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Evaluation of Environmental Impacts Resulting from Electric Power Generation and Steel Manufacturing using Coal as Fuel Source

Aniekan E. Ikpe[a,*], Owunna Ikechukwu[a], Ememobong Ikpe[b]

[a] *Department of Mechanical Engineering, Coventry University, Priory Street, CV15FB, West Midlands UK*
[b] *Department of Instrumentation and Control, Exxon Mobil Producing Nigeria, Eket, Akwa Ibom State, Nigeria*

Abstract

Our environment is extremely important to Intergovernmental Panel on Climate Change (1PCC) and other environmental protection agencies because it is a place where flora and fauna as well as the entire human population of the world exist. This report evaluates the environmental impacts resulting from the use of coal as a source of fuel for electricity power generation and coal as a fuel source to generate electricity for steel production process. GABI models were developed for each of the processes and used for the assessment and analysis to ensure compliance with ISO 14044 standards. After identifying the numerous forms of emission obtained from GABI software, the results were compared to determine the environmental impact and severity of each process. The result for Global Warming Potential (GWP) using coal as a fuel source for steel production accounted for 129.7029 Kg of CO_2 equivalence compared to 0.447267Kg of CO_2 equivalence result obtained as the GWP for using coal as fuel source for electric power generation. Similarly, the result obtained for acidification when coal is used as a fuel source for steel production recorded 0.360921Kg of SO4 equivalence compared to 1.4026Kg of SO_4 equivalence obtained as acidification value for using coal as fuel source for electric power generation. Furthermore, the result obtained for Eutrophication when coal is used as a source of fuel for steel production accounted for -1389.273e^{-4}Kg of phosphate equivalence compared to 2.2417Kg of phosphate equivalence obtained as the Eutrophication value for using coal as a source of fuel for electric power generation. From the aforementioned results, Eutrophication potential and Acidification potential would have lower environmental impacts for both processes whereas, the GWP for electric power generation was quite minimal while GWP for steel production using coal as a fuel source would have relatively high impact on the environment. For this reasons, it was concluded that electric power generation using coal as a source of fuel has less environmental impact whereas, steel production using coal as a source of fuel may not be environmentally friendly due to the high GWP obtained in this report.

Keywords: *Coal, Life Cycle Analysis, Environmental Impact, Power Generation, Steel Manufacturing.*

1. Introduction

Late 1960s to early 1970s is reported to be the beginning of environmental movement, in USA where Environmental Protection Agency was established. Consequently important environmental regulation were passed by the congress including water pollution control and clean air act to tackle the environmental threats in places like Cuyahoga river in flames and toxicant waste in canals [10]. However, with all the great efforts to eradicate environmental issues and preserve a developing economy, the challenges of recent times with regards to the environment is of complex nature which involves emissions to land ,water and air [3]. In recent times, the general awareness and knowledge has risen in the society about the influence of emission on the environment. Numerous solutions have been put forward to eliminate these unsustainable events in attempt to minimize or possibly eliminate environmental burden to suitable level. This form the basis of this report, which seeks to implement a technological and scientific approach in the

* Corresponding author.
E-mail: ikpeaniekan@gmail.com

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evaluation of the impact on environment of coal as carbon (low) fuel for electricity power generation and as source of fuel for steel production, to assess and prescribe some resolution to these processes in other to support and maintain a sustainable environment. Furthermore, GABI software is used to aid in this process. The GABI 5 educational software is a programmed data base system with the capability of assessing the environmental impacts of numerous ranges of industrial, engineering and scientific processes. The primary aim of this report is to evaluate the environmental impact when coal is used as a fuel source for power generation and the impact of using coal as a source of fuel for steel manufacturing. Cradle to gate life cycle analysis in both cases was carried out using GABI 5 educational software and the environmental impact such GWP, Acidification, Eutrophication etc for both processes were compared.

2. Life Cycle Assessment (LCA)

There are methods and tools often used for proper understand of activities associated with the environment, which is caused mainly by industries such as oil and gas mining etc and various environmental protection agencies have compelled industries to operate at levels that will have minimal impacts on the environment. One of the most important tools is the Life cycle analysis (LCA) which provides industries with the knowledge needed to regulate their operations in a manner that suits existing environmental standards [6,8]. Life cycle analysis is a method adopted globally by various companies with regards to natural gas and oil producing, energy management and natural resources related cases [12]. The main idea behind LCA is to provide technical information required by scientist and engineers to develop the strategies and designs that will lead to reduction in environmental impact [1,2,3]. LCA is a structured approach that can be used to evaluate and estimate environmental impacts, by attributing the case or impact to process/product life cycle. Significant LCA impact assessment on the environment includes carbon dioxide alongside other potential emissions, GWP, Eutrophication, Acidification, climate change, toxicological stresses on ecosystem and human health among a number of numerous factors [6,7]. Hence, LCA provisional technique or method used in tabulating emissions result from resources consumption and the environmental interaction with other elements related to product development stages such as extraction of raw materials, processing, manufacture, transportation, use and disposal is represented in Fig 1.

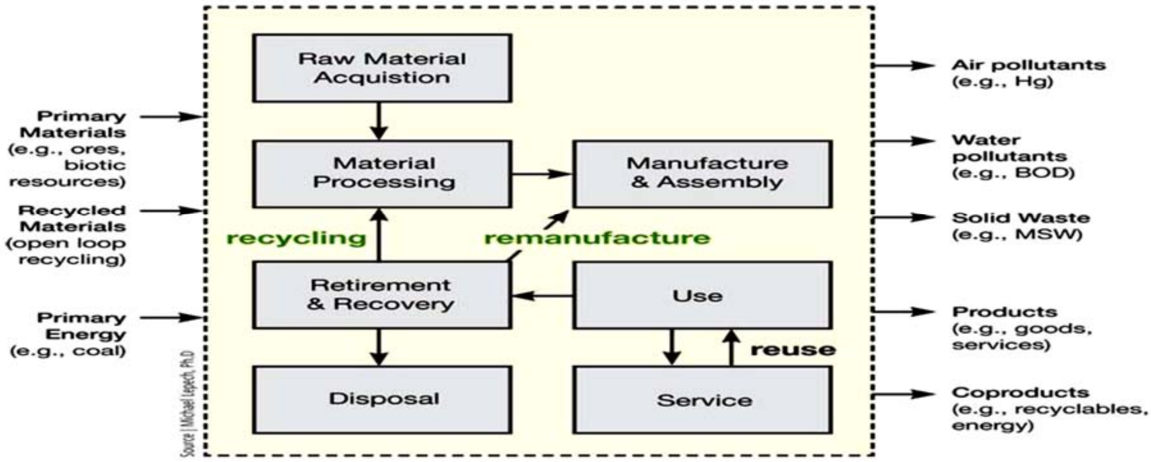

Fig 1. Product development Generic life cycle processes [5]

2.1. Life Cycle Assessment (LCA) based on ISO 14040 (2006)

Life cycle assessment is a method used for analysing the life cycle of a product from the raw material extraction to disposal stage in which the rate of environmental impact during the life cycle of the product is assessed and evaluated. Based on the ISO 14040 (2006), the system boundary for a typical LCA of a product is comprised of four categories which extend across the life cycle of the product as shown in Fig 2.

System boundary is a significant aspect in the life cycle assessment because it shows the processing product life from the raw material extraction stage to disposal. In this paper, Cradle to Gate life cycle will be used as the system boundary for coal as a fuel source for electric power generation and coal as a fuel source for steel production. Based on the ISO 14040 (2006), the first stage of life cycle assessment approach is goal and scope definition which involves defining the main function of the process to be carried out and based on that, other categories of the LCA can be addressed respectively. The following section provides detailed content of the goal and scope definition of the process.

2.2. Goal definition

The main goal of this paper is to examine the environmental impacts of using coal as a fuel for electric power generation and to show the percentage of emissions and wastes from the raw material till production. Also, to compare the results obtained from the process of using coal as fuel for electric power generation to the process of using coal as fuel for steel production in order to determine which process is more environmentally friendly.

2.3. Scope definition

The scope of the study describes the process system characteristics such as function of the process system, the functional unit, description of the system, system boundaries, impact categories and assessment process, assumptions of data, limitations and data quality requirements which is illustrated in the following sections.

2.4. Functional of the process system

This study is aimed at assessing the environmental impacts resulting from the process of using coal as a fuel for electric power generation.

2.5. Functional unit

In this part, 1 KWh of electricity was used for life cycle assessment by using GABI 5 educational model.

2.6. Description of the system

GABI 5 software is used to evaluate the life cycle assessment of electric power generation by using coal. All the process input data in the GABI 5 model and majority of inputs in the process were hard coal.

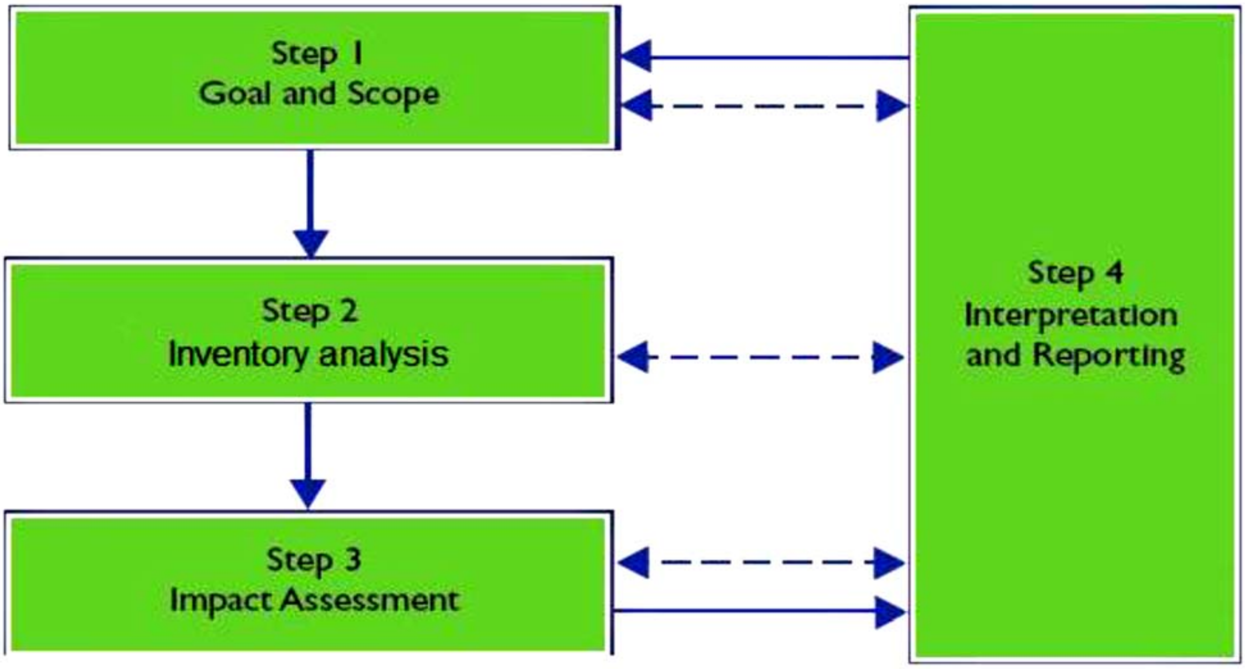

Fig 2. Life cycle assessment steps [6]

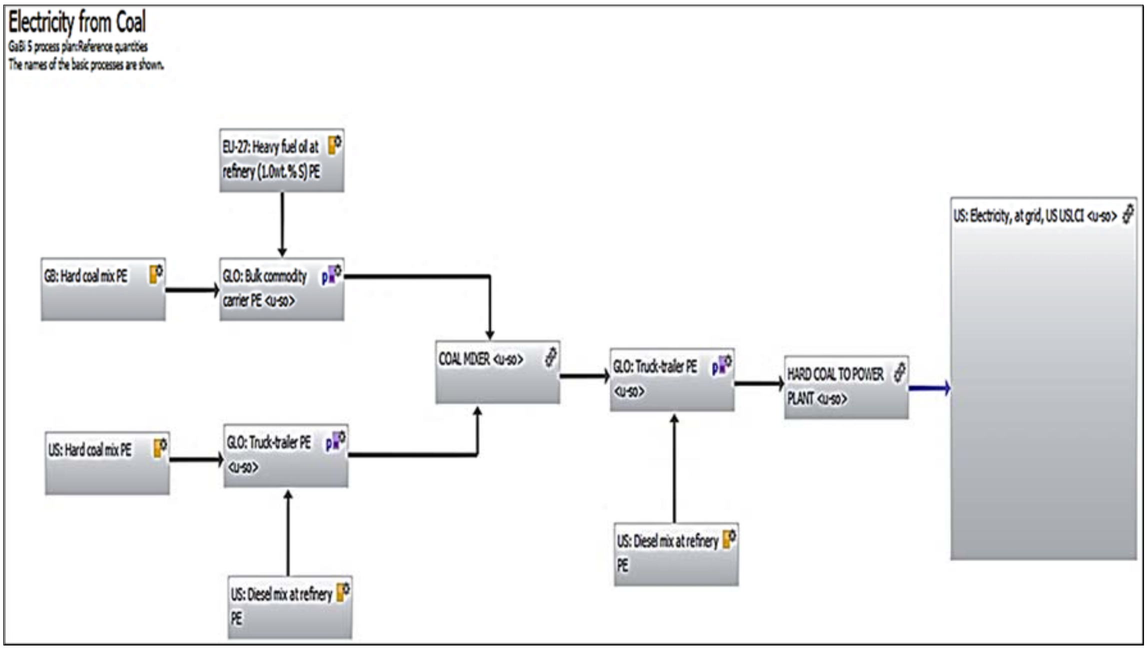

Fig 3. GABI Model process of Electric power generation using coal as fuel Source

3. Methodology

The processes involved in Electric Power Generation and Steel Manufacturing using Coal as Fuel Source was adequately generated using GABI model. The model was simulated in GABI software which generated a report that served as a tool used in evaluating the environmental impacts often experienced in real life scenario.

3.1. GABI Model

GABI software is a life cycle assessment tool that is used for calculating the rate of environmental impact during the life cycle of a product based on the life cycle assessment steps. The first step of LCA methods was defined for both processes where coal was used as fuel source for generating electric power and coal used as fuel for steel production. Putting all the requirements in the GABI 5 education software which already contains majority of the process input and linking each of the processes according to how they are carried out in real life case scenarios, the GABI 5 education software evaluated the input and connections and presented the final results based on the inputs data. The results were analysed and compared based on the influence of a particular emission when released into the environment. The process input into GABI software and output result in terms of environmental impacts for using coal as a fuel source for both electric power generation and steel production are described in the following sections;

3.2. GABI model for electricity generation using coal

As illustrated in Fig 3, in the GABI model for electricity generation using coal as fuel source, it was assumed that the United States of America was the country where the power plant is sited. The source of hard coal was from two locations, one was indigenous while the other was assumed to be imported from Great Britain. It is known that the major exporter of coal to the United States is Columbia, accounting for about 70% of U.S. coal import in 2012 [9]. The Coal from the United States (U.S) was transported by diesel powered trucks, while that from Great Britain was transported via heavy oil powered bulk commodity carriers to the coal mixer located in the U.S. From the coal mixer, the blended coal was transported by trailer trucks to the power plant where it is combusted to generate electricity via Rankine Cycle system to generate electricity [4] which is finally distributed to the U.S electricity grid. The results obtained from GABI model for power generation using coal as a fuel source is presented in Table 1, Fig 4 and

Table 1. LCA input and output results obtained from using coal for electric power generation

Inputs for Electricity Generation from Coal	
Flows	87.3
Resources	87.3
Outputs for Electricity Generation from Coal	
Flows	85.3
Deposited goods	10.8
Emission to air	1.93
Emission to fresh water	72.2
Emission to sea water	0.443
Emission to agricultural soil	2.95E-007
Emission to industrial soil	8.62E-007

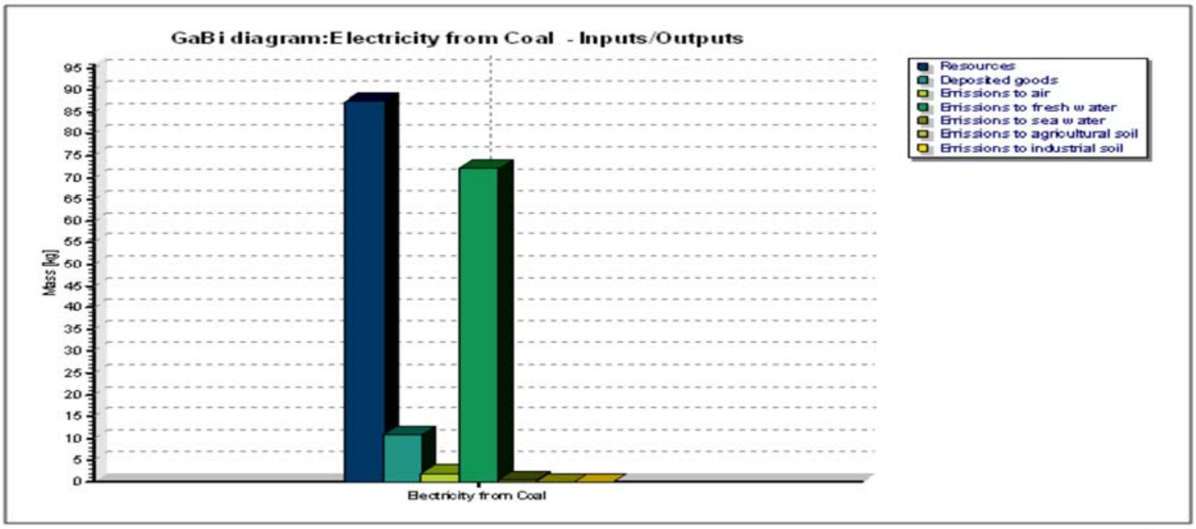

Fig 4. Comparison of LCA results for input and output obtained from Electricity power generation using Coal

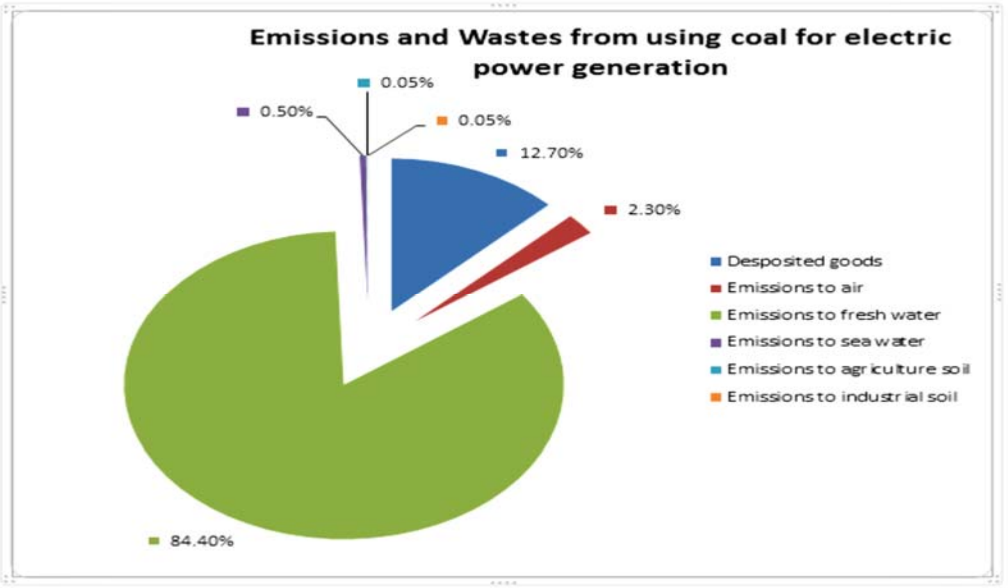

Fig 5. Emissions and wastes by using coal for electric power generation

As shown in Fig 5, it can be observed that majority of emissions released to fresh water was about 84.40%. The second part which was about 12.7% was deposited goods. However, the emissions to air is the third part of the LCA outputs which was about 2.3% of total Emissions and wastes. The remaining percentage was 0.6 % which is the emissions to the sea water, agriculture soil and industrial soil. From the result in Table 1, emission to fresh water accounted for the highest emission (72.2Kg) when coal is used as a fuel for electric power generation. Furthermore, the value obtained for environmental impact for using coal as a source of fuel for electric power generation which comes from the raw material extraction stage, processing and electric power generation process are presented in Fig 6, 7 and 8.

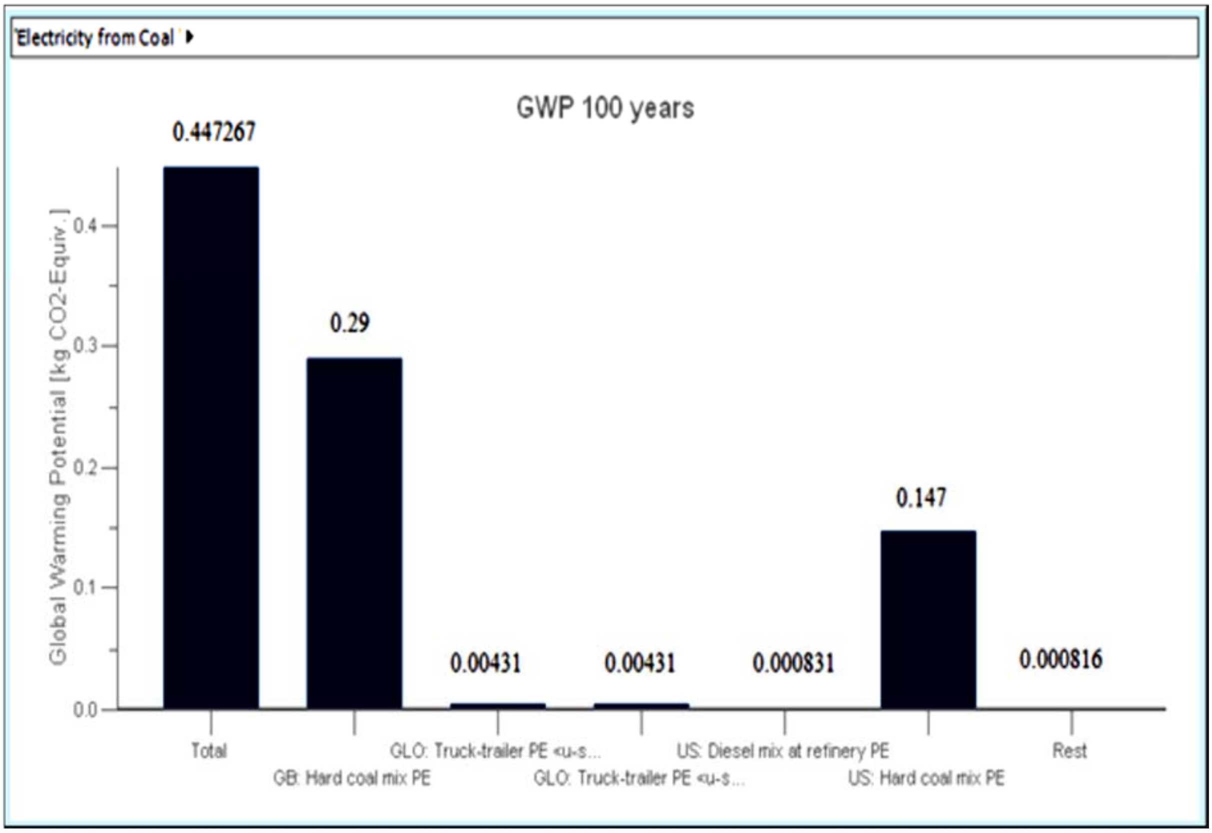

Fig 6. Global warming potential of electricity from coal

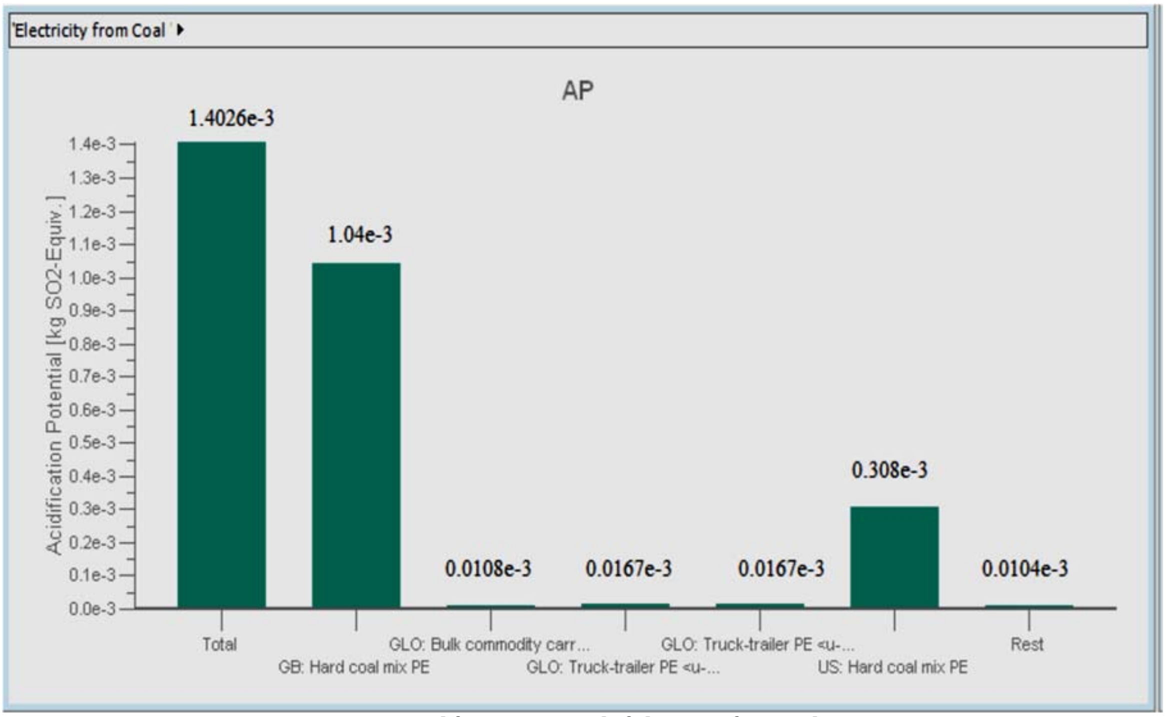

Fig 7. Acidification potential of electricity from coal

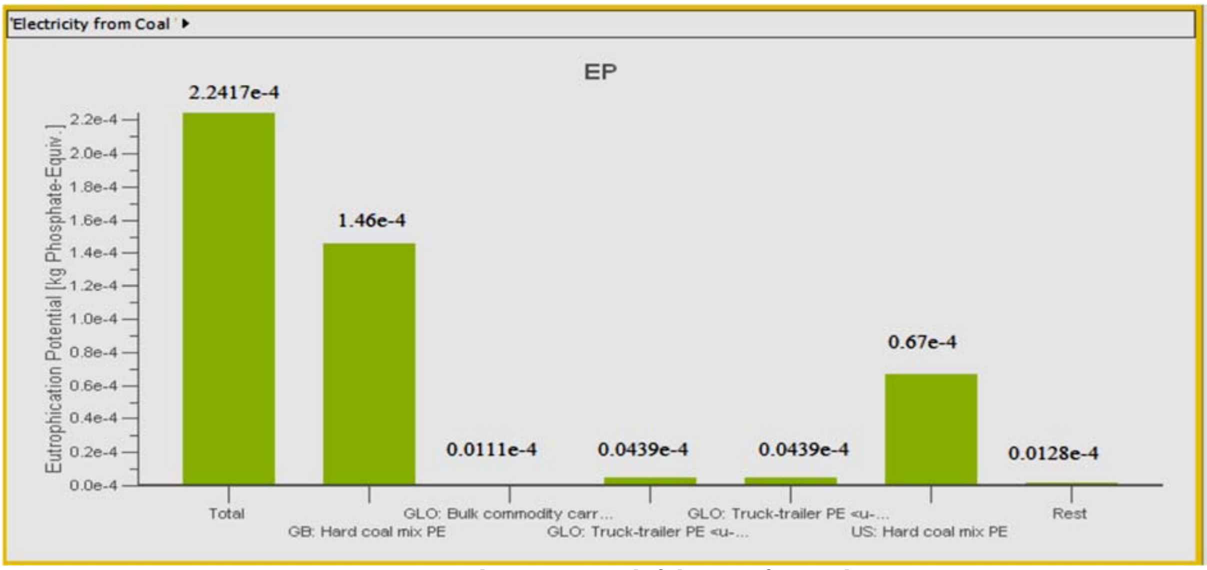

Fig 8. Eutrophication potential of electricity from coal

As shown in Fig 6, 7, and 8, it can be observed that the total emissions to air in terms of GWP from using coal as a fuel source for electric power generation was 0,447267Kg of CO_2 Equivalence. However, the total Acidification potential (AP) from this process released to air and water was 1.4026e-3 Kg SO_4 equivalence. Also the total Eutrophication potential (EP) to water was 2.2417e^{-4}Kg Phosphate equivalent. Moreover, it can be observed that the highest emissions for all environmental impact resulted from using GB: Hard Coal mix PE and US: Hard Coal mix PE which were 0.29 and 0.147 Kg of CO_2 equivalent for Global Warming Potential (GWP 100 years), 1.04e^{-4} and 0.308e^{-3}Kg SO_4 equivalent for Acidification potential (AP), and also 1.46e^{-4} and 0.67e^{-4}Kg Phosphate equivalent for Eutrophication potential (EP).

3.3. GABI Model for steel production using coal as fuel

As illustrated in Fig 9, in the GABI model for steel production using coal as fuel source, the United States was also assumed to be the location where the steel manufacturing facility is sited. The assumption was due to similar reasons given for that of electric power generation using coal as fuel. The hard coal source was from USA and Great Britain. The coal from USA was transported to a mixing station using diesel powered trucks, while the coal from Great Britain was transported to the coal mixing station located in USA using a bulk commodity carrier. From the mixer, the mixed coal was transported with diesel powered truck to the steel plant. Steel billets were produced at the steel plant and the raw materials used were lime stone, cast iron, oxygen and desalinated water.

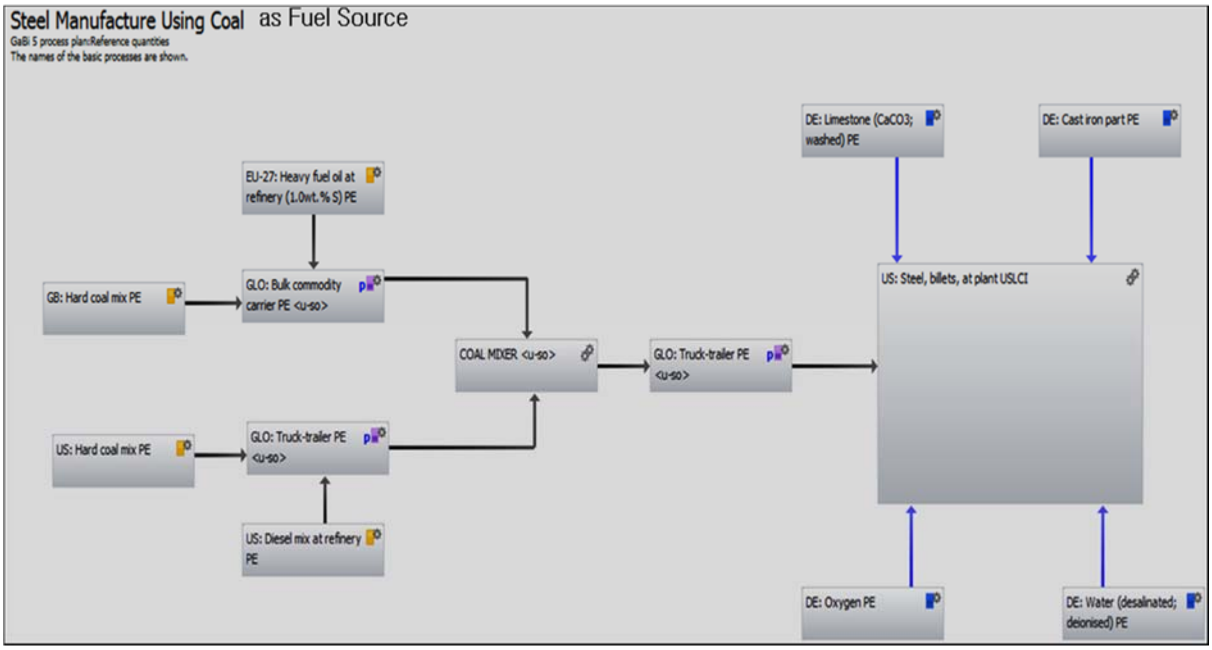

Fig 9. Steel Production process using coal as a source of fuel

The result of using coal for steel production from GABI 5 educational software is presented in Table 2, Fig 10 and 11

Table 2. LCA input and output results that come from the Steel manufacturing using Coal as a raw material

Inputs for Steel Manufacturing from Coal	
Flows	5.6E003
Resources	5.6E003
Outputs for Steel Manufacturing from Coal	
Flows	5.56E003
Deposited goods	24.4
Emission to air	212
Emission to fresh water	5.31E003
Emission to sea water	6.66
Emission to agricultural soil	2.35E-006
Emission to industrial soil	4.08E-005

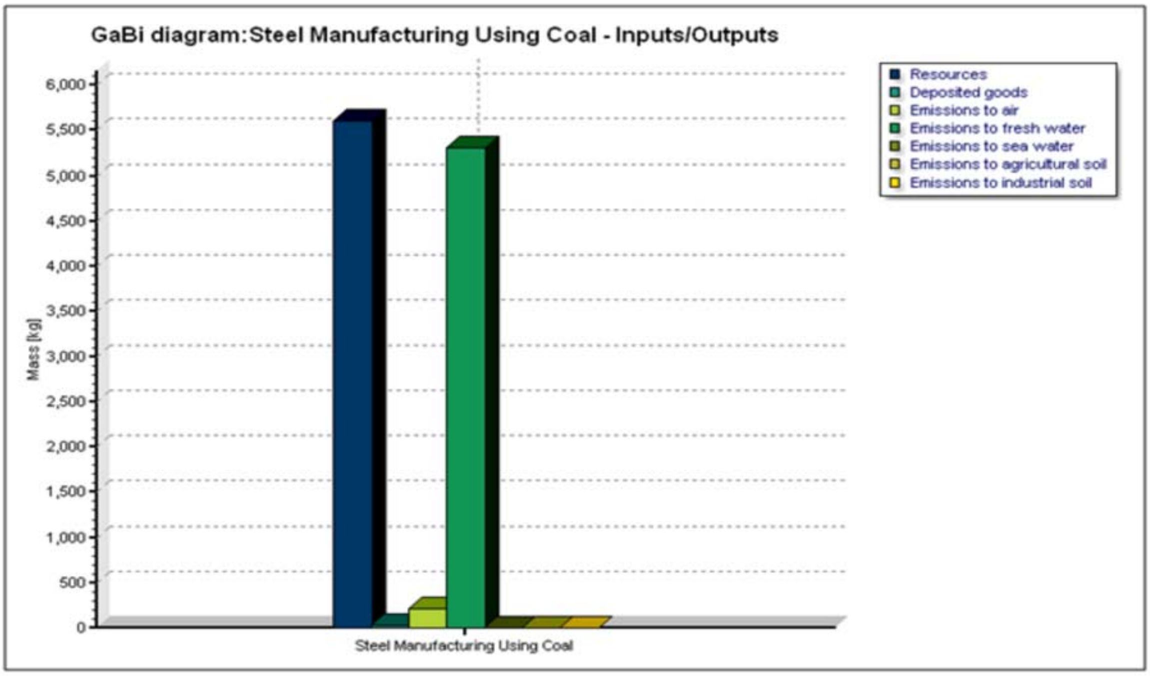

Fig 10. Comparison of LCA results for input and output obtained from steel manufacturing using coal a Fuel Source

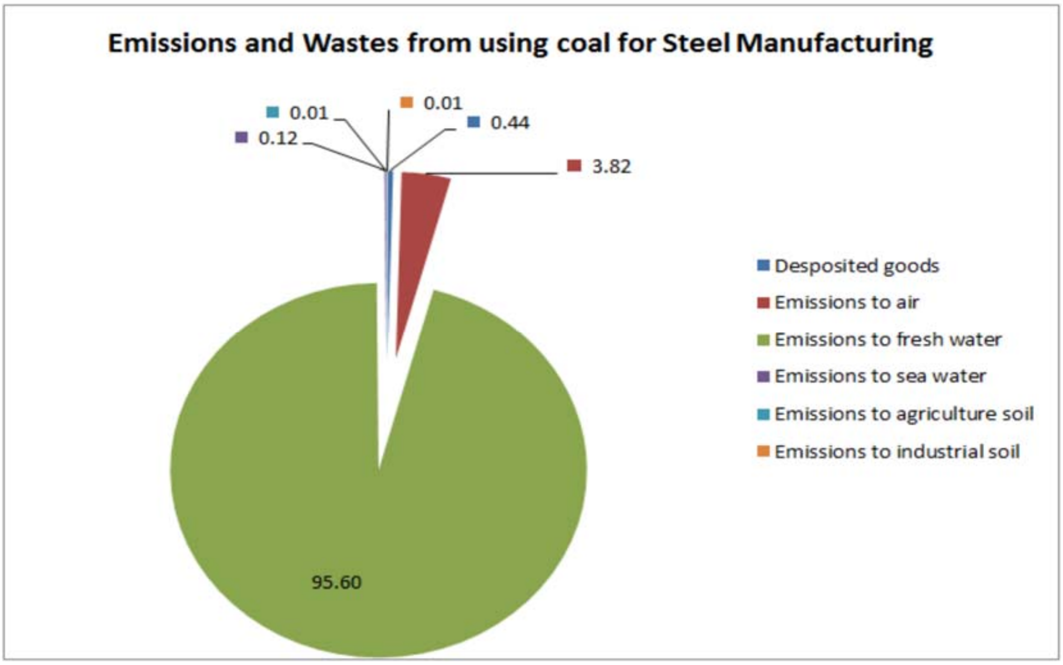

Fig 11. Percentages of Emissions to air, water, and soil as a result of steel manufacturing using coal Fuel Source

As shown in Fig 11, it can be observed that majority of emission discharged to fresh water accounted for about 95.6 %. The second part which was about 3.82 % is the emission to air. However, emissions to sea water, agriculture soil, industrial soil, and deposited goods accounted for 0.12%, 0.1%, 0.1%, and 0.44% respectively. According to the result from Table 2, emission to air accounted for the highest emission (212Kg) when coal is used as a fuel for steel production. Further, the total value of environmental impacts obtained from using coal as fuel source for electric power generation and using the electricity for steel manufacturing process from the raw material extraction stage, manufacturing process, and production process are presented in Fig 12, 13 and 14.

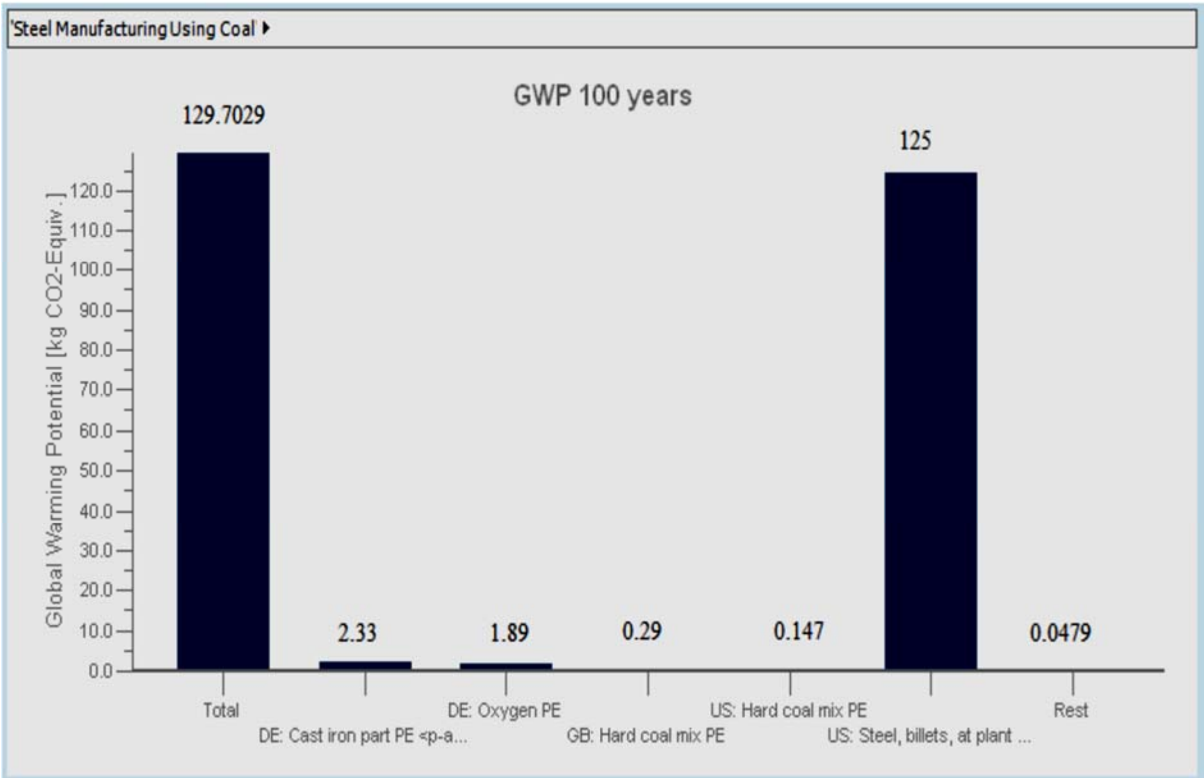

Fig 12. Global warming potential of steel production by using coal as a raw material

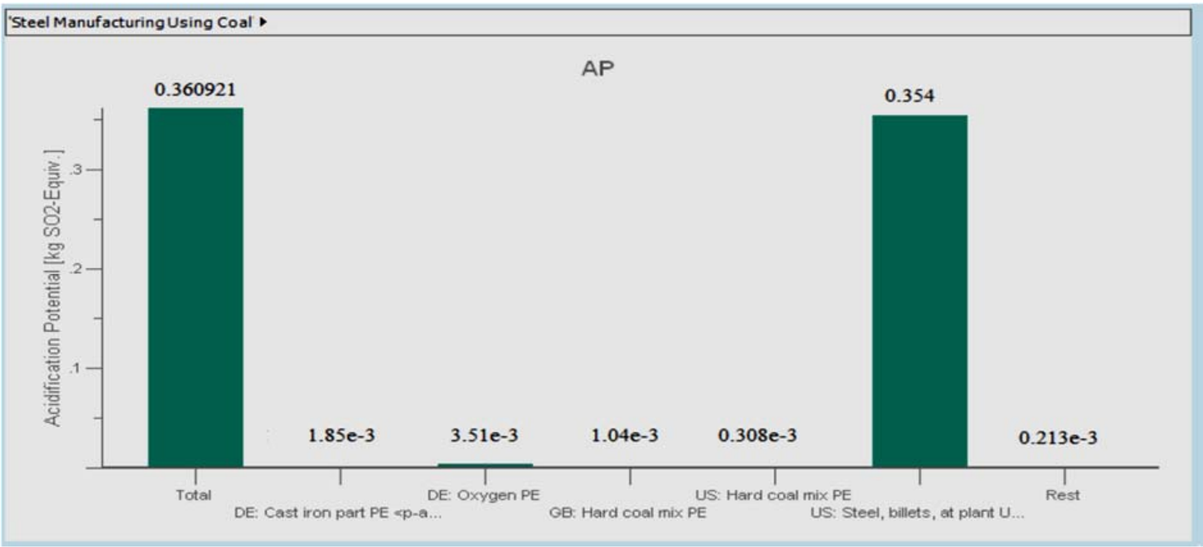

Fig 13. Acidification potential of steel production by using coal as a raw material

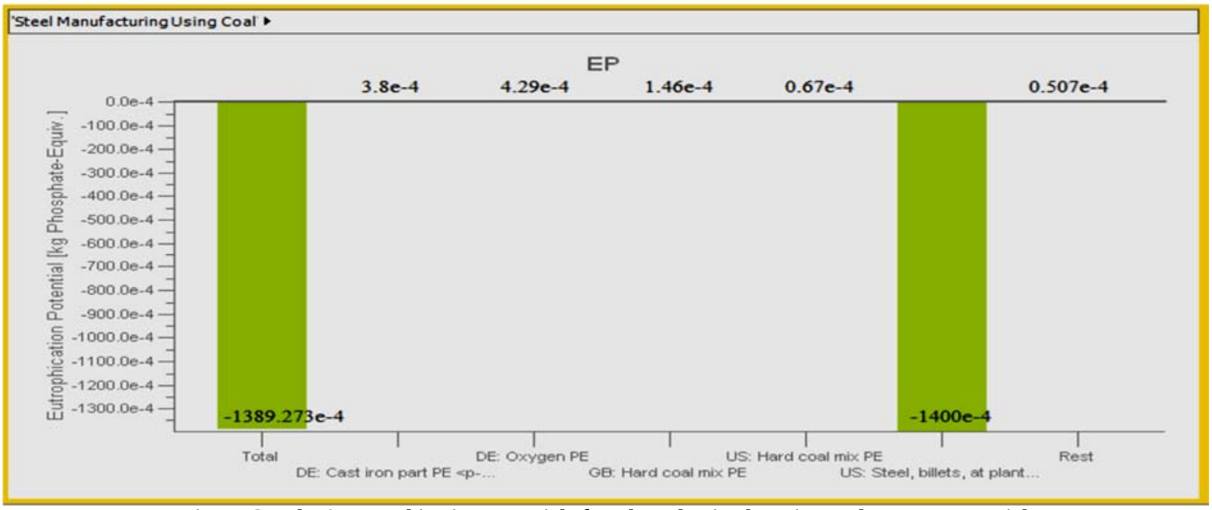

Fig 14. Graph 10 Eutrophication potential of steel production by using coal as a raw material

From Fig. 12, 13 and 14, it can be observed that the total emissions to air obtained by using coal as a source of fuel for steel production which accounted for Global Warming Potential (GWP for 100 years) of 129.7029Kg of CO_2 Equivalence. However, the total Acidification potential (AP) from the process released over 0.360921Kg of SO_4 equivalence to air and water. Also, the total Eutrophication potential (EP) on water accounted for about -1389.273e^{-4} Kg of Phosphate equivalence. It can be seen that the highest emissions for all environmental impact resulted from using steel billet manufacturing plant which accounted for about 125Kg of CO_2 equivalence of Global Warming Potential (GWP 100 years), 0.354Kg of SO_4 equivalence of Acidification potential (AP) and -1400e^{-3} Kg of Phosphate equivalent for Eutrophication Potential (EP).

4. Results and Discussion

The LCA results for processing of using coal as a source of fuel for electric power generation and steel production obtained from GABI 5 educational software is summarized in Table 3. From Table 3, it can be seen that the overall environmental impact obtained when coal is used as a fuel source for steel production process is higher than the overall environmental impact of electricity generation process using coal as a fuel source because after generating electricity from coal, the electricity is further used throughout the steel manufacturing process and the steel manufacturing process consumes and may even use up the entire electricity generated from coal if enough quantity of coal is not available for constant feeding into the combustor reactor. Although the the result of acidification potential and Eutrophication potential from steel production is lower than that of electric power generation, the values are quite minimal considering the period of 100 years which the LCA of both processes were conducted for. Furthermore, based on the GABI 5 software results, it can be seen that the total emissions and wastes from steel production was higher than that of electric power generation because the result of Global Warming Potential (GWP for 100 years) from steel production accounted for 129.7029Kg of CO_2 equivalence which was much higher than the result from electric power generation which accounted for 0.447267Kg of CO_2 Equivalence. However, the result for both Acidification potential (AP) and Eutrophication potential for steel production accounted for 0.360921Kg of SO4 equivalence and -1389.273e^{-4} Kg of Phosphate equivalence which were lower than the results from electric power generation which accounted for 1.4026e^{-3} Kg of SO_4 equivalence and 2.2417e^{-4}Kg of Phosphate equivalence respectively.

Table 3. Comparison of GABI results using Coal as a Source of Fuel for electric power generation and steel production

Process	Global Warming (CO_2-Kg)	Acidification (SO_4-Kg)	Eutrophication (Phosphate-Kg)
Electric Power Generation using Coal as Fuel source.	0.447267	1.4026	2.2417
Steel Production using Coal as a source of Fuel.	129.7049	0.360921	$-1389.273e^{-4}$

4.1. Embodied Energy

Embodied energy is related to carbon emissions based on the primary energy used to power the process [11]. Embodied energy is the total energy inputs consumed throughout a products life cycle. It involves the energy used in raw material extraction, transportation to site, processing, manufacturing etc. The embodied energy for steel production was expected to be higher because the first process for both steel and electricity are similar and the steel manufacturing plant uses large amount of energy to process the raw materials required for steel production.

4.2. Effect of Environmental Impacts

Each impact identified had certain effects on the environment, some of which are long term effects as it takes several years to be felt while some are short term. In any case, the impacts have negative effects on the environment depending on the severity. Impacts identified and their effects are as follows;

4.3. Emission to Air-Global Warming

Climate change and global warming describes the rise in earth's average temperature and the effects that occurs as a result of this phenomenon. The effect of global warming to the environment such includes;

1. Climate change
2. Migration and/or ecosystem extinction (fauna and flora)
3. Results in loss of coral reef
4. Hurricanes with high intensity.

4.4. Emission to Air-Acidification

This can be described as a reduction in PH. levels caused by acid rain, which occurs as a result of the combustion of fossil fuels which contain acids of sulphur and nitric acids that gives rise to acid rain. The effect of acidification to the environment can result in;

1. Results in cardiovascular diseases and problems with the respiratory system of humans and other health issues.
2. Damages to tissues of plants and death of sea animals as a result of acid rain.
3. Redundant plant growth as a result of effects on the soil.
4. Visibility impairment.

4.5. Emission to Water-Eutrophication

This can be described as a process whereby high concentrations of high level toxic nutrients particularly phosphates and nitrates absorbed by a body of water. These toxic nutrients particularly increase or lead to rapid algae growth. When the algae eventually die and are decayed, organic matter at high levels and the organisms that have decayed drain oxygen available in the water body, thereby, causing deaths of aquatic organism like fish. The effects of Eutrophication on the environment can result in the following environmental impacts;

1. Reduction in aquatic life and species
2. Reduction in quality of water
3. Increase in water turbidity
4. Formation of water anoxic conditions
5. Reduces lake lifespan and increases sedimentation

5. Conclusion

In this report, the theory of LCA, the stages of LCA and the system boundaries of product life cycle based on the ISO 14040 were reviewed. The processing of coal as a source of fuel for electric power generation and steel production where illustrated in a model created with GABI 5 educational software. Based on LCA framework and GABI 5 educational model, both processes were analyzed to find the rate of emissions into the environment. The effects of GWP and Acidification and Eutrophication on the environment were explained. Due to the results from both processes, it was concluded that the effect (in terms of environmental impact) of steel production using coal as a fuel source is higher than the effect of electric power generation using coal as fuel source. Hence, for the interests of the environment, LCA as shown in this paper should always be carried out before embarking on any engineering, industrial, environmental and scientific exploration.

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