OUTRANKING MATRIX-BASED COMPARATIVE STREAMLINED ENVIRONMENTAL LIFE CYCLE ASSESSMENT OF DIFFERENT PACKAGING MATERIALS OF AN INDUSTRIAL SYSTEM

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INTRODUCTION

Traditionally, the most important objectives of manufacturing industries are productivity and quality improvement[2], but now environmental considerations are gradually being integrated into industrial operations. Government bodies, consumers and manufacturers are now requiring an assessment of the environmental quality of certain products[3]. These include finding ways on how to minimize solid wastes generation, water and energy consumption and even greening the supply chain of process industries. Moreover, there is already an increasing pressure on the improvement of process efficiencies on different chemical and process industries[4]. Manufacturing industries have been using various end-of-pipe treatments technology but using inherently clean processes can minimize dependence on these. This entails the incorporation of environmental factors into the process design for the optimization of environmental performance of a product throughout its life cycle that includes the selection of which raw material or component is the best option to consider, which is known as the Design for Environment or DFE. In this study, secondary packaging materials, which are used to contain individual products in bulk, are examined and compared to other materials such as plastics cases and paper boxes.

Section 20 of the Philippine Clean Air Act of 1999[5] banned incineration of solid wastes in any form that results to more problems in disposing solid wastes. Currently, Metro Manila Development Authority or MMDA[6] addresses the present disposal requirements of Manila with an estimated volume of about 1,848 tons of garbage coming from both residential and industrial sources. The authority is utilizing controlled dumpsites but these provide only short-term remedies, still minimization is the best option. In terms of the energy insufficiency in the country, there is an increasing energy demand as reported in the Philippine Energy Plan[7] (PEP) 2002. High energy requirements of several industries in the Philippines and the depletion of energy resources are some of the major contributors on possible energy insufficiency in the

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country. Lastly, clean water supply and water shortage are also problems facing manufacturing industries. Unfortunately, Manila is now facing water shortage problem due to the decreasing water reserve in Angat Dam. The National Water Resources Board or NWRB[8] is considering cutting down by 20 percent the water supply in Metro Manila and Central Luzon.

Due to these problems faced by manufacturing industries, several methodologies were developed by international organizations to prevent the use of end-of-pipe treatments. The International Organization for Standardization has developed ISO 14000, a series of environmental management standards for Environmental Management Systems (EMS), which includes the ISO 14040 standards or Life Cycle Assessment (LCA). LCA is a method of quantification of environmental intervention and evaluation of different environmental improvement options throughout its entire life[9]. It employs the calculation of total input and output streams of materials and energy from and to the environment in every stage of the product life[10] for the assessment of the environmental impact of the product in a holistic manner. Cost, time and aggravation are the three major reasons why experiments on making shortcuts on LCA or so-called simplified or streamlined LCA (SLCA) are made[11]. The main intent of SLCA is to preserve the concept of LCA and yield credible results, while at the same time meeting the economic, scientific and logistical constraints that are present[12]. SLCA for DFE requires the utilization of Multicriteria Decision Making or MCDM[13] [14] [15]. It is a suitable mean in order to implement LCA into integrated decision processes[16]. Among the different MCDM methods, Le Teno[17] identified PROMETHEE as a suitable method. In fact, it is known as one of the most efficient but also one of the easiest in the field[18]. It allows either partial or complete ranking of alternatives (PROMETHEE I and II) and produce readable and easy to understand results.

This study will focus on the identification of which secondary packaging material will be the best environmental option for a particular industrial system using SLCA, which incorporates PROMETHEE algorithm. The alternatives available will be evaluated in terms of solid waste generation, embodied energy and net water consumption. These three categories were identified

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as the main concern of the manufacturers of secondary packaging materials, which affects both global and local environmental problems.

METHODOLOGY

Life cycle assessment procedure consists of four major steps. Setting up the goal and scope of the study, life cycle inventory, impact assessment and interpretation analysis. It has been stated that the full LCA methodology is a tedious task. It requires expensive and confidential data that may not be obtainable and is time consuming. Streamlining the methodology can be a suitable way to alleviate these problems, after all, full and streamlined LCA are not two different approaches but rather are points in continuum that may differ in the intensity of the effort but not on the findings. This study identified three different methodologies that can be combined to formulate a streamlined LCA model namely, limiting or eliminating life cycle stages, focusing on specific environmental impacts or issues and the use of surrogate data. Most of the past LCA models are coded in a spreadsheet environment due to its capability to calculate vast number of information and equations, produce readable and accurate results. This particular project utilized the same environment in developing a prototype SLCA software model. The developed model includes the following:

- Determination of the total energy and water consumption and solid wastes generated by each alternative from a cradle-to-grave perspective, which are the basis for the comparative assessment.
- The determination includes different factors in the calculations such as the percentage component of the raw material, recycle and reuse fractions.
- Outranking of the alternatives based on three different criterions stated will be done for the impact assessment phase. PROMETHEE algorithm will be utilized and *reciprocal weights method* for the weighting process.
- Sensitivity analyses are also done through variation of the different functions of the model.

Goal Definition

The goal of this study is to have a comparative analysis on the different packaging material of the industry. The analysis is done to identify which among the alternatives is the best environmental option. The alternatives that are being analyzed are the following:

- Corrugated Paper Board Boxes
- High Density Polyethylene Plastic Cases
- Polypropylene Plastic Cases

Functional Unit

The functional unit used is 1 delivery cycle of payload with dimensions 27.9 x 22.9 x 30.5 centimeters and weight of 7.1 kilograms.

Scope Definition

The scope of this study is limited to the three alternatives. Data specifications and assumptions are collected for the inventory analysis.

Alternative A : Corrugated Paper Board Boxes

Currently, the company is using the CPB boxes as its secondary packaging material for its product. The following data and assumptions were taken:

- The boxes were produced from 15% virgin Kraft pulp and 85% old corrugated container.
- To produce a kilogram of paperboard box requires 24.88 MJ of energy. This is based on a 15% virgin Kraft pulp and 85% old corrugated container ratio.
- The material is designed to be utilized once. Although the material may seem to have a possibility of being reused, due to the lack of schematics for the proper usage, it cannot be done.
- The weight of the corrugated paperboard boxes is 0.5 kg.

Alternative B: High Density Polyethylene Plastic Cases

HDPE plastic case is one of the viable alternatives as a replacement for CPB boxes.

Alternative C: Polypropylene Plastic Cases

PP plastic case is also considered as another option as a replacement for the existing packaging material of the company.

Systems Boundary

Corrugated Paper Board Boxes

The scope of the inventory is primarily concentrated on the usage of the materials but the manufacturing stage will still be included (cradle-to-grave perspective). The current flow path of the corrugated paperboard boxes is shown below: (Figure 1)

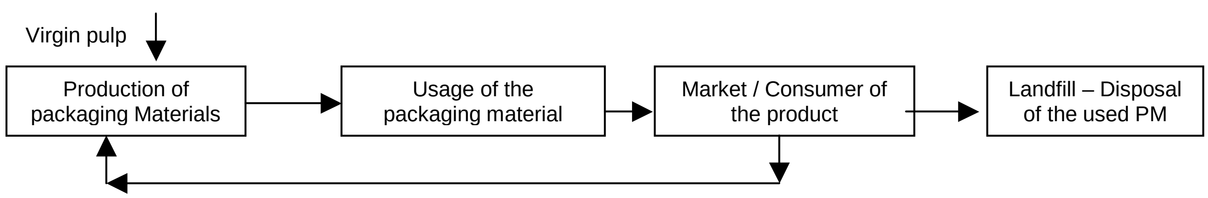

Figure 1 CPB boxes system boundary

HDPE and PP Plastic Cases

The proposed flow path of the reusable plastic cases are the following: (Figure 2)

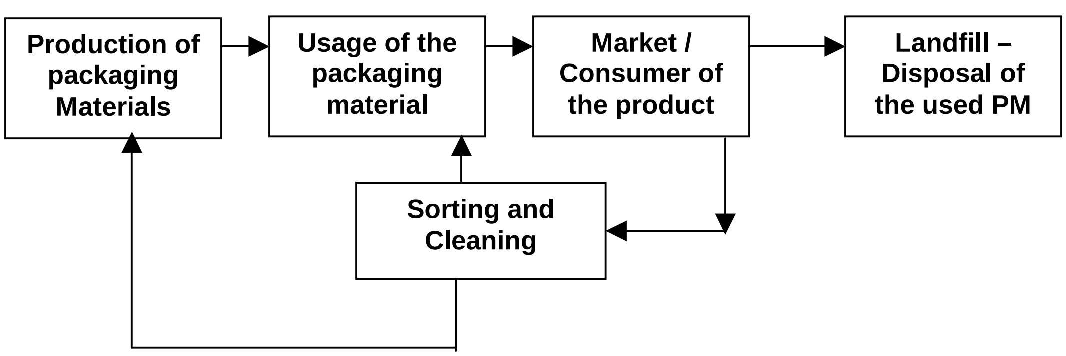

Figure 2 HDPE/PP plastic case system boundary

Streamlined Life Cycle Inventory

The life cycle inventory of the three packaging material is focused on three major impact categories: embodied energy, solid waste generation and water consumption. The total amount of each category will be calculated from manufacturing to usage, reuse, recycle and disposal for each material and with different scenarios. Data are gathered to complete the task. Most of these data are collected from the company and some of them are from literature.

Included in the life cycle inventory steps are scope and boundary definition, data gathering, model development and assessment of the results. A model has been developed to quantify the amount of the environmental impacts of each material. The model utilized PROMETHEE algorithm for the outranking process.

The general idea of integrating PROMETHEE algorithm into the model is to have a simple but efficient outranking of the alternatives. The outranking scheme is stated below:

- Each material is modeled to yield an amount of each priority inventory parameter:
    - Embodied Energy (EE)
    - Water consumption (WC)
    - Solid waste generated (SWG)
- The alternatives will be compared to each other based on each criterion (*e.g.* CPB vs HDPE, CPB vs PP et, al)
- The scoring for the comparison will be done through a matrix as shown below. It is based on the six generalized criteria on the use of PROMETHEE algorithm, *usual criterion*:
- Table 1 shows a sample matrix,

Table 1 Sample Matrix

	CPB	HDPE	PP
CPB	-		
HDPE		-	
PP			-

- If alternative A is acceptable than B based on the life cycle inventory results the computer will automatically generate a score of 1. Otherwise, the score generated is 0.
- *Reciprocal weights method* will also be integrated into the model to calculate for the relative weights of each environmental impact.

RESULTS AND DISCUSSION

Scenario Analysis

Variations on the different functions within the model are done to conduct a scenario analysis. The following assumptions are applied to lessen the number of scenario to be analyzed.

- Current component of CPB boxes: 85% recycled and 15% virgin pulp
- Ideal recycling percentage of CPB boxes is 90% and the worst is 60%
- Ideal reusing percentage of HDPE/PP plastic cases is 90%; worst 50%
- Variations on the ranking of different criterion depending on the priority

A three part scenario analysis will be done to comprehensively analyze the impact contributions of each alternatives:

- Test the sensitivity of the model on variations on % recycle and reuse of the materials.
- Test the sensitivity of the model on variations on the ranking of the impact categories.

- Test the sensitivity of the model on variations on composition of the materials

Scenarios to be evaluated are as follows:

- Scenario A1: CPB recycling percentage: 90%; HDPE/PP % reuse: 90%
  Impact Category ranking: EE=SWG=WC
- Scenario A2: CPB recycling percentage: 60%; HDPE/PP % reuse: 50%
  Impact category ranking: EE=SWG=WC
- Scenario B1: CPB recycling percentage: 90%; HDPE/PP % reuse: 90%
  Impact category ranking: EE>SWG>WC
- Scenario B2: CPB recycling percentage: 90%; HDPE/PP % reuse: 90%
  Impact category ranking: SWG>WC>EE
- Scenario B3: CPB recycling percentage: 90%; HDPE/PP % reuse: 90%
  Impact category ranking: WC>EE>WSG
- Scenario C: Composition of CPB box: 65% recycled and 15%virgin pulp

The ranking procedure utilized reciprocal weights method for the ranking of the different impact categories and PROMETHEE II algorithm.

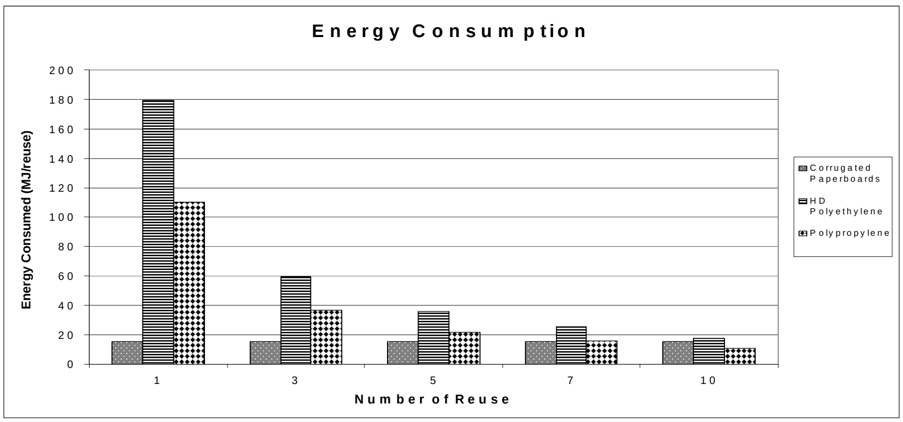

Figure 3 Embodied Energy Analysis for Scenario A1

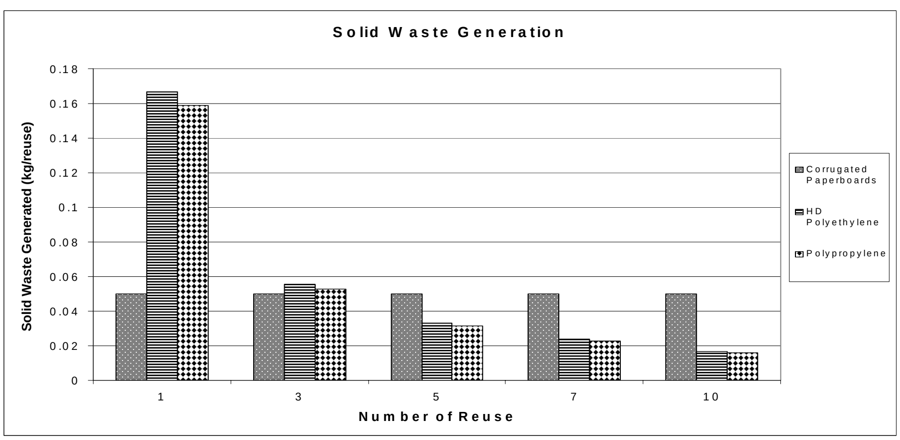

Figure 4 Solid Waste Generation Analysis for Scenario A1

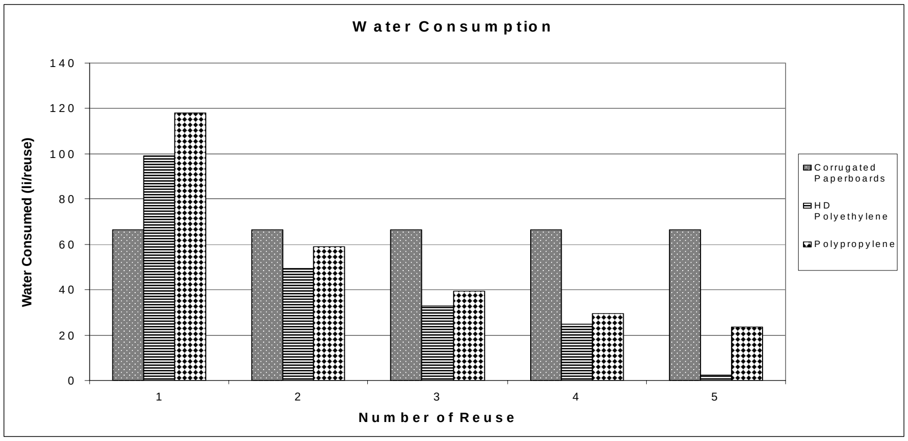

Figure 5 Water Consumption Analysis for Scenario A1

- For single usage of the material, it is unanimous in all scenarios that CPB box is the best option to consider.
- Sensitivity analysis shows that variations on the percentage recycle and reuse of the materials doesn't have a significant effect on the result of the ranking of the different alternatives. The ranking of the different options are the same for ideal and worst scenario, which is shown on Table 2.
- However, a variation on the ranking of the impact categories decreases the number of reuse to meet the equilibrium of the environmental benefits between the CPB boxes and HDPE and PP plastic cases.
- Giving highest priority on the energy and solid waste criteria would mean an environmental break-even point of about 4 reuse cycles. For water consumption it is about 3 reuse cycles.
- Comparing the embodied energy analysis results of scenario A1 and C1, there is no variation on the energy consumption per reuse on the plastic cases but there is a decrease on the amount of energy consumed per reuse by the CPB boxes from 15.54 MJ/reuse from scenario A1 to 14.46 MJ/reuse from scenario C1. But according to PROMETHEE outranking table for scenario C the change in the percentage composition of the CPB box does not have significant effect on the ranking process.

Table 2 shows the summary of ranking of all the alternative for all the scenario investigated:

Table 2 Summary of Scenario Results Based on 5 Reuse Cycles

	Scenario A1	Scenario A2	Scenario A3	Scenario A4	Scenario A5	Scenario A6
CPB Box	3	3	2	3	1	3
HDPE Plastic Case	2	2	3	2	3	2
PP Plastic Case	1	1	1	1	2	1

- In this study, PROMETHEE algorithm appears to be an appropriate method for SLCA because it is:
    - Easy to understand
    - Produce readable results
    - Can be modeled realistically
    - Efficient and simple
    - Allows partial and complete ranking of alternatives

SUMMARY AND CONCLUSION

The main goal of this study is to arrive on a measurement of the total impact per container of the three secondary packaging materials used by an industrial system employing the principle of LCA.

The end results will be used to identify which among the alternatives is the best environmental option in compliance with the concept of design for environment. Each options are assessed based on the different impact categories specified:

- Embodied Energy
- Solid Waste Generation
- Water Consumption

The functional unit used in the model to measure the performance of the three secondary packaging materials is the weight of the packaging material required to deliver 7.1 kilograms of the product, which includes the weight of the primary packaging material.

For single usage of the secondary packaging materials, corrugated paperboard boxes is considered the best option based on the all the specified criterion and is unanimous on all the tested scenarios. The plastic cases consumed almost 10 times the energy requirements, 3 times the solid waste generated and twice the water consumption of the CPB box. Variation on the percentage recycling of the used CPB boxes indicates a significant change in the solid waste impact category. Changing the percentage recycling of used CPB box from 60% *(worst scenario)* to 90% (*ideal scenario*) would mean a 75% decrease on the solid waste impact. HDPE plastic case contributes the highest on the energy consumption and solid waste generation and PP plastic case on water consumption under the ideal scenario.

For multiple-use of the secondary packaging materials, reusable plastic cases are then considered the best alternative. Using the plastic cases twice could reduce all the environmental impact indicated by at least 50%. Increasing further the number of reuse would diminish the environmental impact contributions of the plastic cases. The contributions of all the alternatives on all the environmental impact categories are in equilibrium to at least 4 reuses. Multiple reuses of these secondary packaging materials would require an implementing scheme and guideline for proper usage to attain the minimum number of reuse to at least obtain the equilibrium point impact contributions of the alternatives.

Actually, the corrugated paperboard box is designed to be utilized once but considering practicality, it can used more than once and if the box use is doubled, the production of new box can be avoided and environmental impacts from almost all processes in the life cycled can be avoided. The double use of the box would mean a 50% reduction on all the impact categories specified.

Variations on the priority of the environmental impact would give a significant effect on the ranking of the alternatives.

Finally, based from the comparative analysis of the results to other methods, PROMETHEE appears to be the most appropriate MCDM method for this study.

RECOMMENDATIONS

Due to the limitations of this study, recommendations are suggested for future improvement studies in the same field.

- Graphic user interface of the software model – for a user-friendly software.
- Expanded LCA considering detailed inventory parameters and environmental impacts.
- Study of different alternatives for different fields in the industry.
- Comparison and outranking of more than 3 alternatives or options.

ACKNOWLEDGEMENT

The authors would like to thank the Department of Science and Technology – Philippine Council for Industry and Energy Research and Development (DOST-PCIERD) for the financial assistance.