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Life Cycle Assessment (LCA) in Potable Water Production: An Analysis of Green House Gases Emission from Chemicals and Electricity Usage in Water Treatment in Malaysia

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Abstract: It is undeniable that we cannot live without water. Safe and clean water supply is crucial to human life activities. It is estimated that 80 per cent of all diseases and more than a third of death in this world is caused by using contaminated water. Constant effort that started in the 1980s has brought water services and sanitation to hundreds of millions of the poor population of the world. Among the efforts are the launch of Sanitation Century and International Drinking Water supply in 1981 resulting in the Mar del Plata Action Plan used by the United Nations. But do we know that to produce clean drinking water, chemicals and electricity are needed? Life cycle assessment (LCA) has found that the chemicals and electricity generation in the drinking water production has the potential of releasing green house gases such as carbon dioxide, methane, carbon monoxide and dinitrogen monoxide. Thus raising the dilemma between basic necessity and the issue of saving the world from the impact of climate change. The use of LCA as a tool to achieve sustainable development could detect weaknesses in any system studied. Analysis has shown that the electricity generation using natural gas fuel emits the highest green house gases such as carbon dioxide (95.26%) and methane (4.47%) while PAC contributes the lowest. This situation should be solved by using electricity generated from alternative sources such as photovoltaic and hydroelectric that emits less green house gases.

Key words: Sustainable development, climate change, green house gases, Life Cycle Assessment (LCA), electricity generation.

Introduction

In Malaysia, there are no specific policy created to deal with the climate change issue that leads to global warming, but there are various policies that are indirectly linked with addressing the climate change issue. As an example, the Fifth Fuel Diversification Policy was meant to reduce the reliance on oil and coal and the National Forestry Policy where forest is managed sustainably to absorb carbon dioxide gas. To overcome the issue of climate change trend that lead to global warming, the Government has started the initial step by conducting green house gases inventory in 2000 to identify the main causes of green house emissions in this country. With the inventory, the Ministry is confident that effective strategies and programmes could be planned to deal with the climate change issue in this country. The Government through The Ministry of Natural Resources and Environment had made preparation and underlined the actions for dealing with climate change and its impact through two approaches:

(i) Mitigation approach: steps taken to reduce green house emission of carbon dioxide and methane; and
(ii) Adaptation approach: steps taken to reduce the climate change effects on human and environment.

Through mitigation approach, apart from the ministry, steps are also taken by other Government agencies since climate change issue is a cross-sector issue. Mitigation

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steps underlined in the Ninth Malaysian Plan (Economic Planning Unit, 2006) and relevant programmes are as follows:

(i) Increasing supply and usage of alternative fuel such as renewable energy (RE);
(ii) This renewable energy source would contribute 350 Megawatt from the total supply in 2010;
(iii) The RE project that uses solid waste is encouraged;
(iv) Encouraging efficient energy usage in industrial sector, buildings and transportation sector;
(v) Supplying 55,000 units of houses with electricity using technologies such as solar and hydromicro system hybrid;
(vi) Using Clean Development Mechanism (CDM) facility under the Kyoto Protocol to provide support to the execution of Renewable Energy Small Generators or Small Renewable Energy Programme (SREP); and
(vii) Protecting forest area through sustainable forest management to ensure that forest area remains the filters of green house gas namely carbon dioxide.

Adaptation steps conducted specifically to reduce the effects of climate change to human and environment, on the other hand covers the following subjects:

(i) Conducting Coastal Vulnerability Index (CVI) studies that would be the base in taking steps to deal with rising sea water effects to the coastal area;
(ii) Conducting programmes that reinforce coastal area including planting mangrove trees as an effort to deal with the rising sea water effects and waves;
(iii) Executing flood control programmes such as the Stormwater Management And Road Tunnel (SMART) project;
(iv) Conducting studies to identify the relationship between climate change effects with occurrence of vector-borne diseases; and
(v) Developing Integrated Coastal Zone Management.

Apart from these specific efforts, the Ministry also often conducts general awareness campaign either on their own or through collaboration with various non-governmental agencies to create public awareness including students on steps that could be taken to reduce green house emission. For an example, NRE had organized a regional conference on Climate Change on 29th and 30th October 2007 with the purpose of discussing the climate change issues which are closely linked with sustainable principles ignorance. Development without environmental impact is the kind of development that any country in this world would strive to achieve. But talking is easier than taking actions. To date developments are often given priority and the environment continues to be the victim.

Many researchers agree that development and environmental conservation should move in parallel. Thus, development without affecting the environment is very difficult to achieve. Development without environmental effects or better known as sustainable development is a development that fulfills the needs of the world's population without jeopardizing the future world population's ability to fulfill their needs. In other words, current development must not affect our environment in order that our descendants continue to enjoy this world.

Efforts to achieve sustainable development is well received by many countries. The developed countries lead this effort. This is due to the conditions in developed countries such as readily available laws, technologies, expertise and community acceptance supports sustainable development efforts. Developing and poor countries are rather slow in this matter. But it does not mean that efforts to achieve sustainable development is ignored. Malaysia is also among the developing country that has progressed quite far ahead in this subject. Even before the introduction of sustainable development, Malaysia already has efforts to preserve the environment in place through law, campaigns, forest management etc.

Due to the continuing efforts, Malaysia has achieved a good ranking in sustainable environment. If linked with *Environmental Sustainability Index* of 2002, of 142 countries studied, Malaysia ranked at 68. This ranking far exceeds Japan and United Kingdom which were ranked 78 and 91 respectively. In 2005, Malaysia had improved its ranking to 38 among 146 countries. Once again Malaysia far exceeds developed countries such as USA (45) and United Kingdom (65).

For general knowledge, this index is prepared as a result of collaboration between *World Economic Forum's Global Leaders for Tomorrow Environment Task Force, The Yale Center for Environmental Law and Policy and Columbia University Center for International Earth Science Information Network* (CIESIN). This index measures the overall sustainable development achievement of a country. Under this index, 20 main indicators were studied. Among the indicators are water quality, air pollution, nuclear reactor safety and green house emission. Malaysia's rank in this index is rather

surprising. Who would have thought a country as small as Malaysia could have surpassed the developed countries? Even among the ASEAN countries, Malaysia ranks the highest in this index. Even though this index is an indicator in ensuring sustainable development implementation in every aspect of development, Malaysia must stay ahead in environmental management. Among the efforts is the use of LCA method in products or services assessment. What is LCA and how can this method help to effectively manage the environment?

Methodology of LCA

There are four main phases in LCA as suggested in ISO 14040 series: Goal and scope definition (ISO 14040); Life cycle inventory (LCI) (ISO 14041); Life cycle impact assessment (LCIA) (ISO 14042); and Life cycle assessment and interpretation (LCAI) (ISO 14043).

Goal and Scope Definition

In goal definition and scoping, the use of the results is identified, the scope of the study is stated, the functional unit is defined, and a strategy and procedures for data collection and data quality assurance are established.

Objectives: The purpose of this study is to depict the rate of green house gases emitted from the chemicals and electricity usage during drinking water treatment process. To achieve this, several specific objectives were underlined as follows:

- To collect inventory for input (foreground data) needed for the production of treated water in a day that fit the set standard
- To identify substances that have inclination to emit green house gases
- To suggest corrective measures to overcome green house emission for the identified substances that inclined to emit green house gases

Functional unit: Functional unit is quantified performance of a product system for use as a reference unit in a life cycle assessment study (ISO14000, 2000). A constant value must be created to make the comparison (Miettinen and Hamalainen, 1997). Functional unit for this study is the production of 1000 cm^3 of treated water a day that fits the standard quality set by Ministry of Health, Malaysia.

Description of the system under study: To define the system boundaries for a product, it is essential to understand how a product is manufactured. In producing treated water, raw water goes through several phases before drinking water, that fits the set standard, is produced. Raw water extracted from rivers will go through the following process in the water treatment plant:

- *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. Coagulants need to be added to form floc. The coagulants that are normally used include 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.
- **Sedimentation**. Floc produced will settle on the base of the sedimentation basin. The accumulation of floc settlement is called sludge.
- **Filtration**. Part of the floc which does not settle in the sedimentation basin will go through filtration. Water passes through filtration consisting of sand layers and activated carbon or anthracite coal.
- **Disinfection** process is needed to eliminate pathogen passing through the filters. Among the chemicals used for the disinfection are chlorine, chloramines, chlorine dioxide, ozone, and UV radiation.

Life Cycle Inventory (LCI)

After scoping the product system, the inventory of the system is gathered. It includes information on the input and output (environmental exchanges) for all the processes within the boundaries of the product system (see Figure 1). The result of an 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 (Guinée, 2002). 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:

- Electricity usage, and
- Chemicals such as aluminium sulphate (alum), polyaluminium chloride (PAC), chlorine, and calcium hydroxide (lime)

Foreground data mentioned above was compiled from selected treatment plant while background data is gathered from Simapro and Jemaipro database. The data inventory is shown in Table 1.

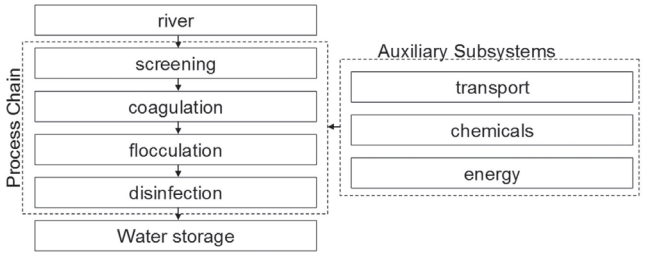

Figure 1: System boundaries and process under study.

Life Cycle Impact Assessment (LCIA)

The purpose of the life cycle impact assessment is to interpret the inventory results into their potential impacts on the areas of protection of the LCA (Michael Hauschild, 2007) i.e. in Eco-indicator 99 (see Table 2), the entities that the use of the LCA shall help protect. Areas of protection for LCIA:

- Human health
- Ecosystem quality
- Natural resources

However, in this study green house gases are categorized in climate change impact of damage to human health category.

Generally there are two steps in LCIA: Classification and characterization; and Normalization and weighing.

Classification and Characterization

Classification is the step in which the data from the inventory analysis (the substance emissions) are grouped together into a number of impact categories (Bovea and Gallardo, 2006). 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. Below is the result of the analysis done in this study (see Table 3).

Analysis has shown that the main substances which contribute to climate change are carbon dioxide (95.26%) and methane (4.47%). While dinitrogen monoxide and carbon monoxide contribute less than 1% that is at 0.23% and 0.05% respectively. Remaining air-borne emission (such as ethane 1,2-dichloro-1,1,2,2-tetrafluoro-CFC-

Table 1: Inventory of green house gases emitted from the process of chemicals production and electricity generation (cut-off 0.01%)

Substance	*Unit*	*Chlorine*	*Alum*	*PAC*	*Lime*	*Electricity*	*Total*
Methane	g	x	x	53.92	x	x	53.92
Butane	mg	x	x	8.13E-05	31.90771	x	31.9078
Carbon dioxide	kg	4.38	5.9034	0.365143	11.38429	304.7138	326.7466
Dinitrogen monoxide	g	0.02263	0.067974	0.00094	0.050359	2.216822	2.358725
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	µg	x	x	1.76E-05	62.64777	x	62.64778
Ethane, hexafluoro-, HFC-116	µg	x	x	8.03E-06	5.236898	x	5.236906
Carbon monoxide	g	2.92	1.395936	0.045007	3.499442	106.0738	113.9341
Propane	mg	x	x	8.08E-05	67.95062	x	67.9507
Chloroform	µg	x	x	4.94E-07	1.000729	x	1.000729

Table 2: Characterization of substances released by chemicals and electricity usage during drinking water treatment process (cut-off 0.01%) dalam unit DALY

Substance	*Chlorine*	*Alum*	*PAC*	*Lime*	*Electricity*	*Total*
Carbon dioxide	9.2E-07	1.24E-06	7.67E-08	2.39E-06	6.4E-05	6.86E-05
Carbon monoxide	9.4E-10	4.49E-10	1.45E-11	1.13E-09	3.42E-08	3.67E-08
Dinitrogen monoxide	1.56E-09	4.69E-09	6.49E-11	3.47E-09	1.53E-07	1.63E-07
Methane	3.69E-08	5.65E-08	1.3E-09	4.74E-08	3.08E-06	3.22E-06
Remaining airborne emission	-4.1E-10	-1.1E-09	-1.8E-13	-8E-11	-4.2E-10	-2E-09
Total of all compartments	9.59E-07	1.3E-06	7.81E-08	2.44E-06	6.73E-05	7.2E-05

Table 3: Comparison table of green house gases emission from five types of electricity generation

Substance	*Unit*	*Electricity from natural gas*	*Electricity from uranium*	*Electricity from hydropower*	*Electricity from lignite*	*Electricity from photovoltaic*
Carbon dioxide	DALY	6.4E-05	4.76E-07	x	0.000113	1E-05
Methane	DALY	3.08E-06	2.41E-08	x	4.58E-07	4.5E-07
Dinitrogen monoxide	DALY	1.53E-07	4.17E-09	x	1.88E-07	1.47E-07
Carbon monoxide	DALY	3.42E-08	7.23E-10	x	1.7E-08	1.37E-08
Remaining substances	DALY	-4.2E-10	-3.4E-10	-	-1.1E-09	4.76E-07

114, ethane hexafluoro-HFC-116, butane, propane and chloroform) contributes insignificant amount. Among the activities that contribute the highest to green house gas emission is the electricity generation process using natural gas. Carbon dioxide (95.26%) and methane (4.57%) are two types of major green house gases contributed from electricity generation process using natural gas. This situation is shown in Figure 2. Chemicals such as lime, alum, chlorine and PAC hardly contribute to carbon dioxide gas. If seen from the perspective of climate change, PAC contributes the least of carbon dioxide and methane. PAC might be seen as environmental friendly but an earlier study has shown that PAC could damage human health and environmental quality due to its production process that releases nitrogen oxides and sulphur oxides (Amir Hamzah, Noor Zalina and Abdul Halim, 2008a, 2008b, 2008c, 2008d, 2008e).

Normalization and Weighing

Normalization expresses the magnitude of the impact scores on a scale which is common to all the categories of impact. Impact scores and resource consumptions from characterization are related to a common reference in order to facilitate comparisons across impact categories (Huijbregts et al., 2003). The impact scores are usually expressed in person equivalents, PE. The PE represents the annual impact from an average person and is useful for bringing the rather diverse environmental impacts on a common scale. Meanwhile weighing is the last step in LCIA where a ranking is performed on different environmental impact categories and resources consumptions reflecting the relative importance they are assigned in the study (Pennington et al., 2004; Soares, Toffoletto and Deschenes, 2006). Weighing is also known as valuation. The aim of this step is to arrive at a further interpretation and aggregation of the data of the impact assessment. The importance of the impact categories in relation to each other is a value-bound procedure based on an assessment of the relative environmental harm. This assessment will therefore reflect social values and preferences (Consoli et al., 1993). Normalization and

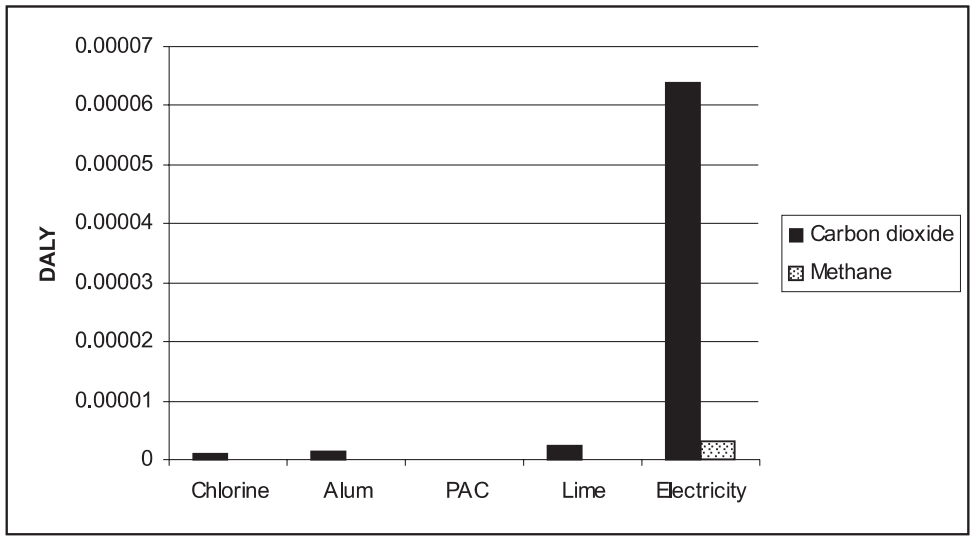

Figure 2: Carbon dioxide and methane gases contribution from electricity generation process and chemicals production process used in production of drinking water.

weighing are an optional element in ISO 14040 series. This study only discusses the weighing analysis. This is done by comparing weighing of green house gases which has the potential to affect climate change. The weighing analysis graph is referred to in Figure 3.

Weighing analysis places carbon dioxide at first ranking with 95.26% while methane in second with 4.57%. Dinitrogen monoxide value is only at 0.23% placing it at third ranking and other green house gases components at around 0.05%.

Life Cycle Assessment Interpretation (LCAI)

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 (such as economic and social aspects) (M. Hauschild, Jeswiet and Alting, 2005).

Improvement Assessment

Analysis has shown that electricity generation process had a huge impact to climate change. This situation occurs as the process involves the use of natural gas as the main fuel which releases green house gases such as carbon dioxide and methane. Apart from this, complete reliance on natural gas also depletes fossil fuel. In this study a comparison was also made to compare the rate of green house emission from five sources of electricity generation. The result of the characterization analysis is shown in Table 3.

From the analysis table, it is found that three types of electricity generation process contributed minimally to climate change. Major green house gases emission is found to be insignificant compared to other types. The electricity generation types meant are electricity from uranium, electricity from photovoltaic and electricity from hydropower. The analysis also found that hydropower does not emit any green house gases at all. Electricity generation using lignite is found to emit higher quantity of green house gases compared to electricity generation using natural gas. Electricity generation from uranium is also found to emit a very low quantity of green house gases compared to electricity generation using natural gas and lignite.

The advantage in water treatment plant is the continuous water flow along the treatment process right from water extraction from rivers until clean water is stored in water storage, which should be used effectively. This water flow is capable of generating electricity. It is the same with the location of water treatment plants which are exposed to solar radiation that could be harnessed to produce electricity. The use of hybrid electricity generation such as combination of natural gas, solar and hydroelectric power generation could reduce the reliance of fossil fuel namely natural gas (Amir Hamzah, Noor Zalina and Abdul Halim, 2008a, 2008b, 2008c, 2008d, 2008e).

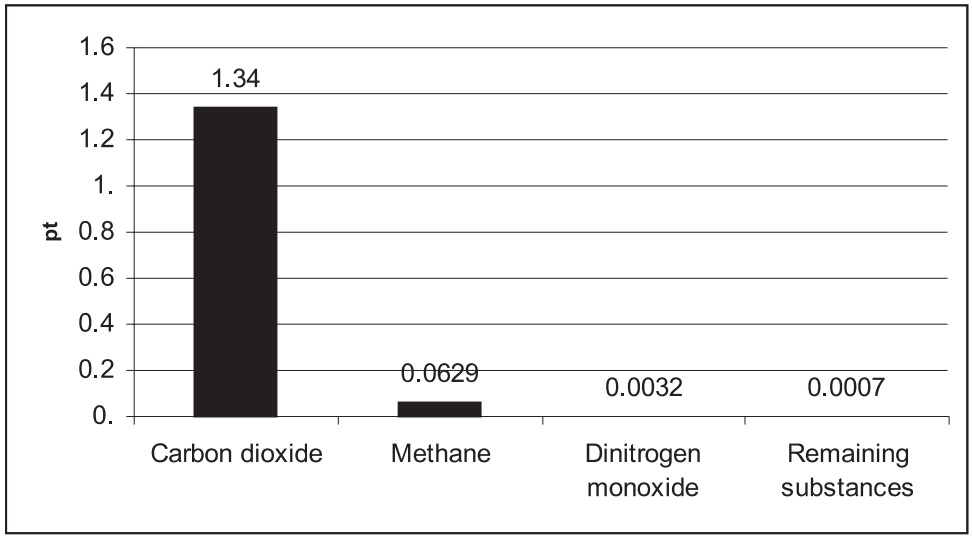

Figure 3: Weighting graph for major green house gases emitted from processes of chemicals production and electricity generation used during water treatment process.

Conclusion

The goal of this study is to gather inventories for green house gases emitted from chemicals and electricity usage in drinking water production process. The result of the inventory analysis has shown that substantial quantity of green house gases are emitted during production of chemicals and electricity generation used to produce clean drinking water which fits the standard. Among the green house gases emitted from chemicals production and electricity generation are carbon dioxide, methane, carbon monoxide and dinitrogen monoxide. Electricity generation using natural gas as fuel emits the highest quantity of carbon dioxide and methane gases. Impact analysis using Eco-Indicator 99 evaluation method has found that electricity generation using natural gas would deplete the fossil fuel source which is one of the controlled impacts. Meanwhile PAC is seen as the least contributor of green house gases compared to the rest. However previous study has found that PAC contributes to the damage of environmental quality and damage to human health from the production process of PAC that releases nitrogen oxides and sulphur oxides gases (Amir Hamzah, Noor Zalina and Abdul Halim, 2008a, 2008b, 2008c, 2008d, 2008e).

Thus a mechanism must be put in place to reduce green house gases especially carbon dioxide. The comparative analysis on five types of electricity generation is conducted to compare the rate of carbon dioxide emission in order for alternatives to be suggested to replace current electricity generation method. This analysis found that hydropower electric does not emit any green house gases at all while electricity generation using lignite emits more green house gases compared to electricity generation using natural gas. Photovoltaic electricity generation only emits minimal green house gases. This analysis suggested that the use of hybrid system could potentially be conducted at the water treatment plant looking at the advantages currently present at these plants such as the continuous water flow and the location of treatment plants that is exposed to solar radiation. Hybrid electric meant is the combination of hydropower and the use of solar panels which has been shown in the previous studies to avoid sole reliance on fossil fuel of natural gas (Amir Hamzah, Noor Zalina and Abdul Halim, 2008a, 2008b, 2008c, 2008d, 2008e). But the use of hybrid electric has to be given detailed assessment not only on climate change impact but on other impacts as well to avoid causing damage to human health, ecosystem quality and depletion of natural resources in the world.

The world climate change demands sustainable development practices. Without sustainable development in environmental management, damage to the environment is inevitable. Global warming is a general example caused by anthropogenic activities. Drinking water is the base of life and humans cannot live without drinking water. To produce clean drinking water, it has indirectly released green house gases which have the potential to cause climate change to happen. This dilemma could be overcome by using LCA as the environmental assessment tool.

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