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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 is 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 inter-state raw water transfer (Pahang-Selangor ISRWT), building more dams and new water treatment plants. The construction of drinking water supply project greatly affected the environment. Nevertheless, questions raised on the effect of these developments only to the nearby affected area but also to a wider environment. Life cycle assessment (LCA) is able to predict the impact on the environment because the analysis involves the durability of the product for example the construction of these projects need construction materials such as cement, steel and concrete. For the production of drinking water, chemical compounds such as Alum, PAC, chlorine and lime are used. From the analysis the comparison between production stage and construction stage shows clearly that the production stage causes higher impact caused by PAC which is coagulant used in the process of producing drinking water. This coagulant causes damage to ecosystem quality and to the health of the human beings. Similarly, cement and steel which are construction material were also found to contribute to the destruction of environmental quality and damage to human health. 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 was mentioned in the 9th Malaysian Plan (9MP)[1]. In the 9th Malaysian Plan, priority was 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 projects which became problematic 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 schduled 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 is in a very high demand compared to other states as in Malaysian as mentioned by Water Industrial Guide 2005. In the year 2003, the domestic water consumption in Selangor recorded

[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 year 2006 to 2010 to all economic sectors in Malaysia (wikipedia)

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478,995,217 cubic meter and non-domestic consumption recorded 245,490,214 cubic meter. As for the total consumption of water in Malaysia in the same year, both domestic and non-domestic 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.

The 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 to reach MYR52 billion (USD 16 billion). From the 47 dams that have been suggested, Johor and Pahang will receive the most allocation or grant of MYR12 billion (USD 4 billion) and followed by Perak state of at, MYR7 billion (USD 2 billion).

The Effects on Environment and Compulsory Measures Taken: These gigantic project whis said to cost more than MYR1 billion would not only spark uneasiness but also worries among nature lovers and environmental activist. Not only the private land which includes rubber and palm oil estate will be taken over but a considerable area from the Lakun Forest Reserve which serve as a good breeding of 'dusky-leaf' monkey, rhinocerous and black hornbills is taken as well for the project. EIA reports outlined 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 limit.

Verily, the effect on the environment due to the search for water resource is not confined only 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 construction of the water supply system will be prominent if the process as involve in the production of the building material are analysed from the time of extraction until they are ready to use or known as 'crade-to-grave'. High demand for water is increasing tremendously due to the high population growth. However, steps must be taken to reduce the impact on the environment. LCA is a tool which able to facilitate the environment and able to identify the weaknesses of certain products. Thus a more friendly environment is possible if the weaknesses the identified at an early stage.

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 analyze the extent of environmental impact from construction materials, chemical substances used and electricity consumed. Apart from that, this study also tries to identify the weaknesses exist from drinking water treatment process life cycle caused by chemical substances, construction materials and energy flows of the potable water production system over the product's life cycle.

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: There are two stages underlying the comparison of this study, namely:

- Production stage
- Construction stage

Production Stage: Raw water extracted from rivers will go through the following processes in the water treatment plant [2]:

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 are 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 consist 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 construction materials used for water treatment plant construction are concrete 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 used are 12m long, with various diameters of 6mm, 8mm, 10mm, 12mm, 16mm, 20mm, 22mm, 25mm and 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 of its high strength. Mild steel reinforcement is 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 1)

- 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

Table 1: 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		

Table 2: 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)

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.

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 namely 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 2.

Generally There Are 3 Steps in LCIA:

- Classification and Characterization
- Normalization and
- Weighting

In LCIA, classification and characterization is compulsory while normalization and weighting on the other hand is optional. In this article only characterization will be discussed. Classification and characterization are using Eco indicator 99 evaluation method which the analysis is aided by Simapro software.

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 it is 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. In Human health damage category, production stage contributes higher than construction stage. Production stage contribute nearly 99% (0.0022 DALY) compared to construction stage which is only 1% (0.00015%). For damage to ecosystem quality, the highest by production stage (98%) whereas the construction stage only contribute 2%. As for damage to resources, production stage contributes higher around 84% compared to construction stage at only 16%.

Figure 2 shows 11 types of impact in comparison between construction stage and production stage. Under damage to human health contributed higher production stage on all impact categories compared to construction stage except for respiratory organic where construction stage contributed higher by around 60%.

As for Damage to ecosystem quality production stage contributes higher compared to construction stage compared to construction stage that is impact to acidification/euthrophication (98%). Whereas land use and ecotoxicity are highly contributed by construction stage at 98% and 70% respectively.

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

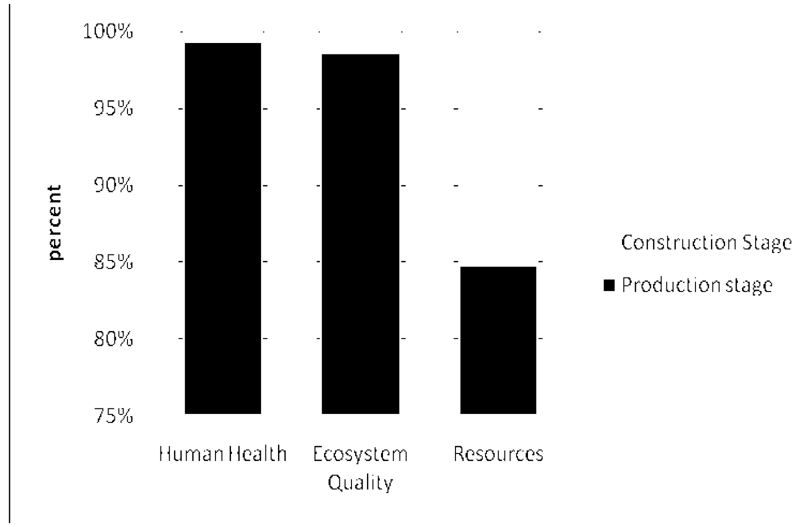

Fig. 1: Damage category comparing construction stage and production stage

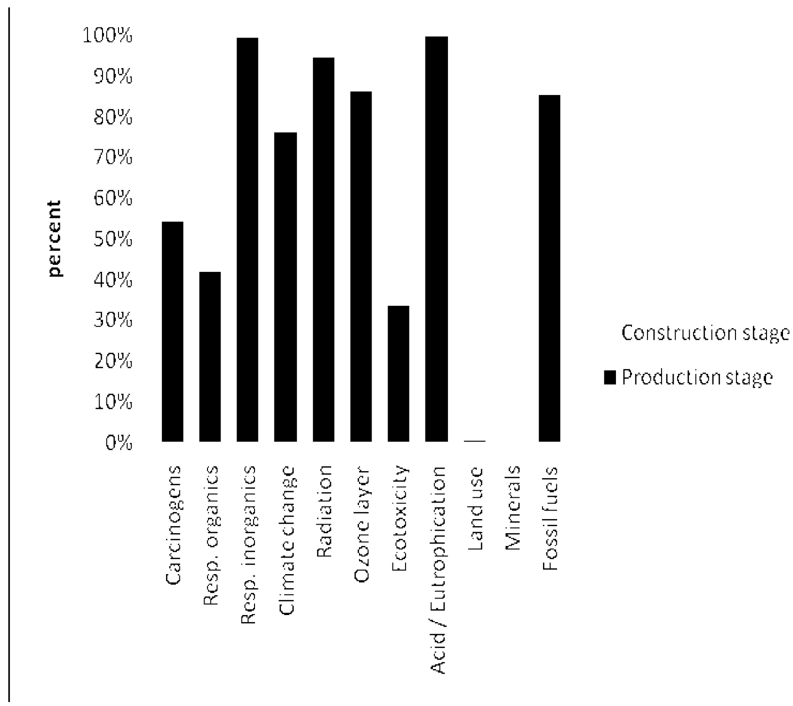

Fig. 2: Impact Category comparing construction stage and production stage

Normalization and Weighting: When values are normalized, comparison between impacts can be done. Figure 3 shows impact to respiratory inorganics is the highest compared to other impacts damage to human health category where production stage contribute higher at 1.42 compared to construction stage at 0.08. In damage to ecosystem quality, impact to acidification/ eutrophication is the highest impact contribute with 0.2 by production stage compared to 0.0008 by construction stage. 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 involving damage to human health, damage to ecosystem quality and damage to resources. Damage to human health is the most significant followed by damage to ecosystem quality and natural resources (Figure 4).

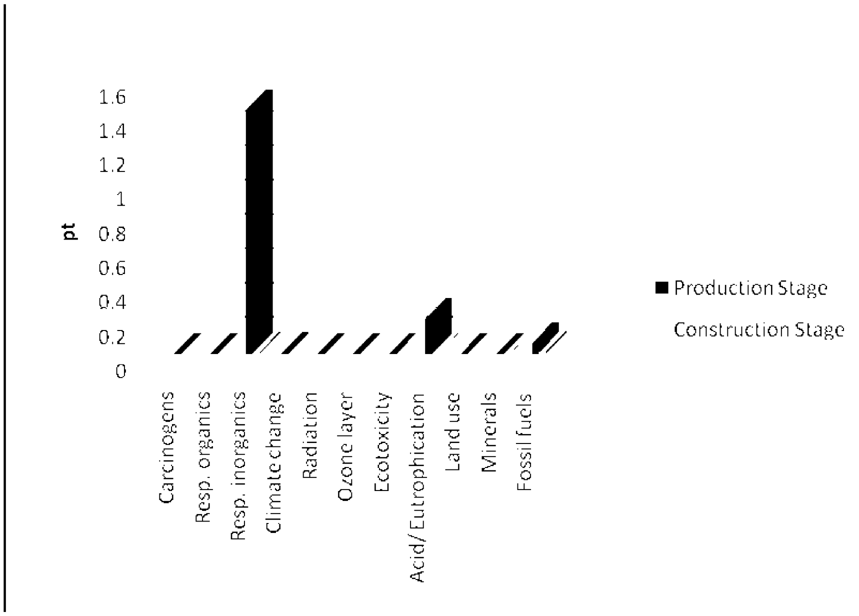

Fig. 3: Normalization to impact category antara production stage and construction stage

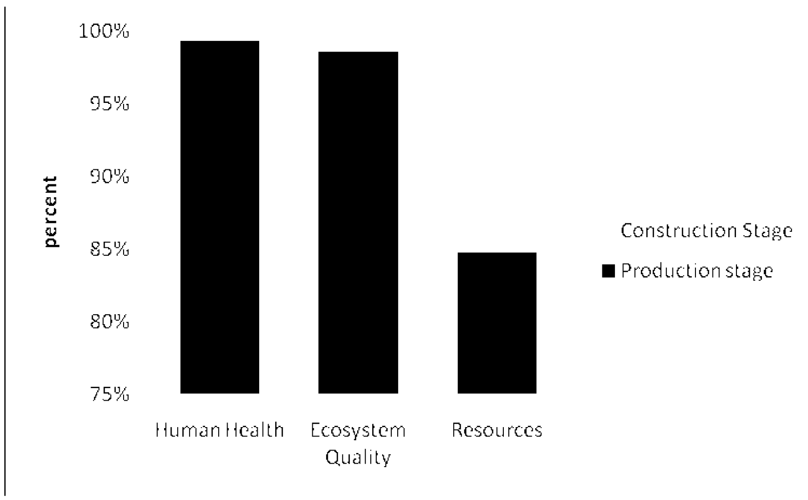

Fig. 4: Weighting to impact category antara production stage and construction stage

Life Cycle Assessment and Interpretation: Interpretation is the phase in 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 social aspects) [6].

Weaknesses Identified in the System under Study: Based on the comparison results 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 with an impact of 10% towards the three damage categories indicated that the damage is due to the production of cement, steel and the output of electricity generation.

Mitigation Measures: Problems 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 show 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 focusing on water treatment plant does not involves the area of water intake and waterway area from water intake to water treatment plant. Future study could be pursued by analyzing the construction stage of water intake and area used by pipe to channel water to the treatment plant.

Due to the cut-off procedure (less than 5%), 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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