LIFE CYCLE ASSESSMENT OF POLYETHYLENE COLOR VEST BAGS

Statyukha G.O., Ruban A.V., Dzhygyrey I.M.
National Technical University of Ukraine "Kyiv Polytechnic Institute", dzhygyrey@gmail.com

Life cycle assessment (LCA) allows measuring an environmental impact of product manufacture and disposal wastes, comparing several different product systems, choosing the best option during decisions making for improving the industrial cycle and decreasing the influence on nature and human health. Numerous methods and models of LCA have been developed and tested worldwide in order to measure the environmental impact of a product production, consumption and disposal. However, most of these methods have the drawbacks, difficulties in using, unreasonable simplifications and so on. But still LCA has become an important part of International organization of standardization (ISO) and EU Eco-Management and Audit Scheme certification. Companies want to get such certificate, because it helps to increase competitiveness on national and global markets. That is financially important, especially in the current economic slowdown.

ISO certification has wide range of families covered all aspects of production and management processes. None of the Ukrainian companies had ISO certification on subfamily 1404X «Environmental Management. Life Cycle Assessment» or the Occupational Health and Safety Assessment Series (OHSAS 18001) in 2010. It is a fact that existing software for LCA evaluation is quite expensive and only special big auditing and certification companies can afford to use them.

LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, by compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts associated with those inputs and outputs; interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study [2]. LCA consists of four phases: definition of goal and scope, inventory analysis, impact assessment and interpretation of results. Life cycle impact assessment (LCIA) is the third phase of life cycle assessment. The purpose of LCIA is to assess a product system's life cycle inventory analysis (LCI) results to better understand their environmental significance. The LCIA phase models selected environmental issues, called impact categories, and uses category indicators to condense and explain the LCI results. Category indicators are intended to reflect the aggregate emissions or resource use for each impact category. The general framework of the LCIA phase is composed of several mandatory elements that convert LCI results to indicator results:

a) Selection of impact categories, category indicators and characterization models.

b) Assignment of LCI results (classification) to the impact categories.

c) Calculation of category indicator results (characterization).

In addition, there are optional elements for normalization, grouping or weighting of the indicator results and data quality analysis techniques:

a) Calculating the magnitude of category indicator results relative to reference information (normalization).

b) Grouping: sorting and possibly ranking of the impact categories.

c) Weighting: converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices.

The total number of life cycle assessment stages may vary from only three mandatory to seven including four optional. The selection number of stages depends on the conditions, requirements and calculation purposes intended by the investigator or auditor.

The aim of this research is to test the LCA model [1], taking into account the peculiarities of the research's object. Included optional stages for life cycle impact assessment (LCIA) are aggregation, normalization and weighing. The scientific relevance of the results lies in the LCA model adaptation which takes into account the characteristics of the research object in order to obtain a single indicator based on used model. The problem-oriented model includes seventeen impact subcategories, which group into ten categories and then into four categories of protection. That allows to obtain a single score indicator of product effects on the environment and human health – Damage Index of a Product (DIP) [1]. The model estimates the life cycle of product system includes the following subcategories: acidification of natural ecosystems, agricultural land occupation, urban land occupation, depletion of non-renewable energy resources, depletion of mineral resources, formation of photochemical oxidants, ozone depletion, climate change, human toxicity, respiratory effects, ionizing radiation, terrestrial eutrophication, freshwater eutrophication, marine eutrophication, freshwater ecotoxicity, marine ecotoxicity and terrestrial ecotoxicity. Subcategory indicator is calculated as follows

$$S_i = \Sigma\,(E_j \text{ or } R_j) \times C_{i,j} \quad (1)$$

where S_i is indicator's value for subcategory i, E_j is emission of the substance j; R_j is usage of resource j; $C_{i,j}$ is characterization factor of substance j or resource j for impact subcategory i. If it is necessary the number of subcategories could be expanded or decreased within an impact category. Impact categories are formed on the basis of one to three subcategories: ecosystems' acidification, climate change, land occupation (agricultural and urban), ozone depletion, photochemical smog, resource depletion (energy and mineral), impact of emissions on human health (toxicity, respiratory effects and ionizing radiation), eutrophication of terrestrial ecosystems, aquatic eutropication (freshwater and marine) and ecotoxicity (freshwater, marine and terrestrial). Category indicator is obtained by using the normalization of values of subcategory indicators

$$I_h = \Sigma\, S_i / N_i \quad (2)$$

where I_h is indicator's value for impact category h, N_i is normalization factor for subcategory i. Impact categories fuse protection categories of "Human health" (impact of emissions and smog and ozone depletion), "Ecosystems" (eutrophication, ecotoxicity, acidification and land occupation), "Climate" (climate change) and "Resources" (resource depletion)

$$P_k = \Sigma\, I_h / W_h \quad (3)$$

where P_k is indicator's value for protection category k, W_h is weighing factor for impact category h. Product damage index is calculated as a sum of protection categories indicators

$$DIP = \Sigma\, P_k \quad (4)$$

and represents single score indicator of environmental aspects and potential impacts associated with estimated product.

Case study. Plastic bags produced by an enterprise «Polymer» was chosen as a case study for testing the model. This factory is constantly working on improvements of service quality and establishment of effective quality control system at all stages of production. The products are made from high quality raw materials that meet Ukrainian requirements of standards. The qualitative and performance characteristics of «Polymer» have awarded diplomas and certificates at various exhibitions and competitions in Ukraine and abroad.

Table 1 – LCI data collection on functional unit (1000 bags)

Resources Emissions	*Units*	*Color bags with pattern*	*Color bags without pattern*
Inputs			
HPPE[1] 15303–003	kg	8,572	9,488
LPPE[2] F 00952	kg	11,573	12,809
Master batch			
EP11006 (white)	kg	1,286	0,238
EP11723 (yellow)	kg	—	1,186
Diesel fuel	l	0,874	0,967

The functional unit for this study is 1000 vest bags of two different types with the same size: color (white) bags with pattern and color (yellow) bags without pattern. Vest bags are ones of the most popular among buyers and sellers because of low cost, large capacity, high endurance, high capacity due to lateral folds, and probability of drawing logo.

[1] High Pressure Polyethylene
[2] Low Pressure Polyethylene

End of table 1

Resources Emissions	*Units*	*Color bags with pattern*	*Color bags without pattern*
Flexographic ink			
Black RC	kg	5,358	—
Red 032 C	kg	8,144	—
Solvent	kg	0,643	—
Emissions to air			
Carbon monoxide	kg	0,0348	0,0386
NMVOC[3]	kg	0,0071	0,0079
Methane	kg	0,00022	0,00024
Nitrogen dioxide	kg	0,0274	0,0304

System boundaries include transportation of raw materials (polyethylene pellets) from the place of purchase to the company directly and production process with the last stage of the placement of finished goods in the warehouses. Raw materials are purchased at JSC «Kazanorgsyntez» (Kazan, Russia) and transported by trucks to enterprise «Polymer» (Vinnitsa, Ukraine); total transportation distance is 1,927 km. Inventory data are presented in Table 1.Water is not used in the production of polyethylene and printing patterns on bags. Similarly, it is assumed that there are no emissions to water or land. The scraps of plastic, which are a byproduct, are collected and melted again. Table 2 represents inventory data of categories of influence. Impact category indicators are obtained by using formulas (1) and (2), characterization and normalization factors are the same as in [1].

Table 2 – Results of normalization, grouping and weighting stages

Category name / Single score	*Indicator value* ($\times 10^{-11}$)	
	Color bags with pattern	*Color bags without pattern*
Impact categories		
Acidification	0,545	0,604
Climate change	0,063	0,069
Emissions (human health)	75,884	2,061
Photochemical oxidation	19,99	0,031
Aquatic eutropication	0,056	0,061
Ecotoxicity	2,929	2,622
Protection categories		
Health	826	18,1
Ecosystems	23,5	21,8
Climate	0,20	0,22
Single score		
DIP	850	40

LCIA (at protection categories' level) of color vest bags with and without pattern shows that the first type has a much bigger impact on human health especially for the reason of printing process. But for climate change protection category the second type of estimated vest bags has slightly less impact than first one, mainly because during production of yellow bags are used more granules of polyethylene. Single score indicator value – DIP – shows relatively twentyfold bigger impact of bags with pattern comparing with ones without pattern.

This study has analyzed environmental impacts one of the most popular plastic bags – vest bags with and without printing. The results indicated that plastics bags without pattern have the least environmental impact especially on human health on account of emissions to air as compared to same plastic bags with pattern. The key note for green responsible end-consumer is using plastic bags with minimum or without printing when it's feasible and the key note for plastic packaging producer is implementation of improvements associated with air pollution throughout the printing process based on pollution prevention strategy that may reduce risk concerns to human health especially workers.

1. *Statyukha, G.O.* An Aggregated Technique for Hazard Impact Assessment of Products on Environment [Text] / G.O. Statyukha, I.M. Dzhygyrey, B.M. Komarysta // Eastern-European Journal of Enterprise Technologies. – 2009. – 1/6 (37) – P. 8–19. (in Ukrainian)
2. ISO 14040: 2006. Environmental management – Life cycle assessment – Principles and framework [Text]. – Switzerland, 2006. – 12 p.

[3] Non-Methane Volatile Organic Compounds