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Full Length Research Paper

Life cycle impact assessment (LCIA) using the ecological scarcity (ecopoints) method: A potential impact analysis to potable water production

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Life cycle assessment (LCA) is a method use to analyze a product or a 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 it is done, the inventory will be interpreted to the environmental impacts in life cycle impact assessment (LCIA). Two LCIA methods identified were “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 was construction stage and production stage indicated that both stages contributed two main impacts namely: NOx and SOx. In the 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, life cycle impact assessment, potable water production, midpoint approach, poly aluminium chloride, steel production.

INTRODUCTION

Impact assessment is used to identify significant potential environmental effect by using the results of life cycle impact analysis (LCIA). 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 elements (Koroneos et al., 2005). According to Jolliet et al. (2003), 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 (Jolliet et al., 2003) where: ‘LCIA 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 aforementioned explanation, two approaches are developed to explain the inter-connection of the LCI results with the environmental impacts through mid-points or end-points approaches (Heijungs et al., 2003; Jolliet et al., 2003, 2004; Ortiz et al., 2009; Sleeswijk et al., 2008; Soares et al., 2006). According to Bare et al. (2000), the main difference between both models is the methodology how category indicators are presented to translate the achieved impact categories. Figure 1 explains about the impact pathway beginning 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.

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Abbreviations: LCA, Life cycle assessment; **LCIA,** life cycle impact assessment; **EIA,** environment impact assessment; **LCI,** life cycle inventory.

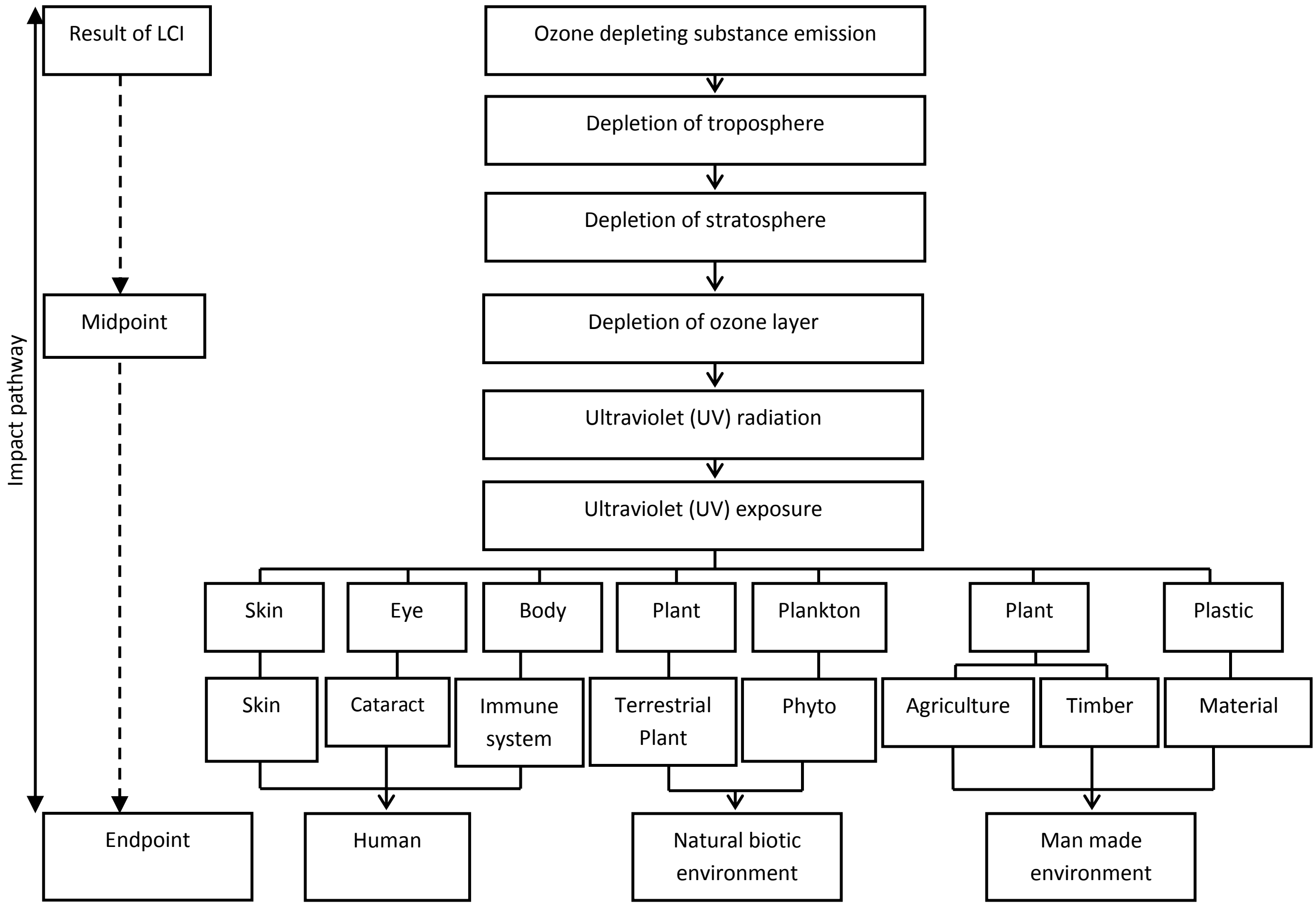

Figure 1. Impact pathway connecting the emission to several deterioration categories.

Midpoint approach

The LCIA mid-point approach is also known as problem-oriented approach (Dreyer et al., 2003; Ortiz et al., 2009) or classical impact assessment method (Jolliet et al., 2003, 2004). 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 (Josa et al., 2007). Mid-point translates the category impact into real phenomenon such as climate change, acidification and aquatic toxicity (Sleeswijk et al., 2008). Example of methodology that was developed using the midpoint approach is CML 2001 (Dreyer et al., 2003; Heijungs et al., 2003), EDIP 97 and TRACI (Jolliet et al., 2004).

Endpoint approach

The end-point LCIA methodology is also known as damage-oriented approach (Dreyer et al., 2003). End-point approach according to Heijungs et al. (2003) is the elements inside the impact pathway that consists of independent value for society. The term ‘end-point’ refers to the category indicator for each impact category located at the end of impact pathway as in 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 (Bare and Gloria, 2008). Examples of end-point methodology are Eco-indicator 95 and 99, EPS 92, 96 and 2000 and LIME 2003 (Pennington et al., 2004). According to Reap et al. (2008), there are several factors affecting the level of confidence and suitability of LCA research result which include the options of LCIA methodology either using the mid-point or end-point approach. Reap et al. (2008) mentioned that 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 (that is 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:

(1) Goal and scope definition (ISO 14040).
(2) Life cycle inventory (LCI) (ISO 14041).
(3) Life cycle impact assessment (LCIA) (ISO 14042).
(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 the procedures for data collection and the data quality assurance are established.

Objectives

The objective of this study was to get a clear picture of impact potential which is produced from potable water production where two phases were involved namely: Production stage and construction stage using LCIA method that is Ecopoints method. This study will identify which impact is more outstanding by comparing them using normalization and weighting procedures so that suggestions to reduce the impact can be recommended.

Functional unit

Functional unit is a quantified performance of a product system 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 1 m^3 of treated water a day that fits the standard quality set by the Ministry of Health, Malaysia.

Description of the system under study

There are two stages which became the basis of comparison in this study namely: Production and construction stage.

Production stage: Raw water extracted from rivers will go through the following processes in the water treatment plant (Sastry, 1996):

(a) Screening, to remove floating big sized rubbish on the surface of the water.
(b) 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 used 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.
(c) Settling, aggregated flocs settle on the base of the settler. The accumulation of floc settlement is called settling sludge.
(d) Filtration, part of the suspended matter that did not settle goes through filtration. Water that passes through filtration consists of sand layers and activated carbon or anthracite coal.
(e) 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:

(a) Cement.
(b) Fine aggregate/sand.
(c) Coarse aggregate.
(d) Water.

The quality of the concrete which is produced depends on the quality of the raw materials that are 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 good in quality, the concrete produced will have low quality and it causes the concrete to be weak and unable to fulfill the fixed specifications. So, concrete technology warrants that all the materials that will be used should first be tested and certified through fixed standardizations before it is used in the construction work. 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:

(1) Mild steel reinforcement/mild steel.
(2) Reinforcement steel with high tensility.
(3) Fabric steel (fabric).

The steels that are provided are 12 m long, with the diameter of 6, 8, 10, 12, 16, 20, 22, 25 and 32 mm. 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. Fabric steel (fabric) is used in a wide concrete surface area such as floor, it comes in sizes of 2.4 x 1.8 m with steel diameter of 4 to 12 mm and distance between each steel rods are different based on the types of fabric. Reinforcement steel 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 a material and energy balance, the inventory table, or the eco-balance of the product (Guinée, 2002). This LCA study is a streamlined LCA with 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 shown in Table 1:

(1) Electricity usage, and
(2) Chemicals for water treatment such as Aluminium sulphate (alum), poly aluminium chloride (PAC), chlorine, and calcium hydroxide (lime),
(3) 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.

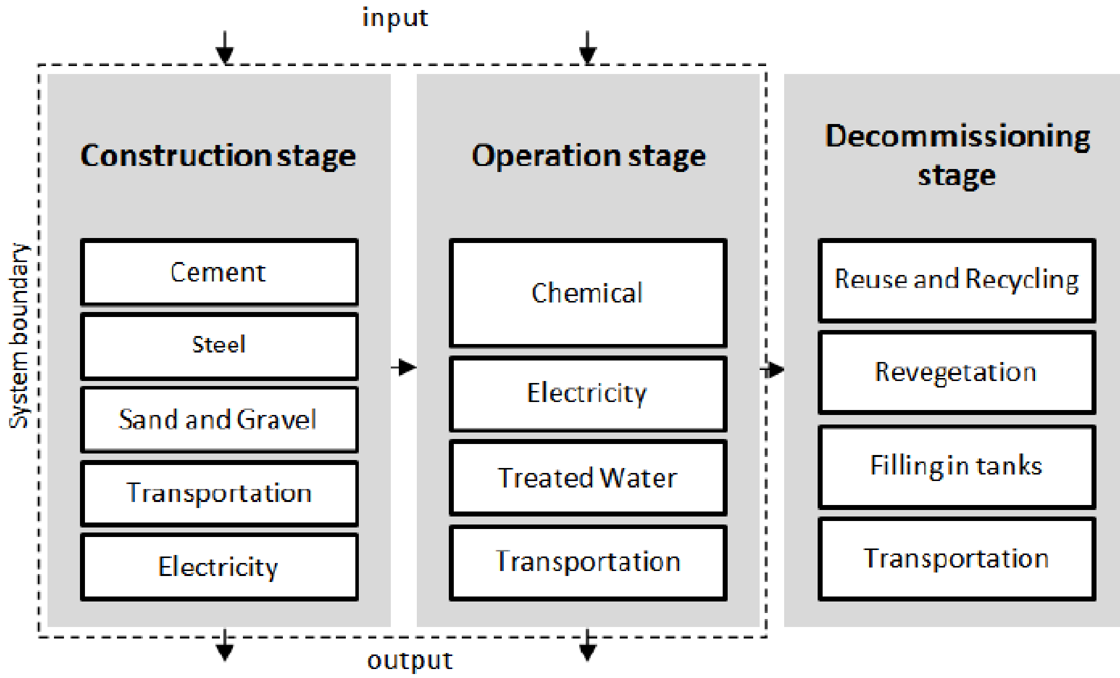

Figure 2. System boundary of potable water treatment plant.

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		

Background data for all building materials and chemicals were 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)

In this study of LCIA, “the ecological scarcity method” or also known as Swiss Ecopoints is used. This method enables doing 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 flow or current flow and annual flow that are considered as critical flows at certain location such as region or country (Brand et al., 1998). This eco-factor made is based on Switzerland, where current flows are taken from the latest statistic data whilst critical flows had been 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 is 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 such as pesticides or NM-VOC (non-methane volatile organic compounds). This approach was built to make as a standard for environmental assessment to all the 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 the data for 2004 (Ahbe et al., 1990; Brand et al., 1998; Müller-Wenk, 1994). Generally there are 3 steps in LCIA:

(i) Classification and characterization.
(ii) Normalization, and

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

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

(iii) Weighting.

Classification and characterization

Classification is an inventory collection process from life cycle to several impact categories (Moberg et al., 2005), while characterrization according to Bovea and Gallardo (2006), is a type of summation of life cycle inventory for every element under the same impact category. The summation of every element using characterization factor and summation value then recognized as category indicator (Ntiamoah and Afrane, 2008). In ISO 14040 (2000 and 2005), category indicator of life cycle impact category indicator can be defined as a value that indicates each impact category. Curran (2006) suggested that the equation for category indicator is given as follows 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 indicates that steel production contributes higher impact to most impact categories listed. Steel production contributed 60 to 90% of the impact compared to other building materials and electricity. Steel production contributes around 90% to Pb (air), Cd (air), Zn (air), Hg (air), NOx, SOx, NMVOC, Cd (water) and energy. Also, it contributes over 60% of NH_3, ozone, COD, P, N, Cr (water), Zn (water), Pb (water), Ni (water), AOx (water), waste, LMRD and HRAD. There are three impact categories which are not contributed 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%.

Characterization for production stage: Generally, most of the impact categories are from the electricity usage. There is more than 60% of the contribution to 14 impact categories 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 chemical substances which contributed nearly 100% of the impact for example, PAC contributed to NOx and SOx, lime contributed to dust PM10 and metals, and chlorine contributed to waste (Table 3). Furthermore, alum also contributes between 25 to 70% of impact to several

Table 3. Chemical substances and electricity contribution to a few impact categories.

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

Alum, Aluminium sulphate; PAC, polyaluminium chloride.

impact categories such as ozone, Pb (water), Cd (water), Zn (water), N, Ni (water) and AOX (water). Table 2 shows the contribution from chemicals that gave impact to environment especially from electricity generation process (coloured column).

Normalization

According to (Mangena and Brent, 2006) normalization enables 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 secondly, to obtain the magnitude of environmental degradation produced during the life cycle of the product (Goedkoop et al., 2007). Normalization is determined based on the following formula (Pennington et al., 2004):

$$N_k = S_k / R_k$$

Where, K is the impact category; N is normalisation indicator; S is the category indicator (from characterization) and R is the reference value.

Normalization for construction stage: Figure 3 indicates that CO_2 impact category outstand more than the 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 the production stage, normalization showed that NOx, SOx and CO_2 impact categories are more outstanding compared to other impact categories (Figure 4). In the second place, NOx and Sox, almost 100% contributed from PAC are NOx – 99.6% and Sox – 99.7%. Meanwhile, contribution of CO_2 is more 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 (Bovea and Gallardo, 2006). Since this method is not damage oriented, the weighting

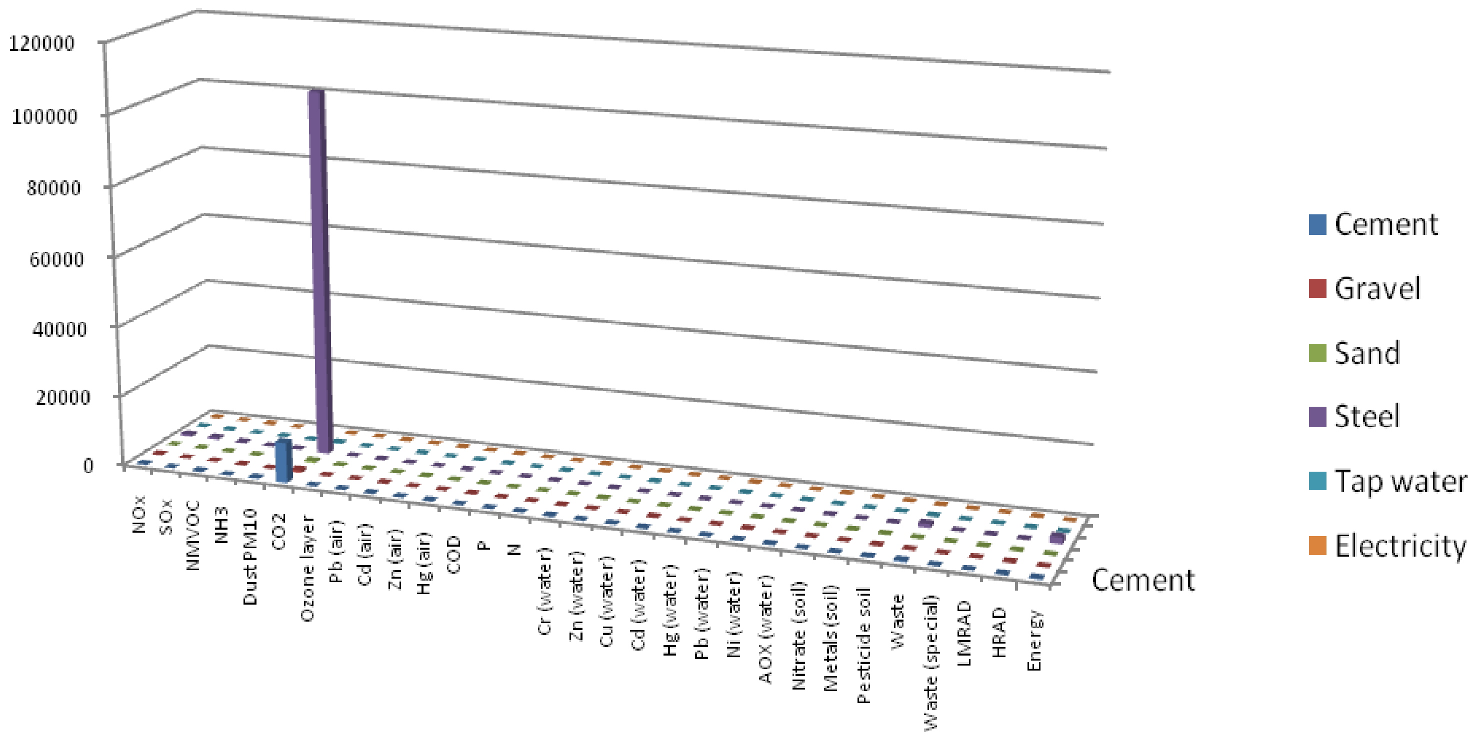

Figure 3. Normalization for impact categories from construction substances and electricity.

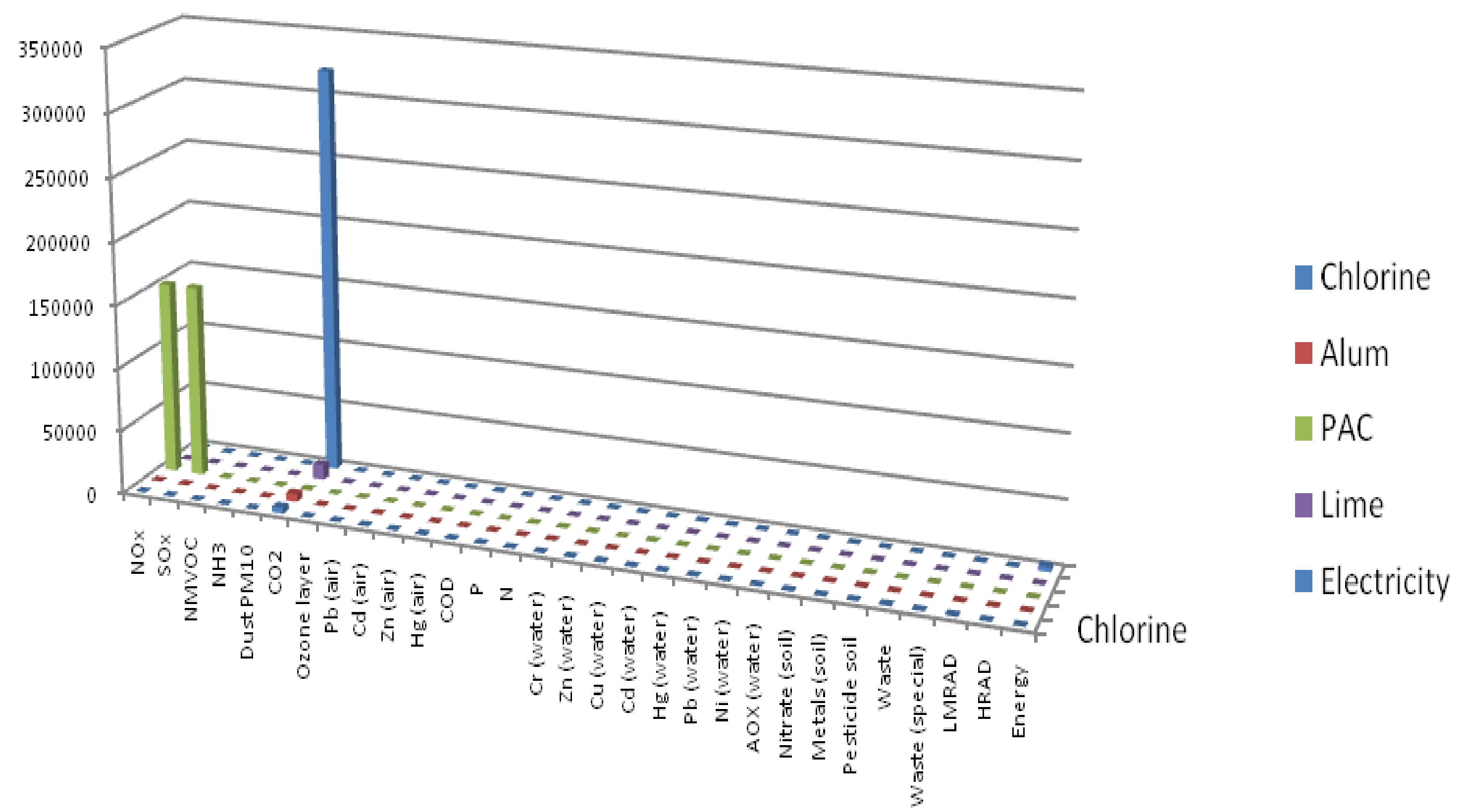

Figure 4. Normalization graph for impact category contributed from chemical substances and electricity.

Table 4. Weighting factors for emission to air, surface water, groundwater, topsoil and for waste according to Brand et al. (1998).

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

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 the following formula as in Pennington et al. (2004):

$$EI = \sum V_k N_k \text{ or } EI = \sum V_k S_k$$

Where, k is the impact category; EI is the indicator to all environmental impact; V is the weighting factor; N is the normalisation indicator and S is the category indicator (from characterization).

Weighting factors used in Ecopoints method as reported in Brand et al. (1998) is shown in Table 4.

Weighting for construction stage: There are four outstanding impact categories compared to others namely: NOx, SOx, CO_2 and dust PM10 (Figure 5). NOx and SOx contributed as much as 92.5 and 96.05% respectively by steel production. NOx is the biggest impact followed by SOx, CO_2 and dust PM10. CO_2 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 impacts but at the production stage, only these two impacts are obviously outstanding (Figure 6). Both impacts nearly 100% contributed by PAC (NOx – 99.6% and SOx – 99.7%).

Life cycle assessment and interpretation (LCAI)

The analysis indicated that production stage creates more impact than construction stage. The impacts 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 CO_2. NOx and SOx contributed by PAC while NOx and SOx in construction stage contributed the highest by steel processing. Network analysis had been carried out to identify the processes that contributed to NOx and SOx from steel processing. The analysis (Figures 7 and 8) showed that both impacts are contributed by transports which use fossil fuel. Meanwhile in construction stage, process of producing steel contributed more CO_2. Network analysis (Figure 9) discovered that more CO_2 is released by fossil fuel generated transports.

CONCLUSION AND RECOMMENDATION

The weaknesses that were identified at production stage are NOx and SOx released from PAC which is used as coagulant in potable water treatment. Previous research (Amir et al., 2008a, b) discovered that using "alum" is better because it does not release NOx and SOx. Meanwhile in construction stage, both substances are released 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 (Clarke, 1998). However, it has to go through the LCA analysis process before it is declared as nature friendly or has the equal quality as steel. Most of the CO_2 are contributed by transport and electricity energy. Previous research which was about comparison among a few types of alternatives generating electricity energy have been conducted and discovered that photovoltaic, hydro and uranium are better than electricity energy using fossil fuel (Amir et al.,

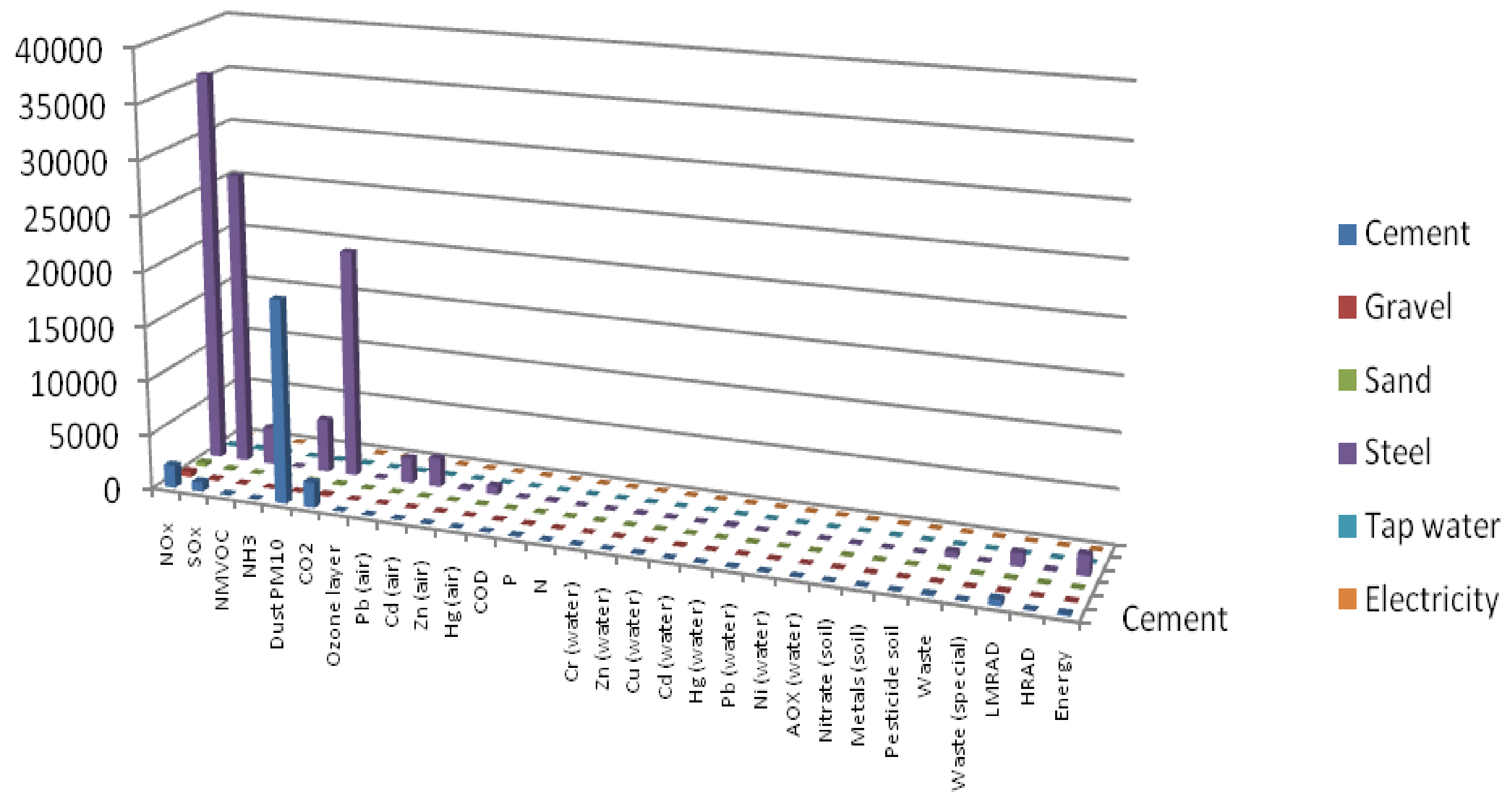

Figure 5. Weighting for impact categories contributed from construction substances and electricity.

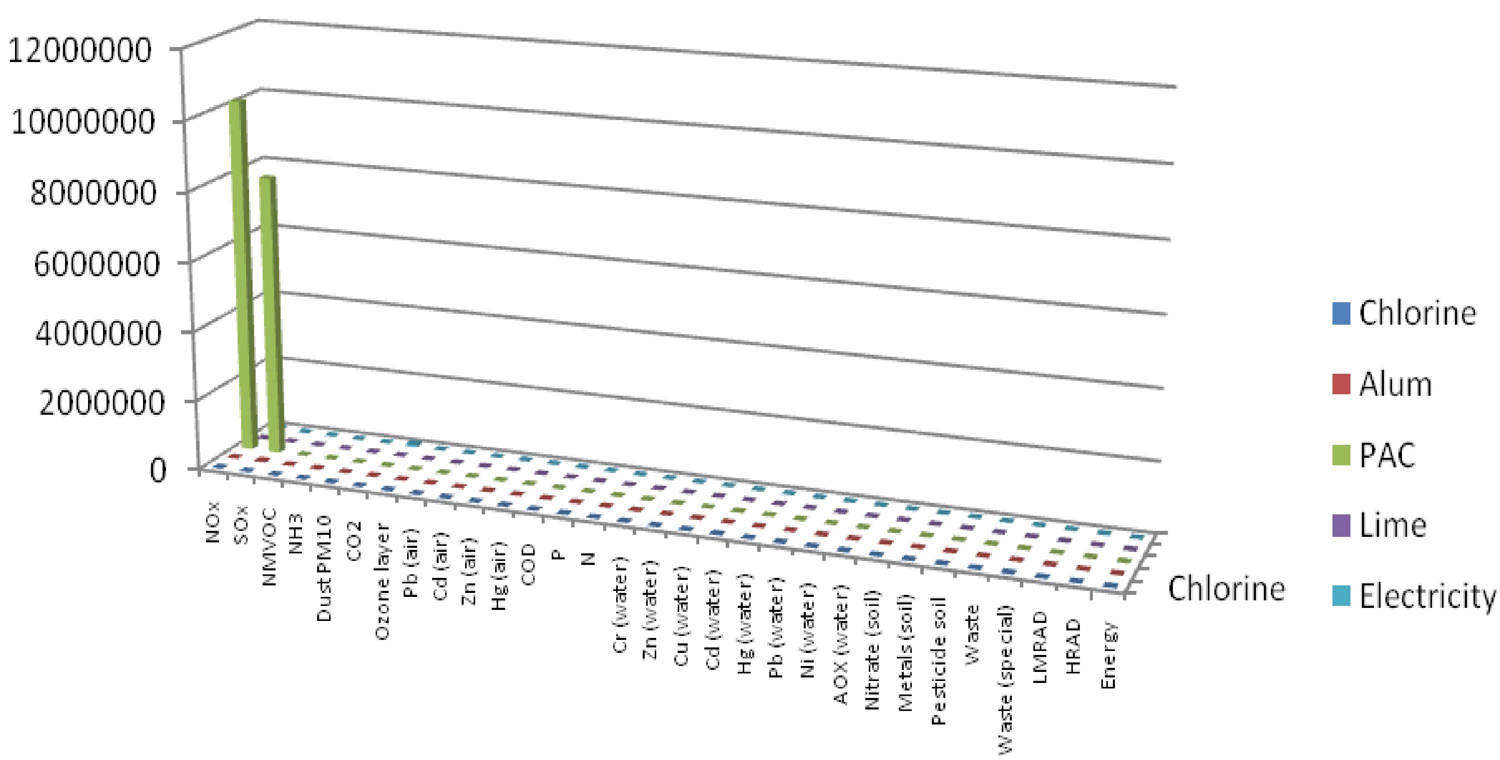

Figure 6. Weighting for impact categories contributed from construction substances and electricity.

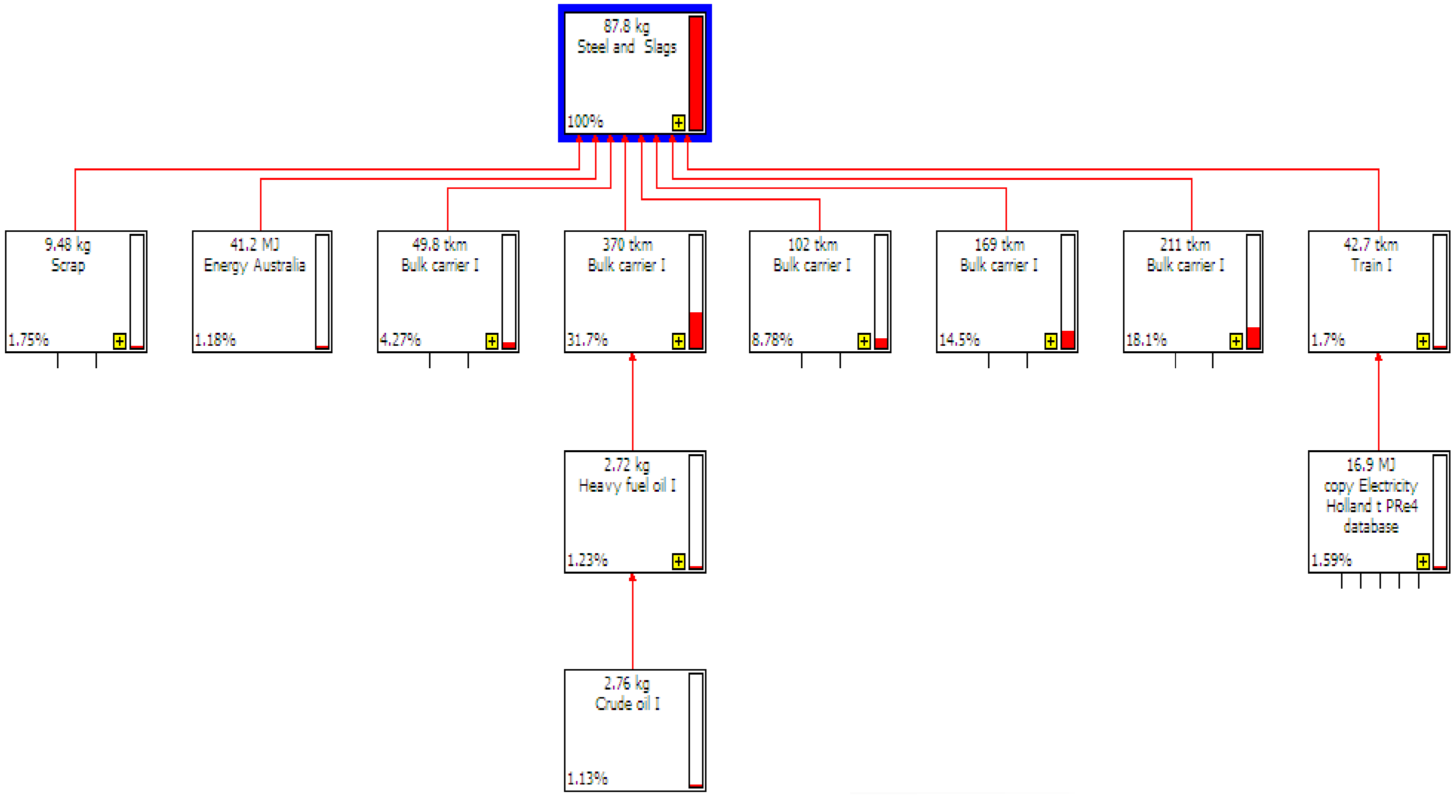

Figure 7. Network for processes in producing steel. Coloured bar in each box showed the contribution of NOx.

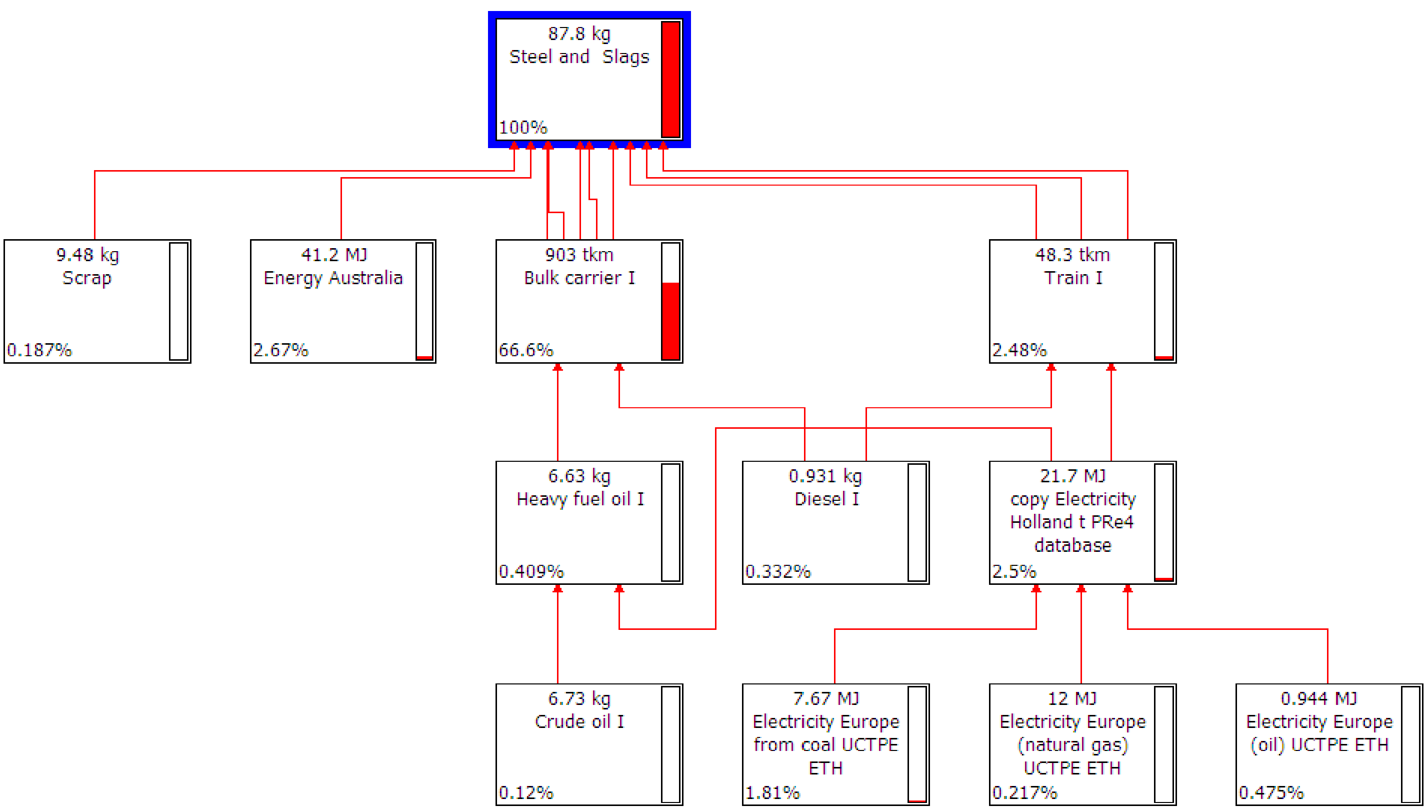

Figure 8. Network processes in producing steel. Coloured bar in each box showed the contribution of Sox.

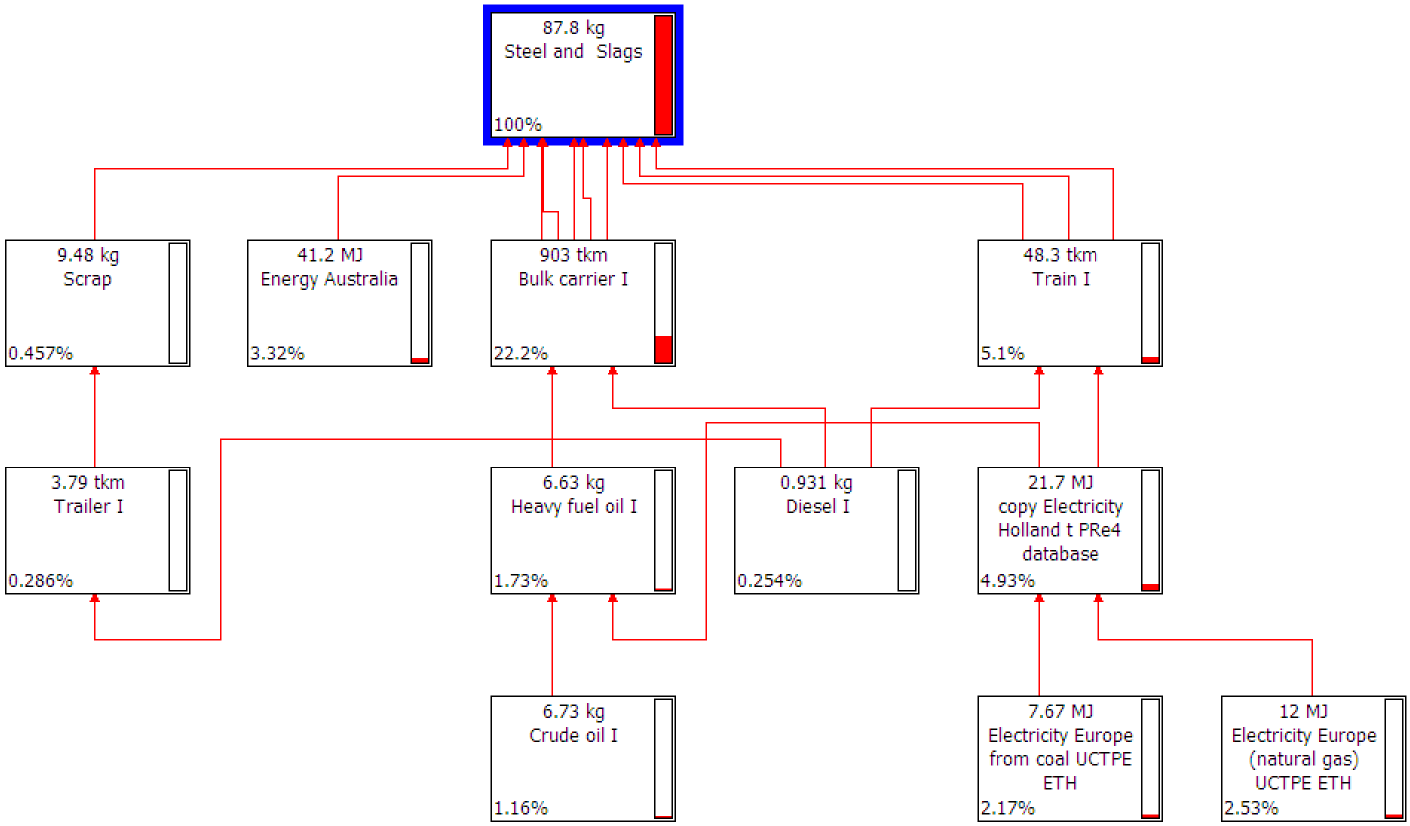

Figure 9. Network for processes in producing steel. Coloured bar in each box showed the contribution of CO_2.

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