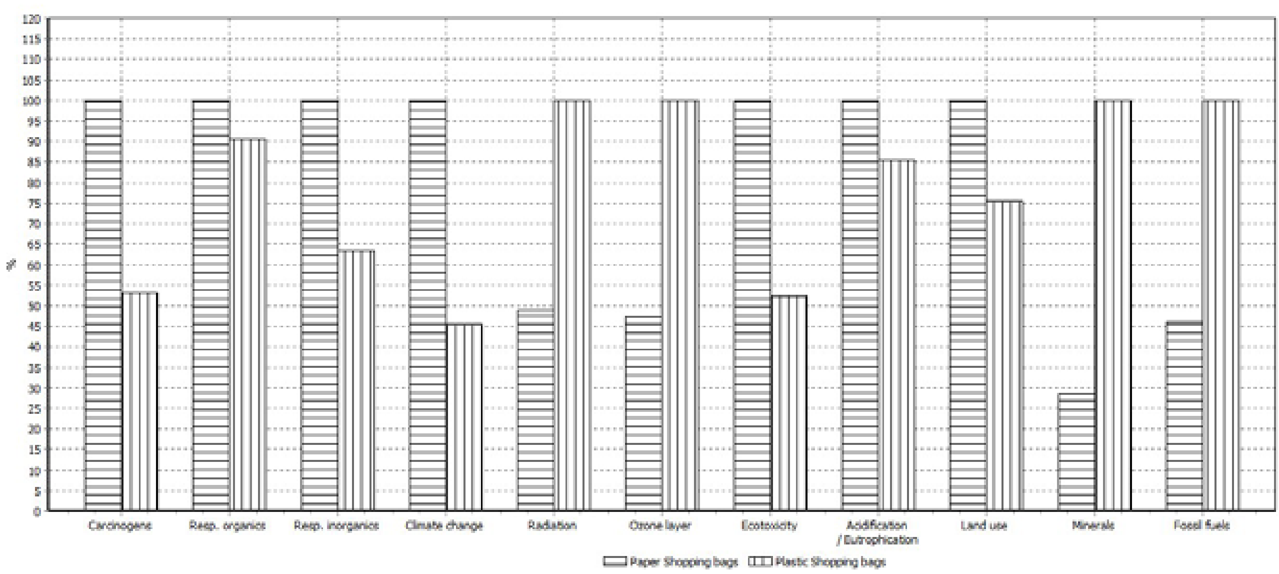

Figure 8 Characterisation results.

Damage Assessment Results

Figure 9 shows the damage assessment results of this comparative study. Comparing the life cycle stages of the paper and plastic bags, it is remarkable that Carcinogens, Respiratory organics, Inorganics, Climate Change, Ecotoxicity, Acidification/ Eutrophication and land use have the greatest contribution to the overall impact by the paper bags, but these impacts are assigned to comparatively lesser contribution to the impact made by Plastic bags. As stated above in characterization step, the maximum contribution of damage is made by paper bags on Carcinogens, Respiratory organics, Inorganics, Climate Change, Ecotoxicity, Acidification/ Eutrophication and land use categories and plastic bags contribute to the damage on Radiation, Ozone Layer Depletion, Minerals and Fossil Fuels categories. The percentage of damage made by each bag on other categories can be viewed from Figure 9.

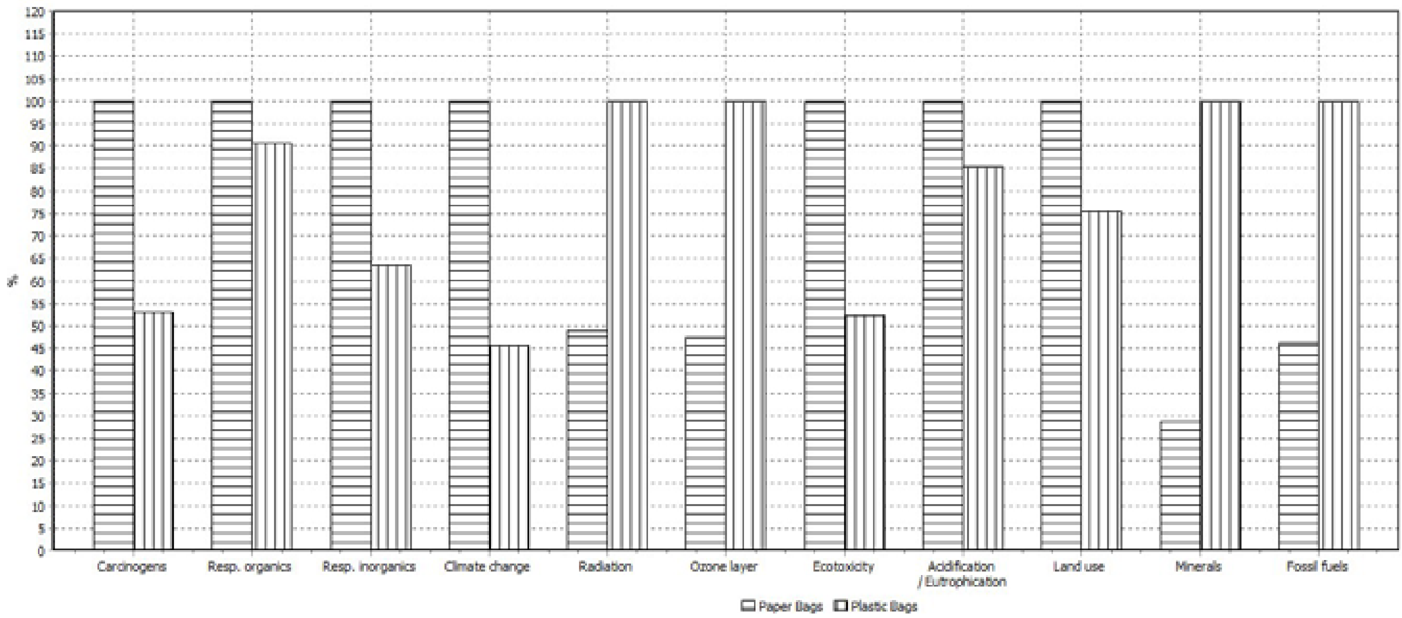

Figure 9 Damage assessment results.

Normalisation & Weighing Assessment Results

Figure 10 and 11 show the normalisation & weighing results of this comparative study on paper and plastic bags. One can visualize the normalized results of impact categories from Figure 10 and 11 showing the results of weighing in value sphere modelling, as explained earlier. Both of the principles of normalisation and weighing can be seen from the Figure 6-7. A detailed explanation can be found from the references [53-59].

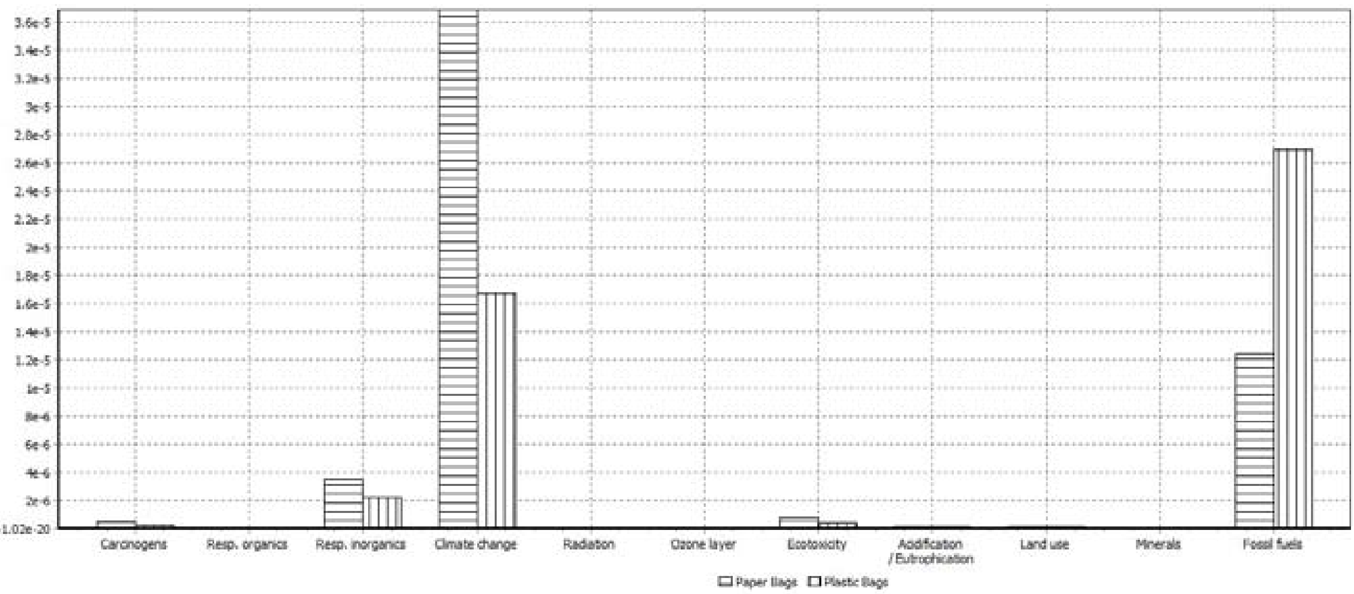

Figure 10 Normalisation results.

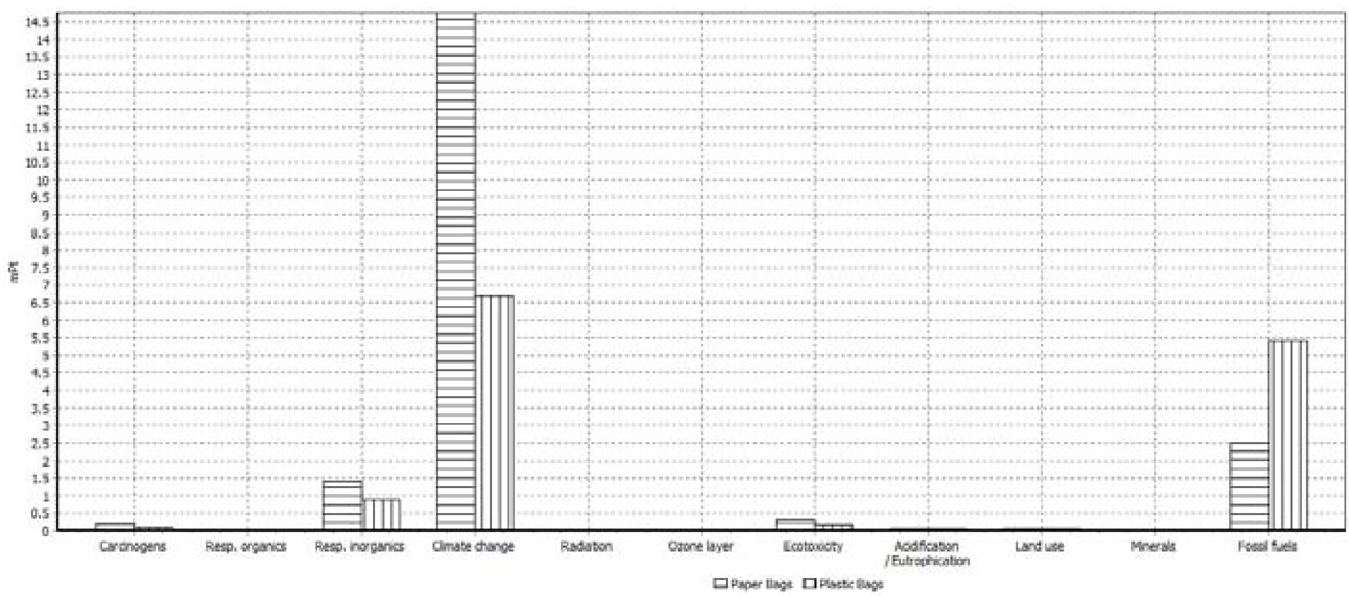

Figure 11 Weighing results.

4.4.3. Interpretation of Results

Carcinogens, Respiratory Organics and Inorganics and Climate Change

The maximum amount of contribution made by paper bags on the impact categories such as Carcinogens, Respiratory organics, Inorganics and Climate Change is attributed to the fact that these impact categories are significantly depend upon the amount of energy consumed [60]. Since the amount of energy consumed by paper bags is very much higher compared to plastic bags, these factors turned to be much higher for paper bags.

Radiation & Ozone Layer Depletion

Radiation is a kind of damage resulting from radioactive radiation. A good example of an element which can cause radiation is carbon, which is employed much during the production of plastic bags than paper bags. Ozone layer impact, which is mainly due to increased UV radiation as a result of emission of ozone depleting substances to air, is higher for plastic bags than paper bags.

Ecotoxicity

Ecotoxicity, which is primarily as a result of emission of eco toxic substances to air, water and soil is much higher for paper bags [61].

Acidification/Eutrophication

Also the acidification/ Eutrophication potential which results from the emissions of acidifying substances to air and water, and Eutrophication of water [61]. The reasons for the same can be understood very well from the inventory data.

Land use

This damage on land use could be due to either occupation of land or conversion of land to some thing else. Although this category of damage is applicable to plastic bags, it is much higher for plastic bags and it is obvious for paper bags, since they are obtained from trees which damage land use much.

Minerals & Fossil Fuels

All Impact categories except radiation, ozone layer, minerals, and land use favour plastic bags. This can be explained by the fact that the plastic bags use more amounts of fossil raw materials and energy.

They consume more amounts of crude oil and natural gas than paper bags. This is also correlating with the findings of a report on Socio-economic Impact Assessment of the Proposed Plastic Bag Regulations by Bentley West Management Consultants, Johannesburg, South Africa [35].

Single Score Values

Deduction of Life cycle analysis modelling to single score values enable us to bring out the results to a fully aggregated score/value, out of which one can understand the scores earned by each product under comparison. More the points earned by a product, more will be the environmental impact, and vice versa. Figure 12 portrays the single score values of paper and plastic bags, which gives a lucid explanation of noticeable impact of paper bags on climate change, respiratory inorganics and maximum impact of plastic bags on damage to fossil fuels. All of the other contributing factors of both bags can be noticed from the single score values and the detailed explanation pertaining to them were discussed above.

The emphasis on interpretation phase of this analysis is not on concluding which one is much better. Actually the conclusion needs to be drawn on how to reduce the environmental impacts by both of them. One of the possible ways to decipher this is by means of finding ways to reduce, reuse, and recycle both of them [62-65]. In fact, many retail stores have started utilizing this philosophy of reducing, recycling and reusing the grocery bags. Building up public awareness and motivation to reduce, reuse and recycle both of the bags will definitely help to resolve the environmental problems to a greater magnitude.

Also the authors would like to point out that the Life cycle Impact must consider the impacts made by the raw materials say, wood for instance for paper bags in terms of oxygen consumption, nutrient cycles, etc. and also include consideration of sustainable measures.

5. Conclusion

In this research paper, an exploratory study was performed to analyse the life cycle impact assessment study of paper and plastic bags by using a secondary data for LCI. According to the LCI data and the software used for this study, which also has certain hypothesis and assumptions, plastic bags are found to be little better in terms of environmental impacts compared to paper bags. However this stage of conclusion solely depends upon the secondary data and the LCA software employed for the study.

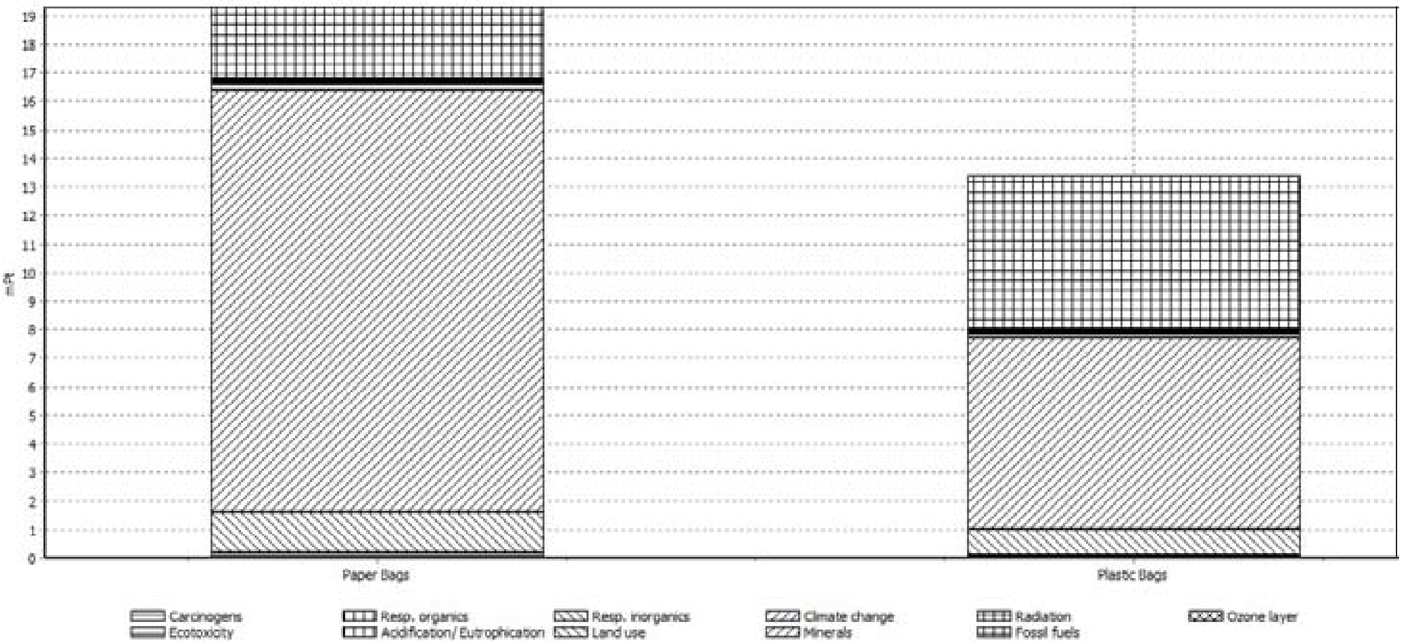

Figure 12 Single score value results.

References:

[1] Information on http://www.oregonlive.com/environment/index.ssf/2007/05/ paper_or_plastic_which_is_best.html.

[2] Information on http://www.msnbc.msn.com/id/18538484/

[3] Information on http://www.reusablebags.com/facts.php?id=7

[4] Information on www.ecogeek.org/content/view/1315

[5] Information on www.treehugger.com/files/2008/07/paper-bags-or-plastic-bags-everything-you- need-to-know.php

[6] Information on http://healthychild.org/blog/comments/

[7] Information on http://www.bankrate.com/brm/news/cheap/20041215a1.asp

[8] Information on http://science.howstuffworks.com/paper-plastic.htm/printable

[9] Information on http://www.reason.org/commentaries/smithheisters_20080417.shtml

[10] Information on http://www.wisegeek.com/are-paper-or-plastic-grocery-bags-better-for-the-environment.htm

[11] Information on http://www.healthgoods.com/education/environment_information/Solid_Waste/paper_or_plastic.htm

[12] Information on http://www.grrn.org/resources/paper_plastic.html

[13] Information on http://www.greenfeet.net/newsletter/debate.shtml

[14] Information on http://www.angelfire.com/wi/Paper Vs Plastic/

[15] Information on http://www.plasticsnews.com/blog/2008/04/proof_that_plastic_bags_are_gr_1.html

[16] Moore CJ. et al. A Comparison of Plastic and Plankton in the Pacific Central Gyre. Marine Pollution Bulletin 2001; 42: 297-1300.

[17] Information on http://www.plasticsareforever.org/paper_v_plastic.html

[18] Information on http://www.enviroliteracy.org/article.php/1268.html

[19] Information on http://www.natural-environment.com/blog/2008/01/12/paper-bags-vs-plastic-bags/

[20] Lajeunesse S. Plastic Bags. Chemical and Engineering News 2004; 82; 38: 51.

[21] Sara E. et al. Plastic Grocery Bags: The Ecological Footprint, Student publications, VIPIRG publications, University of Victoria, PO Box 3050 STN CSC, Victoria, 2005

[22] Information on http://turnkey.taiwantrade.com.tw

[23] Stevens E. Green Plastics: An Introduction to the New Science of Biodegradable Plastics. Princeton, NJ: Princeton University Press, 2001.

[24] Williamson LJ. It's Not My Bag, Baby! On Earth: Environmental Politics People 2003; 25; 2: 32-34.

[25] SETAC workshop report (1992).A conceptual framework for Life-Cycle Impact Assessment. Edited by James fava, etal, February 1-7, 1992, USA.

[26] SETAC. Guidelines for Life-Cycle Assessment. A Code of Practice, SETAC Workshop, SETAC, Sesimbra, 1993.

[27] ISO 14040,Environmental Management- life cycle assessment-principles and frame work Geneva: International Organisation for Standardisation, 1997

[28] ISO 14041, Environmental management-life cycle assessment- goal and scope definition and inventory analysis. Geneva: International Organisation for Standardisation, 1998

[29] ISO 14042, Environmental management- life cycle assessment-life cycle impact assessment. Geneva: International Organisation for Standardisation, 2000.

[30] Guido S. et al. Integrated Life-cycle and risk assessment for industrial processes. Lewis Publishers, New York, 2003.

[31] ISO 14043, Environmental management-life cycle assessment-life cycle interpretation. Geneva: International Organisation for Standardisation.

[32] Guinee JB. et al. Handbook on life cycle assessment. Operational guide to the ISO standards. Dordrecht: Kluwer, 2002.

[33] Information on http://iere.org/ILEA/lcas/franklin1990.html, Last Modified on October 28, 2004.

[34] Information on http://www.myownbag.com/bagsbynumbers.html.

[35] FRIDGE. Socio-economic Impact Assessment of the Proposed Plastic Bag Regulations. Report for the National Economic Development and Labour Council. Bentley West Management Consultants, Johannesburg, South Africa, can be viewed at: sfenvironment.org/downloads/library/asticlifecycleanalysis.pdf.

[36] Brower. et al. The Consumer's Guide to Effective Environmental Choices - Practical Advice from the Union of Concerned Scientists, Three Rivers Press, New York, 1999. p. 132-133.

[37] Chet C, Bernard R. Life Cycle Assessment for Three Types of Grocery Bags - Recyclable Plastic; Compostable, Biodegradable Plastic; and Recycled, Recyclable Paper. FINAL REPORT, Boustead Consulting & Associates Ltd, 2007.

[38] Information on http://www.sustainability-ed.org/pages/look4-2.htm

[39] GUA - Gesellschaft für umfassende Analysen, The Contribution of Plastic Products to Resource Efficiency, Vienna, can be viewed at: http://www.plasticseurope.org/Content/Default.asp?PageID=517#, 2005

[40] Boustead Consulting, Life Cycle Assessment for Three Types of Grocery Bags - Recyclable Plastic; Compostable, Biodegradable Plastic; and Recycled, Recyclable Paper.2007.

[41] Life Cycle Inventories for Packagings, Volume 1, SAEFL, 1998, Environmental Series 250/I and Eco-Profiles of the European Plastics Industry, developed by I. Boustead for Plastics Europe, March 2005.

[42] The ULS Report , Review of Life Cycle Data Relating to Disposable, compostable, Biodegradable and Reusable Grocery Bags, 28 March 2008.

[43] Nakazawa K. et al. Life Cycle Impact Assessment of Wood free Papers Containing Non wood Pulp or Deinked Pulp. Japan TAPPI Journal, 2003; 57: 1212-1221

[44] Meike S. LCA on a Bus Body Component Based on Biomaterials. 3rd International Conference on Life Cycle Management, August 27-29, Zurich, 2007.

[45] Helena D. et al. Combining Ecological and Economic Assessments of Waste Management - Newspaper disposal case study. PEER Environmental Technology Seminar, October11-12, 2006, Montpellier, France.

[46] Gerald R. et al. The role and implementation of LCA within life cycle management at Alcan. Journal of Cleaner Production, November-December 2005;13:1327-1335

[47] Rey FJ. et al. Life cycle assessment and external environmental cost analysis of heat pumps. Environmental engineering science, 2004; 21: 591-605.

[48] Mauro C. et al. LCA of an Italian lager beer. The International Journal of Life Cycle Assessment 2008; 13; 2: 133-139.

[49] Selwyn T. et al. Eco Assessment of Commercial Buildings. Fourth Australian Life Cycle Assessment Conference, Sydney, 2005.

[50] Goedkoop M. et al. The Eco-indicator 99: A Damage Oriented Method for Life Cycle Impact Assessment Methodology Report. Second and Third Editions, Amersfoort: PRÈ Consultants. The Netherlands, 2000 & 2001.

[51] Beatriz RM. et al. Life Cycle Inventory of Medium Density Fibreboard. Int J LCA 2007; 12: 143 – 150.

[52] Amir HS. et al. Life Cycle Assessment [LCA] of Potable Water Treatment Process in Malaysia: An Environmental Impact Comparison among Different Water Quality and Water Level Supply, International Conference on Environmental Research and Technology [ICERT 2008], 2008.p.1021-1025.

[53] Information on www.pre.nl/eco-ind.html

[54] The Ecoindicator 99, A damage oriented method for life cycle assessment, Manual for Designers, can be viewed from www.pre.nl/.

[55] Information on www.pre.nl/eco-indicator99/eco-indicator_99.htm

[56] Information on www.eco-indicator.nl/eco-indicator99/eco-indicator_application.htm

[57] Tracy B, Vicky L. Design for sustainability – A Practical Approach. Published by Gower Publishing, Ltd. 2007. p.70-71.

[58] Dreyer, Louise C. Comparison of three different LCIA methods: EDIP97, CML2001 and Eco-indicator 99. Does it matter which one you choose. Int J LCA 2003; 8: 191-200.

[59] Proposal for an Australian Eco-Indicator Project, A project to develop an environmental impact assessment methodology for Australia, Centre for Design at RMIT University, August 2003.

[60] Beatriz R. et al. Life Cycle Inventory of Particleboard: A Case Study in the Wood Sector. Int J LCA 2006; 11: 106 – 113.

[61] Mercedes HR. et al. First report on the sustainability evaluation of the selected materials and technologies [LCA and LCC analysis], Innovation and sustainable Development in the Fibre Based Packaging Value Chain, A SustainPack Report, May 2006, ITENE, Valencia [Spain], 2006

[62] Information on www.tennessee.gov/environment/tn_consv/archive/paperplastic.pdf

[63] Information on www.chicocan.org/pdf/9-25-08_Plastic_Goal_Fact_Sheet.pdf

[64] Information on www.recycling-guide.org.uk

[65] Information on http://environment.about.com/od/recycling/a/reusablebags.htm