Life Cycle Impact Assessment (LCIA) Using the Ecological Scarcity (Ecopoints) Method: A Potential Impact Analysis to Potable Water Production

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Abstract: Life cycle assessment (LCA) is a method to analyze a product or service from the beginning of the process where it is extracted until it is not useful anymore or it is known as cradle-to-grave analysis. LCA analysis includes the inventory collecting all types of emission and waste. After this is done, the inventory will be interpreted to the environmental impacts in Life cycle impact assessment (LCIA). Two LCIA methods identified are Midpoint and Endpoint approaches. The Ecological Scarcity (Ecopoints) is an LCIA method using Midpoint approach. From the analysis to both life cycle stages analysis for potable water production which are construction stage and production stage indicate that both stages contribute two main impacts namely NOx dan SOx. In production stage, NOx and SOx were released from PAC production. On the other hand for the construction stage, NOx and SOx were released from steel production process.

Key words: Ecopoints method, LCIA · Potable water production · Midpoint approach · Poly Aluminium Chloride (PAC) and steel production

INTRODUCTION

Impact assessment is used to identify significant potential environmental effect by using the results of life cycle impact analysis (LCI). LCIA is very different from other techniques such as environment impact assessment (EIA) and risk assessment because the approach uses functional unit. LCIA comprises four elements namely the classification, characterization, normalization and weighting but normalization and weighting are the optional element [1]. According to [2], the classification of LCI due to the impact categories is through the impact pathway which begins from LCI results until the end-point. The explanation on impact pathway is also touched in ISO [2] where:

'LCI results are classified into the impact categories and category indicators that can be stated in any LCI results (mid) with the end-point category'.

In accordance with the above explanation, two approaches are developed to explain the inter-connection of the LCI results with the environmental impacts via mid-points or end-points approaches [3-8]. According to [9], the main different between both models is the methodology how category indicators are presented to translate the achieved impact categories.

Figure 1. Explain about the impact pathway begin from LCI results until the end-point. The emission of ozone depletion gasses is used as an example for the characterization of ozone depletion gasses that can be conducted either until mid-point or end-point. Impact in mid-point is the ozone layer depletion and impact in the end-point is the protected area involving human health, natural biotic environment and manmade environment.

Midpoint Approach: The LCIA mid-point approach also known as problem-oriented approach [6, 10] or classical impact assessment method [2, 5]. The term mid-point refers to the category indicator for each impact category which is expressed in the mid pathway of impact between LCI results and end-point [11]. Mid-point translates the category impact into real phenomenon as such as climate change, acidification and aquatic toxicity [7]. Example of methodology that was developed using the midpoint approach is CML 2001 [3, 10], EDIP 97 and TRACI [11].

Endpoint Approach: The end-point LCIA methodology is also known as damage-oriented approach [10]. End-point approach according to [3] are the elements inside the impact pathway that consists of independent value for society. The term 'end-point' is refers to the category

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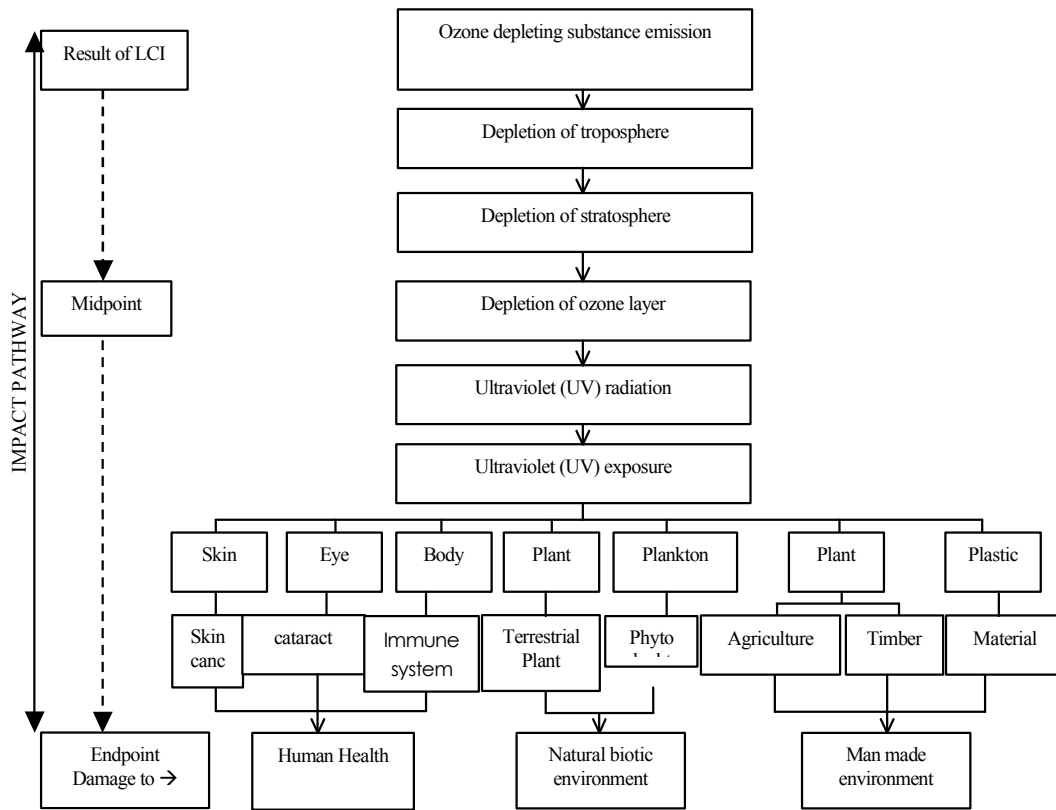14000 Bukit Mertajam, Penang E-mail: amirhamzah5@yahoo.com.

Fig. 1: Impact pathway connecting the emission to several deterioration categories

indicator for each impact category located at the end of impact pathway as in the Figure 1. End-point indicator translates the category impact based on the area of protection such as human health, natural environmental quality, natural resources and human made environment [12]. Example of end-point methodology are Eco-indicator 95 and 99, EPS 92, 96 and 2000 and LIME 2003 [13].

According to Reap *et al*. [14], there are several factors affecting the level of confidence and suitability of LCA research result which include option of LCIA methodology either using the mid-point or end-point approach. Reap *et al*. mentioned, end-point impact category is less comprehensive and posses higher level of uncertainty compared to mid-point impact category. Nevertheless mid-point impact category is difficult to be interpreted especially in the process of decision making because the mid-point impact category is not directly correlated with the area of protection (i.e. damage to human health, ecosystem quality and resource depletion) which is practiced by the end-point.

Methodology of LCA: There are four main phases in LCA as suggested in ISO 14040 series:
2.1 Goal and scope definition (ISO 14040)

2.2 Life cycle inventory (LCI) (ISO 14041)
2.3 Life cycle impact assessment (LCIA) (ISO 14042)
2.4 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 objective of this research is to get a clear picture of impact potential which produced from potable water production where two phases were involved namely production stage and construction stage using LCIA method that is Ecopoints method. This research will identify which impact more outstanding by comparing them using normalization and weighting procedures so that suggestions to reduce the impact can be made.

Functional Unit: Functional unit is quantified performance of a product system for use as a reference unit in a life cycle assessment study [15]. A constant value must be

created to make the comparison [16]. Functional unit for this study is the production of 1m^3 of treated water a day that fits the standard quality set by Ministry of Health, Malaysia.

Description of the System under Study: There are two stages which became the basis of comparison for this study namely production construction stage.

Production Stage: Raw water extracted from rivers will go through the following process in the water treatment plant [17]:

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 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 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 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 (Figure 2). 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 [18]. 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).
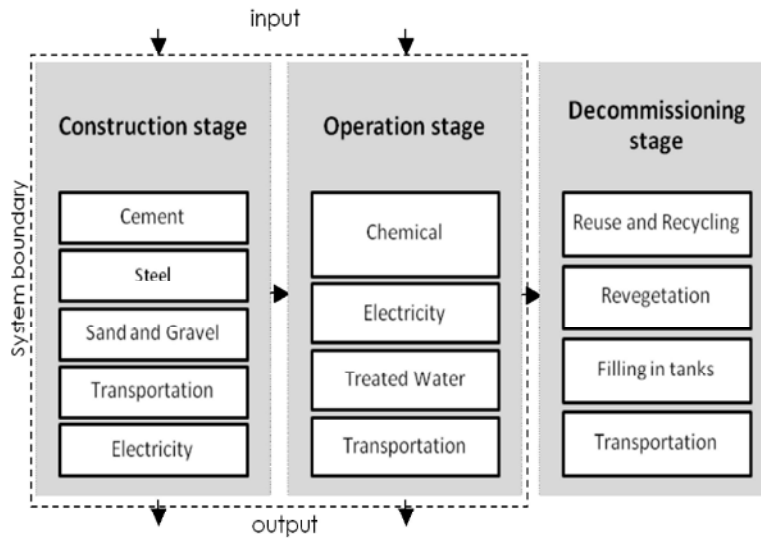
Fig. 2: System Boundary of Potable Water Treatment Plant

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
Electricity (kwh)	0.09	Electricity (kwh)	397.28
Tap water (liter)	477.26		

- 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.

Life Cycle Impact Assessment (LCIA): LCIA for this study uses The Ecological Scarcity method or also known as Swiss Ecopoints. This method enables to do a comparison between weighting and aggregation among environmental interventions or known as eco-factor.

This method provides the different weighting factors to emission/release into the top-soil, groundwater, water, air and energy sources. Eco-factors are based on annual actual flows or current flow and annual flow that consider as critical flows at certain location such as region or country. [19].

This eco-factor made based on Switzerland, where current flows are taken from the latest statistic data whilst critical flows had being deduced from scientific objective that is fixed by Swiss environmental policy. This method is also expanded to not only in Switzerland but in several countries like Japan and Belgium.

This method is developed using the top-down principles and assumption from environmental policy framework. It is used as a reference framework for improvement and optimization product or processes. Various damages on ecosystem quality and human health are considered into target setting process for general environmental policy. Furthermore, this policy becomes a basis to the critical flows. The implicit weighting also accepted as various objectives of environmental policy. The Eco-points method contains the common characterization and classification approach such as

climate change, ozone depletion and acidification. The other interventions are evaluated individually, for example various heavy metal and also by group like pesticides or NM-VOC (non-methane volatile organic compounds).

This approach was built to make as a standard for environmental assessment to all process or product. It is also used as an element in the environmental management system (EMS) of company. This development started in 1997 (first version) and followed by 2005 (second version) which is considering data for 2004 [19-21].

Generally there are 3 steps in LCIA:
2.3.1   Classification and Characterization
2.3.2   Normalization and
2.3.3   Weighting

Classification and Characterization: Classification is an inventory collection process from life cycle to several impact categories [22], while characterization according to

[23], is a type of summation of Life Cycle Inventory for every element under same impact category. The summation of every element using characterization factor and summation value then recognized as category indicator [24]. In [25], category indicator of Life Cycle impact category indicator can be defined as a value that indicates each impact category. Curran [26] suggested that the equation for category indicator is as below and the relationship between impact categories and characterization factor.

Inventory Data x Characterization Factor = Category Indicator

Characterization for Construction Stage: There are 30 main impact categories in Ecopoints method. Those categories are shown in Table 2. Analysis indicate that steel production contributes higher impact to most impact categories listed. Steel production contributed 60 – 90% compared to other building materials and electricity.

Table 2: Contribution from building materials to a few impact categories

Impact category	Unit	Cement	Gravel	Sand	Steel	Tap water	Electricity
1) NOx	g	31.01129	7.229588	4.820066	535.6428	0.352873	0.1341
2) SOx	g SO2 eq.	16.62977	1.693939	1.129372	506.3258	1.361048	0.023907
3) NMVOC	g	1.536866	0.935535	0.623734	105.3366	0.246374	0.011633
4) NH3	g	0.006074	0.000702	0.000468	0.013451	8.08E-05	1.75E-05
5) Dust PM10	g	169.4047	0.019043	0.012697	44.2025	0.061336	0
6) CO2	g CO2 eq.	11511.31	621.6569	414.4672	104252.9	184.9342	72.63223
7) Ozone layer	g CFC-11	0.000123	1.42E-05	9.49E-06	0.000273	0.000115	1.33E-07
8) Pb (air)	g	0.000274	3.17E-05	2.11E-05	0.790806	7.06E-05	3.25E-07
9) Cd (air)	g	1.37E-05	1.58E-06	1.05E-06	0.021981	3.41E-05	2.06E-08
10) Zn (air)	g	0.000492	5.69E-05	3.79E-05	0.385272	0.000103	5.24E-07
11) Hg (air)	g	4.14E-05	4.78E-06	3.19E-06	0.006238	1.7E-06	1.31E-06
12) COD	g	1.133609	0.131986	0.087997	2.525249	0.092393	0.065511
13) P	g	0.020954	0.002422	0.001615	0.046403	0.000175	0.000157
14) N	g	0.012976	0.001596	0.001064	0.029553	0.002065	5.34E-05
15) Cr (water)	g	0.010768	0.001245	0.00083	0.032626	0.000101	8.2E-05
16) Zn (water)	g	0.010836	0.001252	0.000835	0.120575	0.000135	8.05E-05
17) Cu (water)	g	0.005358	0.000619	0.000413	0.025914	4.72E-05	4.01E-05
18) Cd (water)	g	5.83E-05	6.74E-06	4.49E-06	0.000744	3.44E-06	4.04E-07
19) Hg (water)	g	2.5E-06	2.89E-07	1.93E-07	0.000532	1.41E-07	7.04E-08
20) Pb (water)	g	0.00555	0.000641	0.000428	0.02985	6.05E-05	4.03E-05
21) Ni (water)	g	0.00541	0.000625	0.000417	0.011981	4.79E-05	4.03E-08
22) AOX (water)	g Cl-	9.05E-06	1.05E-06	6.97E-07	2E-05	5.34E-06	1.06E-08
23) Nitrate (soil)	g	0	0	0	0	0	0
24) Metals (soil)	g Cd eq	0	0	0	0	3.01E-07	0
25) Pesticide soil	g	0	0	0	0	0	0
26) Waste	g	269.7103	34.00123	21.08485	1003.693	0	0
27) Waste (special)	g	0	0	0	0	0	0
28) LMRAD	cm3	0.166671	0.019264	0.012844	0.369088	0	0
29) HRAD	cm3	0.00074	8.55E-05	5.7E-05	0.001639	0	0
30) Energy	MJ LHV	140.4258	8.063551	5.376081	1856.551	2.422348	0.85417

Table 3: Chemical substances and electricity contribution to a few impact category

Impact category	Unit	Chlorine	Alum	PAC	Lime	Electricity
1) NOx	g	25.55	24.80052	151650.3	8.16887	591.9472
2) SOx	g SO2 eq.	44.43656	313.2135	151650	17.64707	105.5292
3) NMVOC	g	13.53245	5.656589	0.021795	1.945578	51.35229
4) NH3	g	0.006205	0.013886	3.27E-05	0.006184	0.077072
5) Dust PM10	g	0	0	6.23E-06	0.234104	0
6) CO2	g CO2 eq.	4577.91	6200.96	371.8875	11644.08	320614.8
7) Ozone layer	g CFC-11	0.000584	0.001588	2.54E-07	0.000588	0.000589
8) Pb (air)	g	0.000475	0.001687	6.09E-07	0.002272	0.001434
9) Cd (air)	g	4.75E-05	0.000466	3.86E-08	6.72E-05	9.1E-05
10) Zn (air)	g	0.000767	0.002209	9.84E-07	0.004665	0.002312
11) Hg (air)	g	7.66E-05	0.000141	2.46E-06	9.97E-05	0.0058
12) COD	g	1.476425	1.485189	0.122654	1.237757	289.1797
13) P	g	0.023871	0.04011	0.000294	0.044135	0.692423
14) N	g	0.04653	0.094736	0.0001	0.01627	0.235602
15) Cr (water)	g	0.01241	0.020835	0.000154	0.022634	0.361922
16) Zn (water)	g	0.01241	0.021032	0.000151	0.023084	0.355168
17) Cu (water)	g	0.006205	0.010305	7.5E-05	0.011266	0.17679
18) Cd (water)	g	8.03E-05	0.000152	7.57E-07	0.000164	0.001784
19) Hg (water)	g	2.59E-06	3.85E-06	1.32E-07	2.77E-06	0.000311
20) Pb (water)	g	0.0073	0.012594	7.55E-05	0.01163	0.177981
21) Ni (water)	g	0.006205	0.010074	7.64E-08	0.011362	0.000178
22) AOX (water)	g Cl-	4.38E-05	0.000115	2.01E-08	2.29E-05	4.69E-05
23) Nitrate (soil)	g	0	0	0	0	0
24) Metals (soil)	g Cd eq	0	0	1.01E-11	2.68E-06	0
25) Pesticide soil	g act.subst.	0	0	0	0	0
26) Waste	g	362.445	0	0	0	0
27) Waste (special)	g	0	0	0	0	0
28) LMRAD	cm3	0	0	0	0	0
29) HRAD	cm3	0	0	0	0	0
30) Energy	MJ LHV	74.08332	141.606	3.534974	52.947	3770.495

Steel production contribute around 90% to Pb (air), Cd (air), Zn (air), Hg (air), NOx, Sox, NMVOC, Cd (water) and Energy. Steel production contributes to over 60% are NH3, Ozone, COD, P, N, Cr (water), Zn (water), Pb (water), Ni (water), HOX (water), Waste, LMRD and HRAD.

Out of all impact categories listed showed that cement contributes over 20% and the remaining contributes by other substances and electricity. There are three impact categories which are not contribute by construction materials and electricity such as Nitrate, waste (special) and pesticide. Furthermore 100% metal impact category (soil) contributed from tap water. Tap water also contributed more than 20% for ozone layer impact categories. Overall, Gravel and sand contributed the least of all categories that is less than 5%.

2.3.1.2 Characterization for Production Stage
On the whole, most of the impact categories are from the electricity usage. The contribution are more than 60% to 14 impact categories came from the electricity usage. The impacts are NMVOC, NH3, CO2, P, N, Cr (water),

Zn (water), Cu (water), Cd (water), Hg (water), Pb (water) and Energy. Other than that, there are a few Chemicals substances contributed nearly 100% for example PAC contributed to NOx and Sox, Lime contributed to Dust PM10 and Metals and Chlorine contributed to waste.

Furthermore, Alum also contributes between 25% - 70% to several impact categories such as Ozone, Pb (water), Cd (water), Zn (water), N, Ni (water) and AOX (water). Table 2 showed the contribution from chemicals that gave impact to environment especially from electricity generation process (coloured column).

Normalization: According to [27] normalization enable the impact categories to be distinguished**.** There are two reasons why normalization is conducted, first is to identify the impact categories that should give mere attention and second, to obtain the magnitude of environmental degradation produced during the life cycle of the product [28]. Normalization is determined based on the formula shown below [13]:

$$N_k = S_k / R_k \text{ where;}$$

k = Impact category
N = Normalisation indicator
S = Category indicator (from characterization)
R = Reference value

Normalization for Construction Stage: From Figure 3 indicate that CO_2 impact category more outstanding compared to other impact categories. Steel production found to be the biggest contributor where CO_2 contributed as much as 89% (104252.9 unit) compared to the other building materials (cement – 9.8%, Gravel – 0.5%, Sand – 0.4%, tap water – 0.2%) and Electricity (0.06%).

Normalization for Production stage: In production stage, normalization showed that NOx, SOx and CO_2 impact categories are more outstanding compared to other impact categories (Figure 4). For second place, Nox and Sox,

almost 100% contributed from PAC are NOx – 99.6% and Sox – 99.7%. Meanwhile CO_2 is more contributed by using electricity energy (93.4%) compared to others (PAC -0.1%, Chlorine -1.3%, Alum - 1.81% and Lime – 3.4%).

Weighting: Weighting is conducted by multiplying category indicator with weighting factor and summed to get the score [23]. Because of this method is not damage oriented, therefore the weighting value is not summed (summed is based to the same category) to get single score for comparison purpose with other damage categories. Weighting is determined based on formula as in [13]:

$$EI = ? \; V_k N_k \;\; OR \; EI = \Sigma \; V_k S_k \text{ where;}$$

k = Impact category
EI = Indicator to all environmental impact
V = weighting factor
N = Normalisation indicator
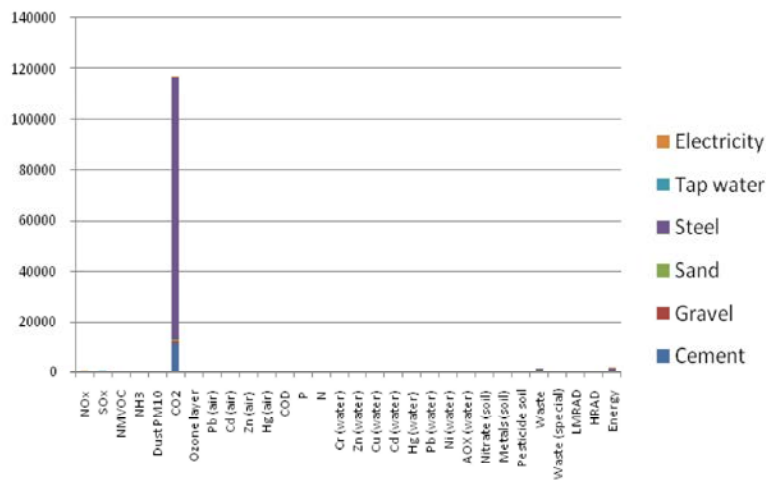S = Category indicator (from characterization)

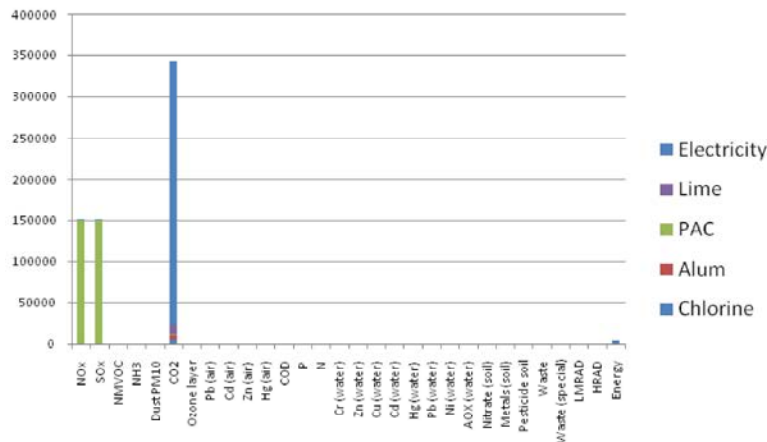Fig. 3: Normalization for impact categories from construction substances and electricity.

Fig. 4: Normalization graph for impact category contributed from chemical substances and electricity.

Table 4: Weighting factors for emission to air, surface water, groundwater, topsoil and for waste according to Brand *et al.*, [18]

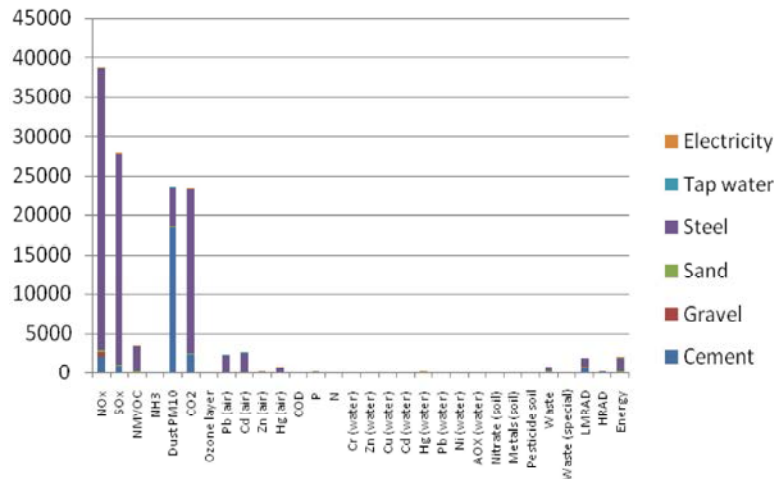| Emission to air	Eco-points/g	Emission to surface water	Eco-points/g	Emission to top-soil	Eco-points/g	Wastes	Eco-points/g
Nox	67	COD	5.9	Pb	2900	Waste to inert,	0.5
SO2	53	DOC	18	Cu	1900	sanitary,	
NMVOC	32	TOC	18	Cd	120000	residual	
NH3	63	Phosphorus (P)	2000	Zn	520	material	
Hcl	47	N total	69	Ni	1900	landfills	
HF	85	NH4+	54	Cr	1300	Waste to	24
PM10	110	NO3-	16	Co	3800	underground	
CO2	0.2	Cr	660	Hg	120000	deposit	
CH4	4.2	Zn	210	Th	96000	Radioactive wastes	
N2O	62	Cu	1200	Mo	19000	Nuclear waste	3300
R11eq	2000	Cd	11000	Pesticides	800	type B	
Pb	2900	Kg	240000			Nuclear waste	46000
Cd	120000	Pb	150			type C	
Zn	520	Ni	190				
Hg	120000	AOX	330				3300
		Emission to groundwater					
		--					
		nitrate	27				

Fig. 5: Weighting for impact category contribution from construction substances and electricity.

Weighting factors used in Ecopoints method as reported in Brand *et al*. [19] showed in Table 4.

Weighting for Construction Stage: There are four outstanding impact categories compared to others namely Nox, Sox, CO2 and Dust PM10 (Figure 5). NOx and SOx contributed as much as 92.5% dan 96.05% respectively by steel production. NOx is the biggest impact followed by SOx, CO2 dan Dust PM10. CO2 contributed higher by steel production (89.1%) followed by cement production (9.8%). While Dust PM10 contributed higher by cement production (79.2%) followed by steel production (20.7%).

Weighting for Production Stage: Similar to construction stage, NOx and SOx are the most outstanding but at the production stage only these two impacts are obviously

outstanding compared to others (Figure 6). Both impacts nearly 100% contributed by PAC (Nox – 99.6% and SOx – 99.7%).

Life Cycle Assessment and Interpretation (LCAI): The analysis indicate that production stage create more impact than construction stage. The impact contributed from production stage are NOx and SOx. The same goes to construction stage where NOx and SOx are also the highest impact compared to two other main impacts namely Dust PM10 and CO2. NOx and SOx contributed by PAC while NOx and SOx in constrction stage contributed the highest by steel processing. Network analysis had been carried out to identify the processes that contribute to NOx and SOx from steel processing. From the analysis (Figure 7 and Figure 8) showed both impacts contributed by transports using fossil fuel.
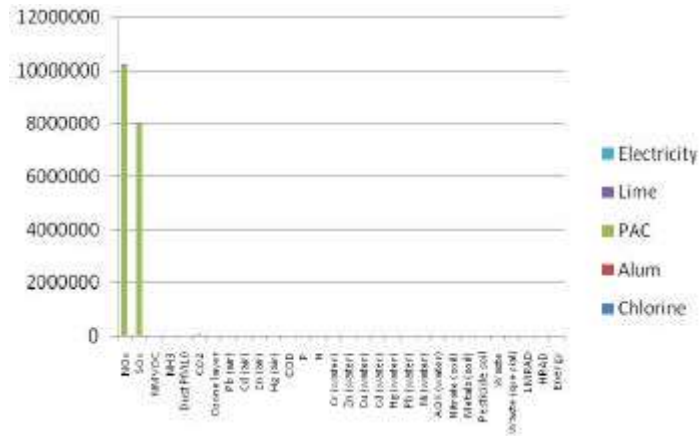
Fig. 6: Weighting for impact category contribute from construction substances and electricity
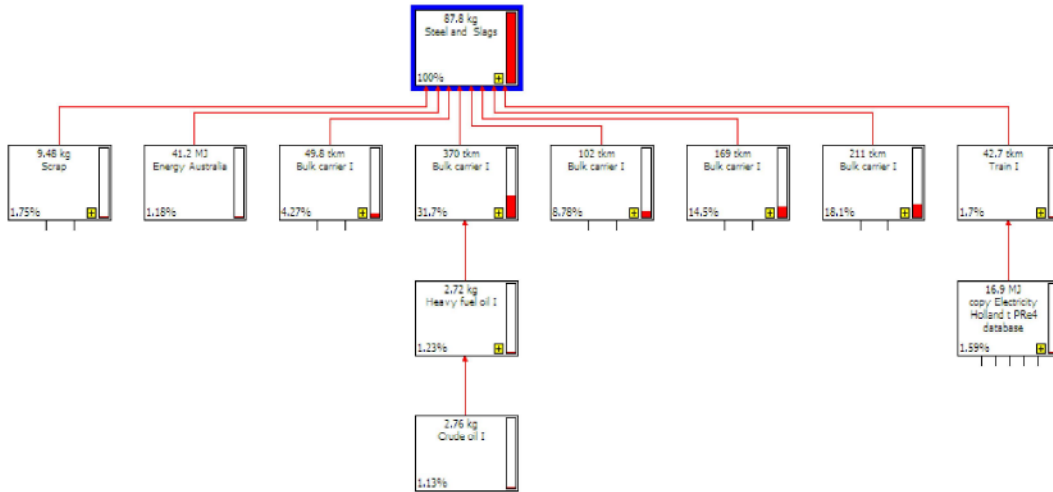

Fig. 7: Network for processes in producing steel. Coloured bar for each box showed NOx contribution in each process.
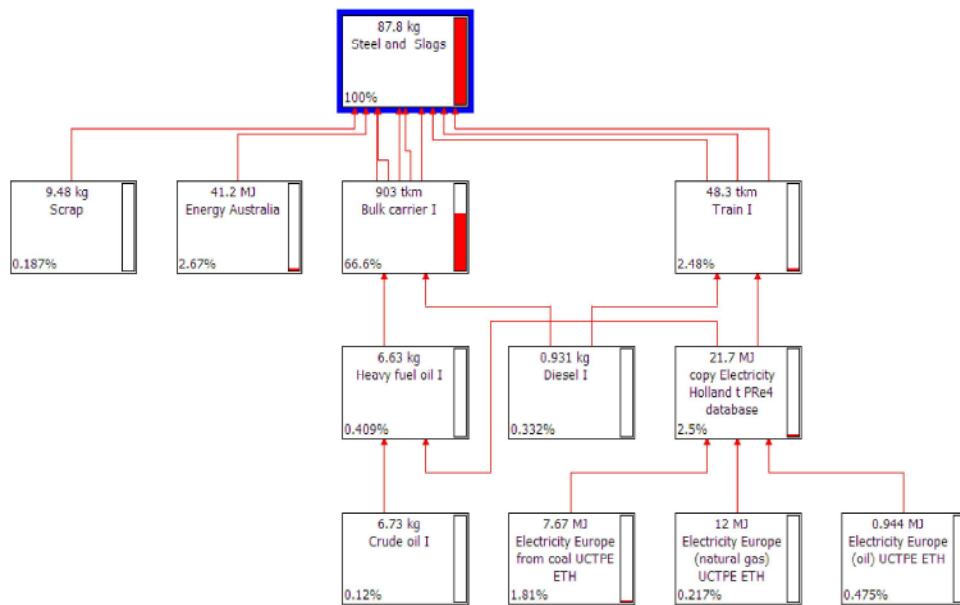

Fig. 8: Network processes in producing steel. Coloured bar for each box showed SOx contribution in each process.
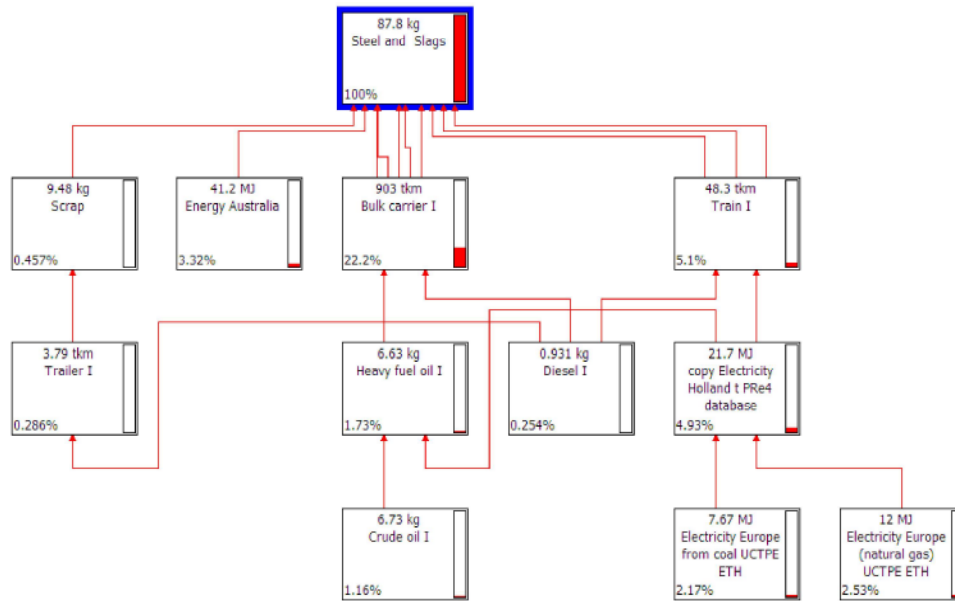
Fig. 9: Network for processes in producing steel. Coloured bar for each box showed CO_2 contribution in each process.

Meanwhile in construction stage, producing steel process contributed more CO_2. Network analysis (Figure 9) discovered that CO_2 released by transport using fossil fuel.

CONCLUSION AND RECOMMENDATION

The weaknesses had been identified at production stage are NOx and SOx released form PAC which been used as coagulant in potable water treatment. Previous research [29, 30] discovered that using Alum is better because it does not release NOx and SOx. Meanwhile in construction stage, both substances are release from steel production.

Steel is the basic component in water treatment plant construction. 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 [31]. Before we can declare this alternative is nature friendly or equal quality to steel, it has to go through LCA analysis process.

As for the CO_2 emission, most of the CO_2 released were contributed by transport and electricity energy. Previous research showed a comparison among a few types of alternatives generate electricity energy have been conducted and discovered that photovoltaic, hydro and uranium are better than electricity energy using fossil fuel [32].

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