World Applied Sciences Journal 11 (10): 1230-1237, 2010
ISSN 1818-4952

Life Cycle Impact Assessment (LCIA) in Potable Water Production in Malaysia: Potential Impact Analysis Contributed from Production and Contruction Phase Using Eco-indicator 99 Evaluation Method

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Abstract: The demand for clean drinking water in Malaysia is increasing every year. This due to the increasing population growth. Hence, in order to overcome this problem the government took drastic steps to increase further the water supply system in this country such as project Pahang-Selangor ISRWT, build dams and new water treatment plants. The building of drinking water supply project greatly affected the environment. Anyway, do we know that the effect on environment not just in the developed area only but it evolves in a wider scope. Life cycle assessment (LCA) is able to see the impact on the environment because the analysis evolves the durability of the product for example the building of these projects need building material such as cement, steel and concrete. For the production of drinking water, chemical compounds such as Alum, PAC, chlorine and lime is used. All these materials are analysed from the beginning of extraction until it is used or known to be as cradle to grave analysis. The comparison between production stage and construction stage shows clearly that the production stage causes a higher impact. PAC is coagulant which is used in the process of producing drinking water. However it causes damage to ecosystem quality and to the health of the human beings. Similarly cement and steel which are building material contribute to the destruction to environmental quality and damage to human health as well. However PAC which contributes to the main destruction can be replaced with alum.

Key words: LCA · LCIA · PAC · Potable water production · Water treatment plant

INTRODUCTION

Problems of Water Shortage and the Need for the Development of Water Facility: Water crisis is a threat which has engulfed the nation. As such, debates and discussions are held one after another to find solution to eradicate this threat and to fight against the impact which may jeopardize the peace of the country and its people. The Malaysian government is actively exploring this critical issue and the positive steps towards it can be found in the 9th Malaysian Plan (9MP)[1]. In the 9th Malaysian Plan, priority is given to the development of water supply between states and low land valleys to overcome the shortage of water and a fair distribution of water in the country. One of the project which became problemic especially among the environmental activist group is the Inter-state Raw water transfer from Pahang to Selangor (Pahang-Selangor ISRWT). The building of this project is schdule to be implemented in the 9MP (2006-2010). At the same time the plan for building more dams in the country became a hot topic for debate as a step to overcome the shortage of water.

Water Problems Is Increasingly Critical: The present state of the water supply is at critical stage. This has been acknowledged by the Selangor state government. The water consumption in Selangor in very high compared to other states as found in the Malaysian Water Industrial Guide 2005. In the year 2003, the domestic water consumption in Selangor recorded 478,995,217 cubic

[1] Ninth Malaysian Plan (Malay: *Rancangan Malaysia ke-9*) abbreviated as '9MP', is a comprehensive blueprint prepared by the Economic Planning Unit (EPU) of the Prime Minister's Department and the Finance Ministry of Malaysia with approval by the Cabinet of Malaysia to allocate the national budget from the yaer 2006 to 2010 to all economic sector n malaysia (wikioedia)

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meter and non-domestic consumption recorded 245,490,214 cubic meter. Therefore, the total consumption of water, both domestic and non-domestic in Malaysia for the year 2003 was 1,609,574,693 cubic meter and 843,388,420 cubic meter respectively. Based on the Environmental Impact Assessment (EIA) Report entitled "Suggested Programme for Fresh water supply from Pahang to Selangor", the Selangor river scheme phase III is expected to increase the capacity of the water supply to 4,350 million litres a day. However, the total output is just sufficient to meet the demands until the end of 2007.

This same report also shows that there would be an increase in population in both Selangor and Wilayah Persekutuan, Kuala Lumpur. The rate of population growth in both areas would be at 4% with projection for 2010 is 8,080,823 people. One step further to meet the demand for water for the country in future is the suggestion to build 47 new dams, besides the three water projects between states including Pahang-Selangor ISRWT project. The cost of building these dams, the water projects between states and other water resource projects is estimated about RM52 billion. From the 47 dams that have been suggested, Johor and Pahang will receive the most allocation or grant of 12 billion and followed by Perak, 7 billion.

The Effects on Environment and Compulsory Measures Taken: These gigantic project whis said to cost more than RM1 billion would only spark uneasiness but also worries as well among nature lovers and environmental activist. Not only the private land which includes rubber and palm oil estate is taken and paid compensation but a considerable area from the Lakun Forest Reserve which serve as a good breeding of monkey 'dusky-leaf', rhinocerous and black hornbills is taken as well for the project. The EIA reports that there is an impact to the biodiversity from this project especially to several plant species which has medicinal values for human being and wild life. The transfer between the river valleys too causes negative effect because the river can only afford to supply water based on its threshold only.

Verily the effect on the environment due to the search for water resource is not confined in the developed areas but it has caused a universal effect. An enironmental impact which has occured due to the production of building materials such as cement, steel and other building materials to develop the water supply system can only be shown if the process of the production of the building material are analysed from the time of extraction until it is ready for use as 'crade-to-grave'. The high demand for water is increasing tremendously due to the high population growth. However, steps must be taken to reduce this impact o the environment. The LCA is an instrument which manages the environment and able to identify the weakness of certain products. Thus a more friendly environment is possible if the weakness is identified at an early stages.

Methodology of LCA: This study is using the procedure suggested by the International Organization of Standardization (ISO) under environmental management namely ISO 14040 series. There are four main phases in the suggested ISO 14040 series:

- Goal and scope definition (ISO 14040)
- Life cycle inventory (LCI) (ISO 14041)
- Life cycle impact assessment (LCIA) (ISO 14042)
- Life cycle assessment and interpretation (LCAI) (ISO 14043)

Goal and Scope Definition

Objectives: The goal of this study is to see the extent of environmental impact from building materials, chemical substances and electricity. Apart from that, this study also tries to identify the weaknesses that exists in the drinking water treatment process life cycle as we follows all the chemical substances, building materials and energy flows of the potable water production system from the natural environment back to the natural environment over the product's whole life.

Functional Unit: The functional unit is the performance of a product system for use as a reference unit in a life cycle assessment study [1]. Functional unit for this study is the production of $1m^3$ of treated water that fits the standard quality set by Ministry of Health, Malaysia.

Description of the System under Study: Terdapat dua fasa yang menjadi asas perbandingan kajian ini iaitu:

- Production stage
- Construction stage

Production Stage: Raw water extracted from rivers will go through the following process in the water treatment plant [21]

- **Screening,** to remove floating big sized rubbish on the surface of the water.

- **Coagulation and flocculation,** coagulation process is a process of forming particles called floc. Coagulant need to be added to form floc. The coagulants that are normally use includes Aluminium Sulphate, Ferric Sulphate and Ferric Chloride. Tiny flocs will in turn attract each other while at the same time pulling the dissolved organic material and particulate to combine, forming a big flocculant particle. This process is called flocculation.
- **Settling,** Aggregated flocs settle on the base of the settler. The accumulation of floc settlement is called settling sludge.
- **Filtration,** part of the suspended matter that did not settle goes through filtration. Water passing through filtration consisting of sand layers and activated carbon or anthracite coal.
- **Disinfection** process is needed to eliminate the pathogen organisms that remain after filtration. Among the chemicals used for the disinfection are chlorine, chloramines, chlorine dioxide, ozone and UV radiation.

Construction Stage: Main building materials used for water treatment plant building are and steel. Concrete is a type of composite material which is usually used in construction. It is a combination of the following:

- Cement
- Fine aggregate / sand
- Coarse aggregate
- Water

The quality of the concrete which is produced depends on the quality of the raw materials that is being used such as cement, coarse aggregate and water, rate of mixing, the method of mixing, transportation and compression methods. If the raw materials used are not of quality, the concrete produced will have low quality and causes the concrete to be weak and doesn't fulfill the fixed specifications. So, concrete technology warrants that all the materials that will be used should be tested first and certified through fixed standardizations. before being used in construction works.

Steel increases the tensile strength of the concrete structure. Reinforcement steel functions to increase the tensility strength of the concrete structure. Types of reinforcement steel that are used are as follows:-

- Mild steel reinforcement /*mild steel*
- Reinforcement steel with high tensility
- Fabric steel (*fabric*)

The steel that are provided are 12m long, with diameter of 6mm, 8mm, 10mm, 12mm, 16mm, 20mm, 22mm, 25mm dan 32mm. The reinforcement steel will be cut and moulded according to the concrete structure design. Reinforcement steel with high tensility is used as the backbone concrete structure because it has high strength. Mild steel reinforcement are usually in fixation for reinforcement steel with high tensility where high tensility is not needed. High tension where high force not needed. Fabric steel (*fabric*) is used in a wide concrete surface area such as floor, it comes in sizes of 2.4m x 1.8m with steel diameter 4mm to 12mm and distance between each steel rods are different based on types of fabric. Reinforcement steed that is used should be free from any dirt and rust, so it has to be protected from water and humidity.

Life Cycle Inventory (LCI): The inventory of the studied LCA system includes information on the input and output (environmental exchanges) for all the process within the boundaries of the product system. The inventory is a long list of material and energy requirements, products and co-products as well as wastes. This list is referred to as the material and energy balance, the inventory table, or the eco-balance of the product [3]. This LCA study is a streamlined LCA where background data for electricity, chemicals and transport using database contained in the Jemaipro and Simapro 7 software. Foreground data collected from the treatment plant are: (Table 3)

- Electricity usage and
- Chemicals for water treatment such as Aluminium sulphate (alum), Polyaluminium chloride (PAC), Chlorine and Calcium hydroxide (lime)
- Building material such as steel, gravel, sand and cement

Filtration material (activated carbon and anthracite) and coagulant (ferrochloride) are not included in this study because all the water treatment plants in Malaysia are not using all these materials.

Background data for all building materials and chemicals obtained from Japan Environmental Management Association for Industry (JEMAI) - PAC, BUWAL 250 - chlorine, alum and Electricity, ETH-ESU 98 - lime, LCA Food DK - tap water and IDEMAT 2001 - cement, steel, sand and gravel.

Table 1: Damage Assessment and Impact According to Eco-Indicator 99 [4]

Damage Assessment	Unit	Impact
Human Health	DALY	Carcinogen, radiation, respiratory organic and inorganic, climate change and ozone layer
Ecosystem Quality	PDF*m^2yr	Land use and acidification/euthrophication,
	PAF*m^2yr	Ecotoxicity
Resources	MJ surplus	Minerals and fossil fuels

DALY	Disability Adjusted Life Years (Years of disabled living or years of life lost due to the impacts)
PAF	Potentially Affected Fraction (Animals affected by the impacts)
PDF	Potentially Disappeared Fraction (Plant species disappeared as result of the impacts)
SE	Surplus Energy (MJ) (Extra energy that future generations must use to excavate scarce resources)

Table 3: Foreground data for construction stage and production stage.

Construction Stage		Production Stage	
Steel (kg)	8.78	Alum (kg)	22.55
Cement (kg)	30.72	Chlorine (kg)	3.65
Gravel (kg)	70.72	PAC (kg)	16.85
Sand (kg)	47.15	Lime (kg)	11.12
Electric (kwh)	0.09	Electricity (kwh)	397.28
Tap water (liter)	477.26		

Life Cycle Impact Assessment (LCIA): The purpose of the life cycle impact assessment is to convert the LCI into its potential impacts on the areas of protection (i.e. the entities that the use of the LCA shall help protect): Human Health, Ecosystem Quality and Natural Resources [4]. The impacts on these areas of protection are quantified by Eco-indicator 99 using the units as shown in table 1.

Generally There Are 3 Steps in LCIA:

- Classification and Characterization
- Normalization and
- Weighting

Dalam LCIA, fasa classification and characterization adalah compulsory manakala normalization and weighting pula adalah optional. Dalam artikel ini hanya characterization akan dibincangkan. Proses bagi classification and characterization menggunakan Eco-indicator 99 evaluation method dibantu oleh perisian Simapro.

Characterization to Damage Category and Characterization to Impact Category: Classification is the step in which the data from the inventory analysis (the substance emissions) are grouped together into a number of impact categories [5]. Grouping to impact categories is according to their ability to contribute to different environmental problems. While characterization are the effect of each item on each impact category is quantified. A typical way is to use equivalency factors, in some instances also called potentials. For example, global warming potential for a substance indicates its relative potential to increase the global warming effect compared to CO_2, whose GWP is set to one. In ISO 14040 series classification and characterization are two basic mandatory elements.

Figure 1 shows the comparison between construction stage and production stage among three types of damage categories. On the whole production stage contributes the highest of all three categories. Human health damage category, production stage contributes higher than construction stage. Production stage contribute nearly 99% (0.0022 DALY) compared to construction stage 1% (0.00015%). For damage to ecosystem quality also contribute he highest by production stage (98%) whereas the construction stage only contribute 2%. Furthermore damage to resources, production stage contributes higher around 84% compared to construction stage 16%.

Figure 2 shows 11 types of impact to compare between construction stage and production stage. On the whole, out of impacts categories under damage to human health contributed higher by production stage. Only one impact category, respiratory organic contributed higher by construction stage around 60%. Carcinogens impact category contributed higher by production stage with the value is more than 50%. Construction stage contribute less than 30% for other categories under damage to human health (Climate change -27%, respiratory inorganic - 1%, radiation - 8% and ozone layer - 17%).

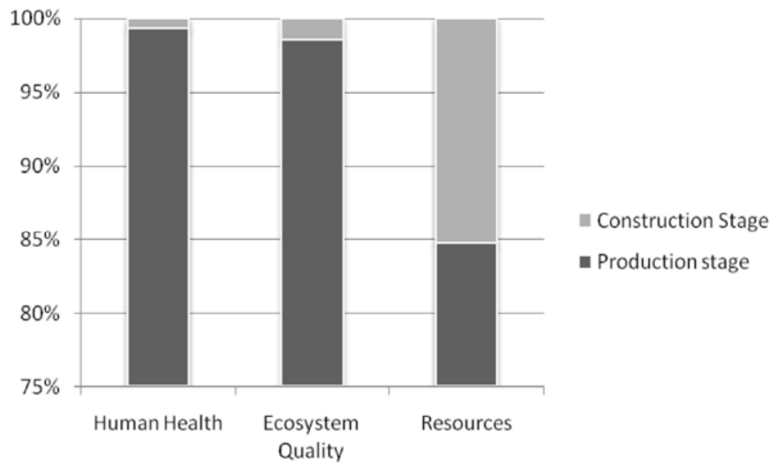

Fig. 1: Damage category comparing construction stage and production stage

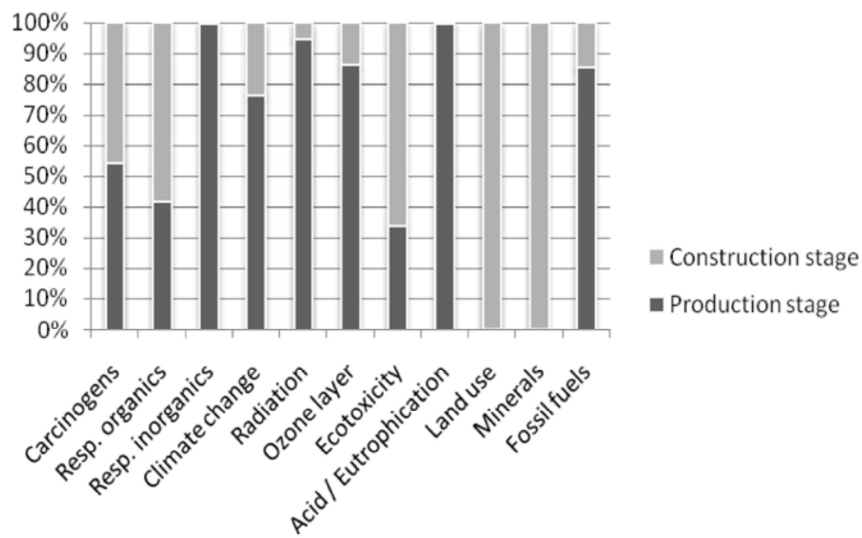

Fig. 2: Impact Category comparing construction stage and production stage

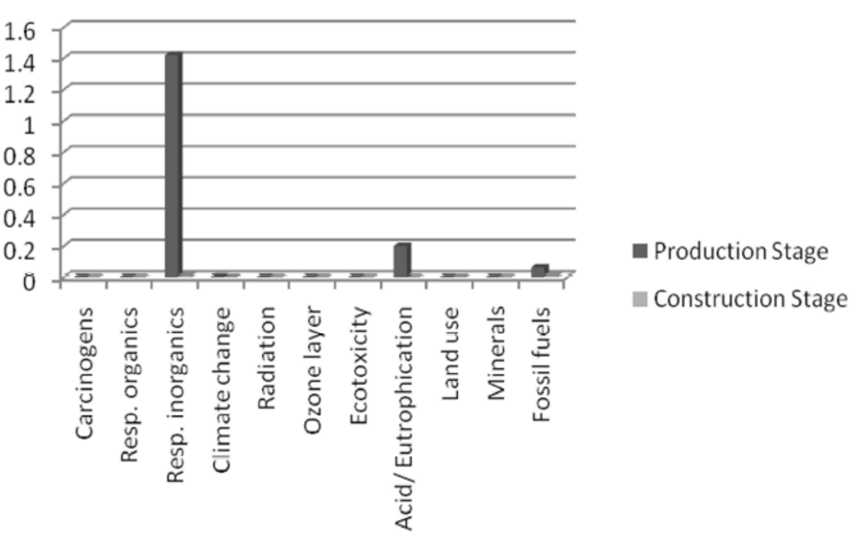

Fig. 3: Normalization to impact category antara production stage and construction stage

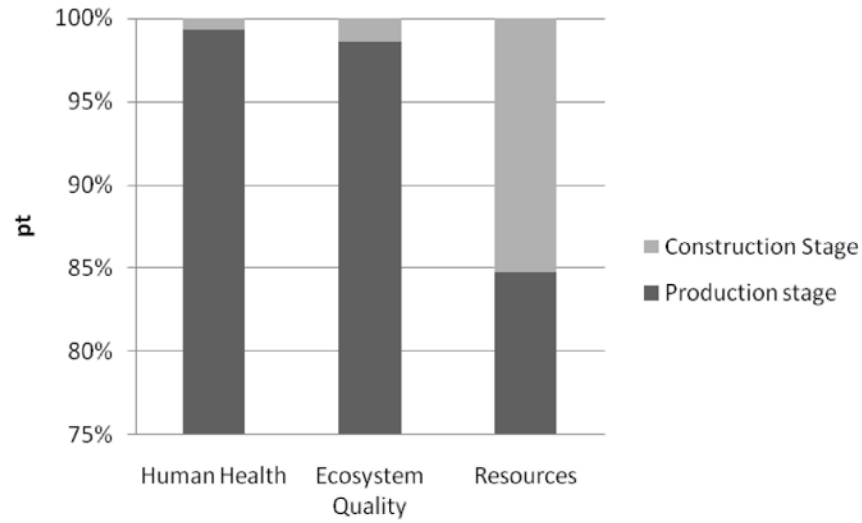

Fig. 4: Weighting to impact category antara production stage and construction stage

Damage to ecosystem quality production stage contributes higher at 1 from 3 impacts compared to construction stage that is impact to acidification/euthrophication (98%). Impact to land use contribute the highest by construction stage (98%). In ecotoxicity is contributed the highest by pula construction stage (70%) compared to production stage (30%).

Under damage to resource category, construction stage contribute the highest in impact to minerals (99%) meanwhile production stage contribute the highest in fossil fuels (98%).

Normalization and Weighting: When values are normalized, comparison between impacts can be done. Figure 3 shows impact to respiratory inorganics is the highest impact compared with other impact in damage to human health. Production stage (1.42) contribute higher compared with construction stage (0.08). In damage to ecosystem quality, impact to acidification/eutrophication is the highest impact contribute higher than other impacts. In impact to acidification/eutrophication in production stage (0.2) contribute higher compared to construction stage (0.0008). In damage to resources, impact to fossil fuels contributes higher compared to impact to minerals. Once again production stage contribute higher compared to construction stage. On the whole, production stage contribut the highest to all damage category, damage to human health, damage to ecosystem quality and damage to resources. Whereby damage to human health is put in the first place contribute the highest followed by damage to ecosystem quality and the lowest impact is damage to resources (Figure 4).

Life Cycle Assessment and Interpretation: Interpretation is the phase of the LCA where the results of the other phase are interpreted according to the goal of the study using sensitivity and uncertainty analysis. The outcome of the interpretation may be a conclusion serving as a recommendation to the decision makers, who will normally consider the environmental and resource impacts together with other decision criteria (like economic and socialaspects) [6].

Weaknesses Identified in the System under Study: Based on the comparison done between the production and construction phase, the production phase gives a higher impact to the 3 categories such as damage to human health, ecosystem quality and resources. Destruction on human health and ecosystem quality contribute 90% whereas destruction on resources contribute 85%. For the destruction of ecosystem quality and human health, the substance identified that causes the destruction is PAC. In the process of producing PAC, nitrogen oxides and sulphur dioxide are emitted. This causes an impact to the inorganic respiratory and acidification/euthrophication. The construction stage just give an impact of 10% toward three damage categories. The analysis shows that the damage is due to the production of cement, steel and the output of electricity generation.

Suggested Mitigation Measures: The problem identified in the production stage is the PAC production whereas in the construction stage is the production of cement and steel. Both the production and construction clearly shows the same problem that is the use of electricity which jeopardize the fossil fuel. The problem in the production stage such as the coagulant, PAC, which causes impact to respiratory inorganic and euthrophication/acidification possibly can be replaced with other coagulant such as alum. The replacement of Alum in the water treatment process can overcome both the impact to less than 10% [7-9].

There were two main problems identified in construction stage namely the electricity generation of cement and steel manufacturing that free those substances that are potentially damaging the environment. For the generation of electricity and cement problem maybe we could do something to overcome this problem such as the carbon sequester. By simply bubbling it through nearby seawater, a new California-based company called Calera says it can use more than 90 percent of that CO2 to make cement.

It a twist that could make a polluting substance into a way to reduce greenhouse gases [10]. Cement, which is mostly commonly composed of calcium silicates, requires heating limestone and other ingredients to 2,640 degrees F (1,450 degrees C) by burning fossil fuels [11-13]. Brent Constantz, founder of Calera claimed that for every tone of cement we make, we are sequestering half a tone of Carbon dioxide this technique probably have best carbon capture and storage technique there is by a long shot [10]. Apart from resolving the release of Carbon dioxide gas problem from the electricity generation, this alternative method is more natural and does not damage environment.

Now, the latest idea is to replace the reinforcement steel with fibre reinforced plastics (FRPs). These materials, which consist of glass, carbon or aramid fibres set in a suitable resin to form a rod or grid, are well accepted in the aerospace and automotive industries and should provide highly durable concrete reinforcement [14]. The durability is a function of both the resin and the fibre, while the amount and type of fibre are keys to determining the mechanical properties of FRPs. The strength of FRP reinforcement tends to be between that of high yield reinforcing steel and prestressing strand - about 1000 MNm^{-2} for glass fibres and 1500 MNm^{-2} for carbon fibres [14]. Nevertheless the reinforcement replacement steel to FRPs is needed to go through the LCA to make sure that this substance is safer compared to the reinforcement steel.

Future Outlook:

- Study only focusing on water treatment plant that does not involve the area of water intake and waterway area from water intake to water treatment plant. Study could be pursued by analyzing the construction stage of water intake and area used by pipe to channel water to the treatment plant.
- Because of the cut-off procedure, some material could not be studied. Materials such as Polyelectrolyte, Formazin and Sodium silico fluoride must be obtained of the background data in detail to complement the inventory for all used chemical material in water treatment process.

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