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LIFE CYCLE IMPACT ASSESSMENT

The formulation of life cycle impact assessment framework for Malaysia using Eco-indicator

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Abstract
Background, aim, and scope Life Cycle Assessment (LCA) is an emerging supporting tool designed to help practitioner in systematically assessing the environmental performance of selected product's life cycle. A product's life cycle includes the extraction of raw materials, production, and usage, and ends with waste treatment or disposal. Life cycle impact assessment (LCIA) as a part of LCA is a method used to derive the environmental burdens from selected product's stages. LCIA is structured in classification, characterization, normalization and weighting. Presently most of the LCIA practices use European database to establish the characterization, normalization and weighting value. However, using these values for local LCA practice might not be able to reflect the actual Malaysian's environmental scenario. The aim of this study is to create a Malaysian version of normalization and weighting value using the pollution database within Malaysia.
Materials and methods This research work used the LCIA top-down approach of the Eco-indicator 99 impact assessment methodology as a guide for the formulation of normalization and weighting value. Normalization values were formulated based on Malaysia's pollutant emission rate while the weighting values were formulated using the results of questionnaire survey that was distributed among local LCA practitioner and experts.
Results and discussion The results from the studies showed that the normalization values for Malaysia in average are four times higher compared to European value while the weighting values for Malaysia are almost similar to the reference European value.
Conclusions In this study, an attempt was made to formulate Malaysian normalization and weighting values of the LCIA step using the Eco-indicator methodology. By adopting these values, the LCA study conducted will be more accurate and meaningful in evaluating Malaysian environmental impact.
Recommendations and perspectives As a recommendation, this study can be further expanded by using different type of software and different type of method in formulating the normalization and weighting values. Besides that, a better collection with more recent data should be use for estimation of the normalization values. While in the weighting values estimation, a bigger size and different social background of panel should be used in the questionnaire survey approach to indicate different perception of average Malaysian citizen on environmental concerns.

Keywords Eco-indicator · Life cycle assessment · Life cycle impact assessment · Malaysia · Normalization values · Weighting values

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1 Introduction

Environmental awareness has been seriously increased recently among societies. Firstly, people ask for cleaner air, then better quality in water, less wastes produced, more efficient energy usage, and a better quality of life in a cleaner planet (Guido et al. 2000). With the increase in the awareness for environmental issues, the European government has started to introduce regulations to meet public's requirements, and formulated legislation to prevent and to avoid environmental burdens (Guido et al. 2000). Meanwhile, in the industries, the demands for "green product" have increase tremendously. The question begins when industries have to identify what is the 'green product' that their customer's desire for (Guido et al. 2000)?

Life cycle assessment (LCA) may be the answer for these questions (Guido et al. 2000). LCA is a tool use to determine the environmental performances of products, processes or services, through production, distribution, usage, maintenance and final disposal. It is a systematic set of procedures developed to compile, examine, and evaluate the material and energy balance of the system by converting those inputs and outputs to associate with potential environmental impact that is directly attributable to the operation of a product or service system throughout its life cycle.

As defined in ISO 14040 (International Standard Organization 2006a), there are four main steps in a life cycle assessment. First stage is the goal and scope definition that identifies the LCA's purpose and the recommended products of the study, and determines the boundaries and assumptions based on the goal defined (International Standard Organization 2006a).

Secondly, is the inventory step (life cycle inventory (LCI)) that quantifies and describes the type of emissions that will take place and type of raw materials will be used during the lifespan of the product. The inventory step will provides a "cradle-to-grave" overview of energy and material flows of the selected products (International Standards Organization 2006b). Third stage is the impact assessment step (LCIA) that evaluates the information and data from LCI by turning the qualitative descriptions into quantitative evaluation of the product's emissions and assessing what impacts will these emissions have and represents the results in inventory loadings and resource use in the form of a numerical category indicator. There is a category indicator for each environmental impact. These simplified category indicators are then being used to make comparisons and consideration of improvement for product. LCIA alone are divided into three main procedures which are

- Classification and characterization,
- Normalization, and
- Evaluation or weighting.

In the classification stage, all inventory data are sorted into impact categories according to the effect they have on the environment. While in the characterization stage, the inventory data within each category will be multiplied by a characterization factor to differentiate the substances according to their severity because some substances may have more severe effect than others. In order to gain a better understanding of the relative size of each impact categories, a normalization stage is required. Each impact categories calculated from the life cycle of a product is benchmark against the known total effect for this impact categories usually within the number of population during a year in the country. Normalization enables assessing the relative contribution of the product's impacts to overall contribution of existing impacts in the country. Although normalization considerably improves insight into the results, however no final judgment can be made because not all impact categories are considered to be of equal importance. In the weighting stage, all normalized impact categories are multiplied by each weighting factors to represent the relative importance of each impact (International Standards Organization 2006b).

The fourth and final stage of LCA is where improvement analysis step is conducted to explore for opportunities in reducing energy use, material inputs, or environmental impact at each stages of the product's life cycle. All conclusions of the LCA studies will be summarized during this final phase (International Standards Organization 2006b).

2 Problem statement

LCIA as a part (third stage) of LCA is structured in classification, characterization, normalization, and weighting. However, currently most of the LCIA analysis uses European database to establish the characterization, normalization, and weighting values that might not be suitable and accurate for LCA practice in the context of Malaysian scenario. This is because the European database which is based on European pollution emission rates and is incapable to represent Malaysian's environmental condition. Thus, it is essential to create a Malaysian version of normalization and weighting values by using the pollution's data collected within Malaysia. The Malaysia version of normalization and weighting value will provide a more representative value of the Malaysian pollutant loads when applied in LCA studies within Malaysia thus enhancing the accuracy of the results.

3 Methodologies

In Eco-indicator 99, there are mainly three types of damage categories. These damage categories are Human health, Ecosystem quality, and Resources consumption (Goedkoop and Spriensma 2001). However, all these damage categories have different units. In order to use a set of dimensionless weighting factors upon these damage categories, these categories must be first converted into dimensionless numbers. The obvious way to do this is to use the normalization step.

The reference system used in this study for the calculation of normalization value was the total amount of emissions and resource extractions in the country, during a certain period of year per the amount of population in the country.

All the pollution emissions rate, resource consumption, and population size in Malaysia for the years 2005 to 2007 were collected from the latest official published data in the country.

The formulation of normalization values in this research consists of two main steps:

1. Finding the total emissions of selected substance in the country during the period of years, where 2007 was chosen as the latest published year while 2006 and 2005 data as a backup if the selected emission was not reported in 2007 report;
2. Calculating the normalization value by multiplying the respective emissions with the damage factors provided in the eco-indicator 99 methodology (Goedkoop and Spriensma 2001). The normalization value for each pollutant was calculated using the pollutant damage factors multiply with the emission rate of the pollutant in the unit of kg/year.

However, not all emissions data from the inventory list of eco-indicator methodology (Goedkoop and Spriensma 2001) were reported locally. This was solved by using the extrapolation method which was introduced in the Eco-indicator 95 methodology (Goedkoop 1996). The method is based on the assumption that the industrial structure and the emission pattern are best represented by the energy use of the country. The emissions are calculated by using the relationship of the emission in a country to the energy use of that country. Thus, one reference country with known emission data and energy usage has to be selected to be used as the extrapolation target (Blonk et al. 1997). The unknown emission can be extrapolated using the known emission data provided in Eco-indicator 99 methodology (Goedkoop and Spriensma 2001) based on energy pattern of both countries.

This study adopted the extrapolation method which used the assumption that the emission of Malaysia is related to the country's energy consumption. The procedures are shown below.

1. Firstly, the yearly energy consumption and emissions data of Malaysia have to be collected from local published reports or government agencies.
2. Then, the emission per energy use of Malaysia is determined by dividing the emissions data of Malaysia with the total energy consumption.
3. Then, the estimation of the unknown emission in Malaysia can be determined by multiplying the calculated emission per energy use of the reference country with the total energy used in Malaysia. The reference countries used in this methodology were the European countries. The Europe emission data for year 1999 were extracted from the report on methodology annex of eco-indicator 99 (Goedkoop and Spriensma 2001) and energy consumptions of Europe in the same year were chosen for the estimation.

4. The calculation used the formula as shown below:

$$\mathrm{Em} = \mathrm{Pm} \times (\mathrm{Er}/\mathrm{Pr})$$

where:

Em Emission of substance A in Malaysia
Pm Energy use in Malaysia in selected year
Er Known emission of substance A of the reference country

Table 1 Summary of the normalization values for the Egalitarian perspective

Egalitarian	Air	Water	Soil	Total	Per capita
Carcinogenic effects (DALY/year)	2.78E+04	1.85E+05	1.48E+04	2.28E+05	8.38E−03
Respiratory effects (DALY/year)	9.43E+04			9.43E+04	3.47E−03
Climate change (DALY/year)	8.85E+03			8.85E+03	3.26E−04
Ozone depletion (DALY/year)	1.68E+03			1.68E+03	6.18E−05
Total human health (DALY/year)				3.33E+05	1.22E−02
Ecotoxicity (PAFm2years/year)	1.23E+09	1.51E+08	1.02E+10	1.16E+10	4.26E+02
Eutrophication (PAFm2years/year)	5.43E+09			5.43E+09	2.00E+02
Land use (PDFm2year/year)	1.44E+08			1.44E+08	5.29E+00
Total ecosystem quality (PDF.m2.year/year)				1.72E+10	6.31E+02
Minerals (MJ/year)				2.45E+09	9.03E+01
Fossil (MJ/year)				2.34E+11	8.61E+03
Total resources (MJ/year)				2.37E+11	8.70E+03

Table 2 Summary of the normalization values for the Hierarchist perspective

Hierarchist	Air	Water	Soil	Total	Per capita
Carcinogenic effects (DALY/year)	2.78E+04	1.85E+05	1.48E+04	2.28E+05	8.38E−03
Respiratory effects (DALY/year)	9.28E+04			9.28E+04	3.41E−03
Climate change (DALY/year)	8.85E+03			8.85E+03	3.26E−04
Ozone depletion (DALY/year)	1.68E+03			1.68E+03	6.18E−05
Total human health (DALY/year)				3.31E+05	1.22E−02
Ecotoxicity (PAFm2years/year)	1.23E+09	1.51E+08	1.02E+10	1.16E+10	4.26E+02
Eutrophication (PAFm2years/year)	5.43E+09			5.43E+09	2.00E+02
Land use (PDFm2years/year)				1.44E+08	5.29E+00
Total ecosystem quality (PDF.m2.year/year)				1.72E+10	6.31E+02
Minerals (MJ/year)				2.45E+09	9.03E+01
Fossil (MJ/year)				3.46E+11	1.27E+04
Total resources (MJ/year)				3.48E+11	1.28E+04

DALY disability adjusted life years, *PDF* potentially disappeared fraction, *PAF* potentially affected fraction

Pr Energy use of the reference country in selected year

In the weighting stage, the weighting factors will be assigned to the normalized results. These weights should as far as possible reflect the average views of the Malaysian society.

Weighting factors will be collected through direct questioning of a representative group in the society. A panel consisting of scientists and LCA practitioner with experience would be better suited than common people to make sound decisions on LCA subjects. This method is also known as expressed preference methods.

This study only weighs the following three main endpoint environmental damages as referred and agreed upon in the Eco-indicator methodology 99 (Goedkoop and Spriensma 2001):

- Human health
- Ecosystem quality
- Resources

This study adopted the mixing triangle concept that was developed by Hofstetter et al. (1999) as a tool to find the weighting factors. This triangle can be easily used to graphically show the outcome of comparisons among these three weighting sets. Each point on the triangle represents a combination of three different weights that add up to 100%.

This study used the three main procedures for executing the mixing triangle (Mettier 1999):

1. Development of the questionnaire survey. The questionnaire contained a number of tests and basic question on LCA in order to check whether the questions were understood in a proper manner. The questionnaire developed will contain five basic parts,
a. The questionnaire will start with an introduction that will contain a brief description of the purpose, the

Table 3 Summary of the normalization values for the Individualist perspective

Individualist	Air	Water	Soil	Total	Per capita
Carcinogenic effects (DALY/year)	6.53E+02	9.10E+04	2.65E+02	9.19E+04	3.38E−03
Respiratory effects (DALY/year)	3.05E+04			3.05E+04	1.12E−03
Climate change (DALY/year)	8.75E+03			8.75E+03	3.22E−04
Ozone depletion (DALY/year)	1.59E+03			1.59E+03	5.84E−05
Total human health (DALY/year)				1.33E+05	4.89E−03
Ecotoxicity (PAFm2years/year)	2.51E+08	1.22E+08	5.56E+08	9.29E+08	3.42E+01
Eutrophication (PAFm2years/year)	5.43E+09			5.43E+09	2.00E+02
Land use (PDFm2years/year)				1.44E+08	5.29E+00
Total ecosystem quality (PDF.m2.year/year)				6.50E+09	2.39E+02
Minerals (MJ/year)				2.45E+09	9.03E+01
Fossil (MJ/year)					0.00E+00
Total resources (MJ/year)				2.45E+09	9.03E+01

DALY disability adjusted life years, *PDF* potentially disappeared fraction, *PAF* potentially affected fraction

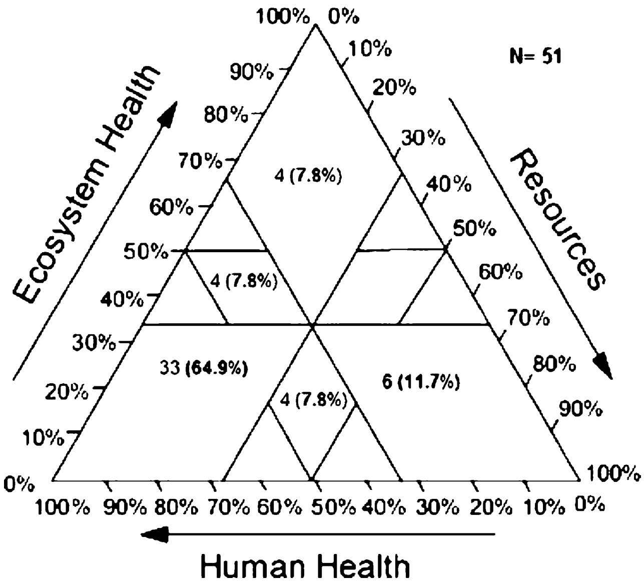

Fig. 1 Results overview of the ranking results of all 51 respondents

outline and intended application of the research methodology, and it also contained a brief description on the damage categories of disability adjusted life years for human health, the potentially disappeared fraction for plant species and on surplus energy for resource consumption.

b. Ranking, where respondents were asked to rank the damage categories in order of importance or state that they were equally important.

c. Assigning weights. The respondents were asked to give weights directly to three damage categories of Human health, Ecosystem quality and Resources consumption.

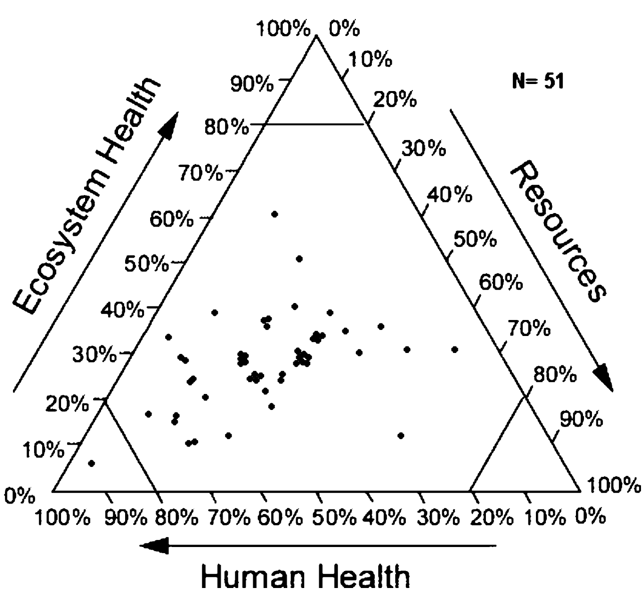

Fig. 2 Representation of all 51 weighting sets

d. Cultural perspectives. This method introduced in the weighting procedure is to consistently manage the subjective choices of respondents (Goedkoop and Spriensma 2001). These three perspectives are,

A. First is the individualist where their choices based upon short-term perspective and consider only proven cause-effect relation;

B. Second is the egalitarian where this perspective chooses to use precautionary principal where long-term perspective is key to the choices made;

C. Third is the hierarchist. This perspective chooses to include facts that are backed up by scientific and political bodies with sufficient recognition. Hierarchical is a balance between individualist and egalitarian (Hofstetter et al. 1999).

2. Sending out online questionnaire to selected respondents. These respondents must at least have a little knowledge on LCA studies in order to have more results that are accurate. The link to the questionnaires was circulated through email to LCA practitioners, researchers and environmentalist. The questionnaire was written in English.

3. Analysing the results by plotting it into the weighting triangle to produce averaged weighting value.

Hofstetter et al. (1999) showed that the results on each choice made by each panel would be determined by the basic value system a person uses. In order to analyze the influence of the perspectives, a number of standard questions are included which should reveal the perspective each respondent adhered to while choosing their answers.

4 Results

The pollution emission and resources consumption data for Malaysia was collected for the estimation of normalization values. Most of the information was extracted from Malaysia Environmental Quality Report 2007 (Department of Environment 2008) published by Department of Environment (DOE) Malaysia, the report of Compendium of Environment Statistics 2007 (Department of Statistic Malaysia 2008) from Department of Statistic Malaysia, Malaysian Minerals Yearbook 2008 (Minerals and Geoscience Department 2009) from the Malaysia Minerals and Geosciences Department, and The World Development

Table 4 Results for the weighting

	Human health	Ecosystem quality	Resources
Weighting factors	40.00%	30.00%	30.00%

Table 5 Weighting factors for all three perspectives

	Human health	Ecosystem quality	Resources
Egalitarian perspective	25%	50%	25%
Hierarchist perspective	40%	30%	30%
Individualist perspective	55%	25%	20%

Indicator 2008 (World Bank 2008) from World Bank. The results of the calculated list of emissions see Tables 1, 2, and 3.

For weighting factors, the mixing triangle developed by Hofstetter et al. (1999) was used to summarize the result of the weighting values attained by the respondents through the questionnaire survey distributed. The weighting values are assigned as factors to the damage categories of Human Health, Ecosystem Quality, and Resources. A total of 51 copies of questionnaire survey results were collected out of 80 online samples distributed, and the results were generated in the analysis below (Fig. 1).

The triangle is divided into several areas to differential respondent's results according to the choices they made on the importance of each damage category. As shown in Fig. 1, 33 (64.9%) respondents chose the weighting in the left part of the trapezium, while the trapezium in the right have six (11.7%) responses, and the top trapezium have four (7.8%) results from the respondents. It can be delineated that these respondents are clear with their choice of ranking the importance of each damage category whenever they locate their weighting factor within the trapezium area in each corner of the mixing triangle. Hence, refer to the answer gathered, 33 (64.9%) respondents placed weighting factor on Human health the highest compared with other damage categories, while four (7.8%) respondents placed weighting on Ecosystem health the highest and six (11.7%) respondents placed weighting on Resources the highest. Meanwhile, eight respondents, with four on center-left and four on center-bottom of the triangle, they have at least weighted two damage categories with the same or almost same weighting. In conclusion, the diagram shows clearly that in the ranking, Human Health got the higher weight compared to other damage categories. Although with relatively low weighs, the Resources got two more weightings compared with Ecosystem quality.

On the second parts of the questionnaire survey, the respondents were asked to assign weights to the damage categories. Their answers were plotted with scatter point into the triangle as shown in Fig. 2. The trend of the scatter points in the triangle shows that Human health obtained the most weighting. While weighting on Ecosystem quality and Resources are more or less symmetrical and obtained lesser weighting compared to Human health. The triangle shows that most weighting factors which were represented by scatter points were all grouped at the center of the triangle. However, there are one particular weights plotted in the left corner of the triangle. This particular weighting factor was given with factors more than 80%, in the Human health. It can be concluded that the lowest weighting of Ecosystem Quality and Resources are at 5% and Human health at 10%, respectively. While the highest weighting on Human health is at 90%, while Resources and Ecosystem Quality is at 60%, respectively.

The results show that the damage to Human Health is considered to be most significant, while Resources and Ecosystem Quality shared the second with same value of weighting (Table 4). Hence as a result of the data collected from this study, the following weighting set values based on median value were decided as the new Malaysian weighting factors

In order to manage the subjective choices of respondent's answers, weights are then categories according to respondent's culture perspective. There are mainly three types of culture perspectives, which are the Hierarchist, Egalitarian and Individualist. The respondent's answers were categorized according to the classification below;

1. Respondent's results that rank and weights Ecosystem Quality as the main concern fulfil the criteria of egalitarian and will all being grouped into the Egalitarian perspective.
2. Respondent's results that rank and weights Human Health as the main concern fulfil the criteria of Individualist and will be categorized into the Individualist perspective.

Table 6 Newly formulated normalization values compared with default values

Normalization	Egalitarian			Hierarchist			Individualist		
	Europe 99	Malaysian	±%	Europe 99	Malaysian	±%	Europe 99	Malaysian	±%
Damage categories									
Human health	64.7	81.7	+26%	65.1	82.08	+26%	121	204.67	+69%
Ecosystem quality	1.95E−04	1.58E−03	+712%	1.95E−04	1.58E−03	+712%	2.22E−04	4.18E−03	+1,782%
Resources	1.68E−04	1.15E−04	−32%	1.19E−04	7.81E−05	−34%	6.68E−03	1.11E−02	+66%

Table 7 Newly formulated weighting values compared with default values

Weighting	Egalitarian			Hierarchist			Individualist		
	Europe 99	Malaysian	±%	Europe 99	Malaysian	±%	Europe 99	Malaysian	±%
Damage categories									
Human health	300	250	−17%	300	400	+33%	550	550	0%
Ecosystem quality	500	500	0%	400	300	−25%	250	250	0%
Resources	200	250	+25%	300	300	0%	200	200	0%

3. Whilst the rest will be categorized into the Hierarchist perspective.

The final results obtained are summarized as below, by taking the median value of all weighting factors for each perspective (Table 5).

5 Discussions

The normalization value in the LCA software SimaPro 7 should be entered as 1/N for all culture perspective. While the weighting data in the LCA software SimaPro are entered as the percentage of the weighting factor multiplied by 1,000 for all culture perspective to represent the weightage in the perception of a thousand people as mentioned in the Simapro Manual (Goedkoop and Oele 2006). From the tables below, the newly formulated Malaysian normalization and weighting values compared with default values for all perspectives are shown:

As shown in Tables 6 and 7, the newly formulated Malaysian normalization values for Human Health are higher compared to defaults European normalization values. This increase in the values is due to the fact that the new factor values were normalized against the much lower amount of pollutant in Malaysia at year 2007 compare to pollutant for European countries in 1999.

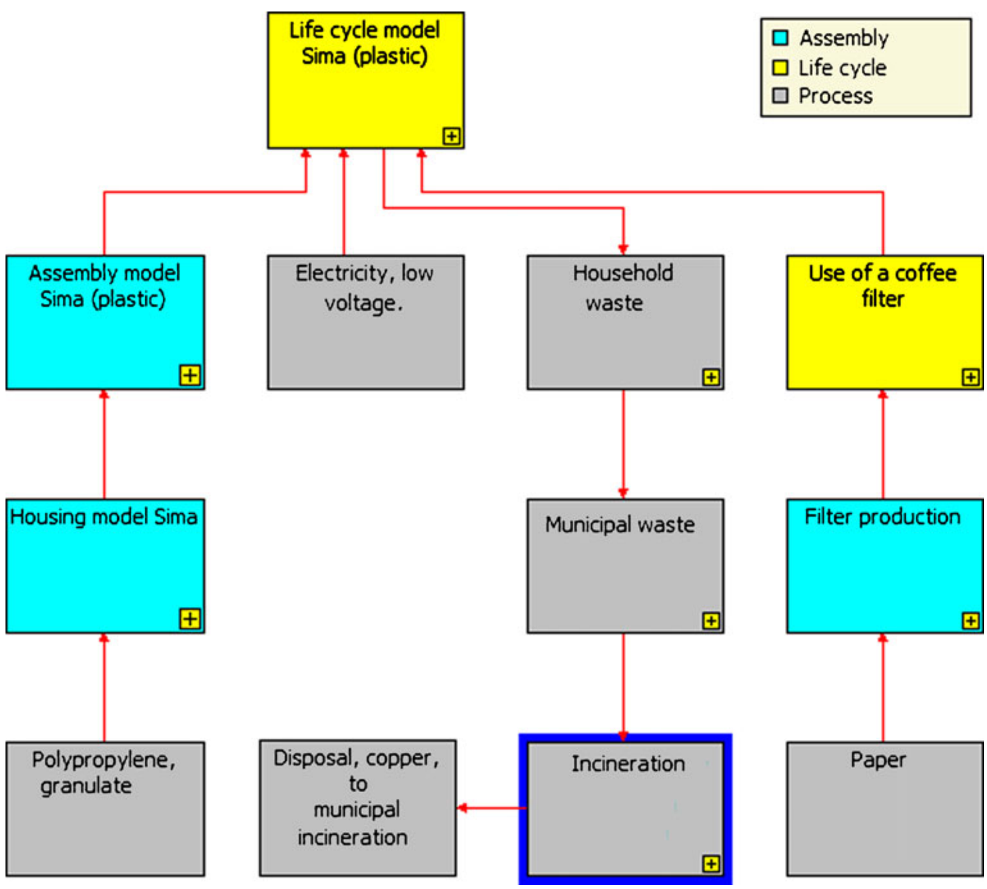

Fig. 3 The inventory flow chart for life cycle of coffee machine (model sima)

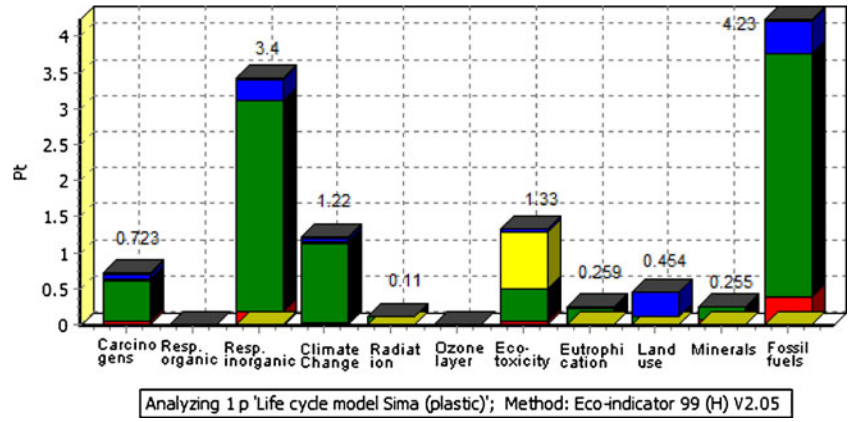

Fig. 4 Impact assessment results for coffee machine using default European value for Hierarchist perspective

Subsequently the normalization values for Ecosystem Quality are higher compared to the default values. The reason may well because of Malaysia environments still have much room for land development and conversion compared with European country.

The formulated Malaysian normalization values for Resources in Egalitarian and Hierarchist perspective are lower compared to the default European values. The main reason for that is because the fossil fuels usages and demand in Malaysia at year 2007 have tremendously increased compared to European countries usage in 1999. However, Individualist perspective which does not consider fossil fuels consumption as a concern to the environment have much larger normalization values compared with the default European value.

The average Malaysians have more concern on the effects and damages that may inflict upon human being itself. As a result, the weighting values for most damage category of Human health formulated are larger compared with the default European value.

At the same time, the weighting values for damage to Resources in average increased slightly in percentage while weighting values the Ecosystem quality values have decreased. Malaysians are more concern on the needs of the resources especially fossil fuel for their daily activities such as transportation compared to the trees and animals which are probably less significant to them.

5.1 Comparative analysis on the newly formed values and the default values

A simple impact analysis on life cycle of the usage of plastic coffee machine provided in the database of Simapro 7 has been selected. Figure 3 shows the inventory flow chart of the processes.

By using the provided inventory database, a comparative impact assessment analysis was conducted by applying the newly formulated Malaysian values and the default European values for Hierarchist perspective. Figures 4 and 5 show the results of the life cycle assessment using both values.

From Fig. 4, a total score of 12 shows that the usage of coffee machine comparable to around 1.2% of the environmental impacts produced by one person in 1 year within European countries. While in Fig. 5, a score of 23.7 with the usage of a coffee machine comparable to 2.37% of the

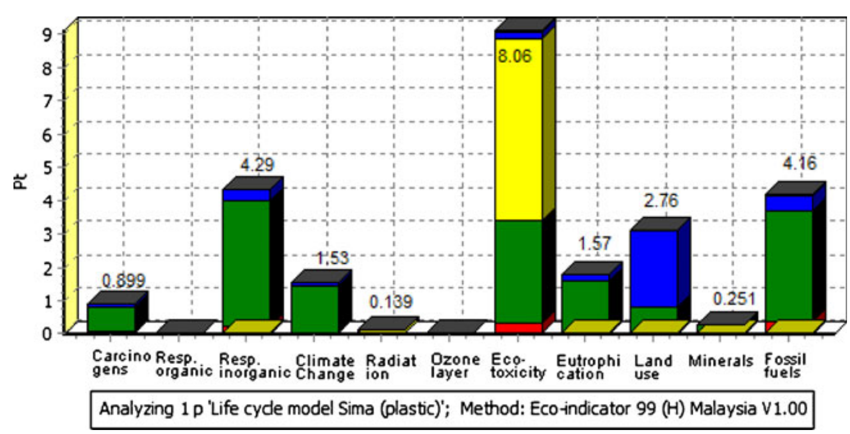

Fig. 5 Impact assessment results for coffee machine using Malaysian value for Hierarchist perspective

environmental impacts produced by one person in 1 year within Malaysia. To summarize, it shown that purchase and use a coffee machine with the life time of a year in Malaysia will noticeably create much more impact per pollution level to our environment compared with Europe.

6 Conclusions

Life cycle assessment has become a valuable decision support tool for industry. LCA helps to keep industry ahead of other competitors with better compliance on regulatory requirements of emissions, effluent discharges, solid waste and hazardous waste. In addition, life cycle strategies also have economic benefits for the industry in term of more efficient production, improved product quality, and minimization of the environmental risks.

One of the subjects under the Ninth Malaysia Plan from Malaysian government is the National LCA project which has been administered to promote the use of LCA and to develop the National Life Cycle Inventory Database. This project is the foundation support for the National Ecolabelling Programme which aims to fulfil the foreign legislation requirements that demand evidence on the control measures taken to reduce environmental impact of products or services throughout their life cycle. However, formulation of the inventory database alone will not be sufficient to provide a comprehensive life cycle assessment study in assessing Malaysian scenario. This is because the component of LCIA also plays an important role in Life Cycle Analysis methodology in accurately identifying products impacts. This study is a milestone project towards the formulation of LCIA for Malaysia. This initial study would play an essential role in providing the national database an optional impact assessment indicator. By adopting these values, the LCA study conducted will be more accurate and meaningful in evaluating Malaysian environmental impact.

Yet, there are still many opportunities for improvement in future for this study. As a recommendation, this study can be further expanded by using different type of software and different type of method in formulating the normalization and weighting values. Besides that, a better collection and more recent data should be use for estimation of the normalization values. While in the weighting values estimation, a bigger size and different social background of panel should be used in the questionnaire survey approach to indicate different perception of average Malaysian citizen on environmental concerns.

Presently, LCA practice and development in the country are limited. Most industries are not really indulging or practicing LCA, although most of them did adopt the Environmental Management System to achieve ISO 14001 certified status. LCA could play an important role in environmental managements system, as the intention of EMS itself is to continuously improve the environmental performance. In the EMS, LCA could help in the quantification of environmental aspects, environmental effects and as a tool to improve the environmental performance.

Finally, it is hoped that the result of this study would contribute towards the enhancement of LCA studies and results conducted in Malaysia and would ultimately result in more optimum environmental management in the country.

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