World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:8, No:4, 2014

A Life Cycle Assessment (LCA) of Aluminum Production Process

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Abstract**—**The production of aluminum alloys and ingots – starting from the processing of alumina to aluminum, and the final cast product – was studied using a Life Cycle Assessment (LCA) approach. The studied aluminum supply chain consisted of a carbon plant, a reduction plant, a casting plant, and a power plant. In the LCA model, the environmental loads of the different plants for the production of 1 ton of aluminum metal were investigated. The impact of the aluminum production was assessed in eight impact categories. The results showed that for all of the impact categories the power plant had the highest impact only in the cases of Human Toxicity Potential (HTP) the reduction plant had the highest impact and in the Marine Aquatic Eco-Toxicity Potential (MAETP) the carbon plant had the highest impact. Furthermore, the impact of the carbon plant and the reduction plant combined was almost the same as the impact of the power plant in the case of the Acidification Potential (AP). The carbon plant had a positive impact on the environment when it come to the Eutrophication Potential (EP) due to the production of clean water in the process. The natural gas based power plant used in the case study had 8.4 times less negative impact on the environment when compared to the heavy fuel based power plant and 10.7 times less negative impact when compared to the hard coal based power plant.

Keywords**—**Life cycle assessment, aluminum production, Supply chain.

I. Introduction

ALUMINUM is the third most abundant element on earth, making 8% of the earth's crust [1]. Aluminum's high strength-to-weight ratio and the ease to work with have led to its increased use in the manufacturing of aircrafts, cars, and trains. Aluminum's corrosion resistance and excellent thermal properties have led to its use in heat exchange systems. Its flexibility has allowed it to be used for packaging, beverage containers and in electronics manufacturing. What makes aluminum further attractive to many industries is its ability to be recycled without losing its metal quality or properties [1]. Bauxite is the original material from which aluminum is produced. Bauxite is first converted to alumina or aluminum oxide which is the raw material from which aluminum metal is produced. During the production process of primary aluminum wastes such as red mud also high levels of atmospheric emissions such as carbon dioxide will be produced. According to the International Energy Agency (IEA) 1% of the annual GHG emissions is caused by aluminum production [2]. Therefore, various measures should be taken into consideration to achieve better use of resources and energy in order to reduce the negative impact of aluminum production on the environment [2].

During the last three decades the production of primary aluminum in the Gulf Cooperation Council (GCC) countries has steadily increased. Bahrain and United Arab Emirates (UAE) were the first countries in the region to build aluminum plants followed by Oman, Kingdom of Saudi Arabia (KSA), Qatar and Kuwait [3]. Nowadays, the GCC region is considered to be a key aluminum producer as it accounts for almost 13% of the world's total production [4]. In this paper the production of aluminum in the GCC region will be studied using a Life Cycle Assessment (LCA) approach. LCA is an effective approach used to analyze and assess the environmental impacts associated with a defined production activity. In a life Cycle Assessment study used and produced materials should be identified and quantified in order to assess the impact on the environment, and hence for making progress in cleaner production [5]. The environmental impacts of aluminum production have been studied by several researchers using the LCA approach [6]. However, no case studies regarding the production of aluminum in the GCC countries have been published. Since large regional differences in technology and energy sources exist among the aluminum industry a life cycle assessment model was developed using GaBi5 software to calculate absolute emissions from the production of primary foundry aluminum alloys and extrusion ingots. The studied aluminum supply chain consisted of a carbon plant, a reduction plant, a casting plant, and a power plant. In the LCA model, the environmental loads of the different plants for the production of 1 ton of aluminum metal were investigated. The impact of the aluminum production was assessed in 8 impact categories.

II. The Case Study

The aluminum production plant includes a carbon plant, a reduction plant (smelter), a casting plant, and a power plant. Alumina is imported mainly from South America and/or Australia. Once brought to aluminum facility, alumina is sent to the reduction plant to be processed into liquid aluminum utilizing carbon anodes manufactured in the carbon plant. The liquid aluminum is then sent to the casting plant which converts the liquid aluminum into primary foundry alloys and extrusion ingots. The electrical energy for the carbon plant, the reduction plant and the casting plant is supplied by a gas fired power plant located in the aluminum plant itself.

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A. Carbon Plant

In the carbon plant the carbon anodes which will be used in the reduction plant are manufactured. The plant consists of a paste plant and an anode baking plant [5]. In the paste plant raw materials (petroleum coke, pitch, and recycled butts) which are used to manufacture the carbon anodes are prepared. Different quantities of crushed and screened coke and butts are mixed with pitch at a temperature about 180°C [5]. Then the mixture is cooled down to a 40°C temperature by water sprays forming the green paste. The green paste is then formed in the shape of blocks making the "green" anodes.

In the anode baking plant the green anodes are baked in baking furnaces at a temperature of 1250°C. At such high temperature the pitch will be partially carbonized and evaporated making the dense, hard anode block. After air-cooling in the furnace, the baked anodes are cleaned from any granular loose material. Rejected anodes will be crushed and recycled in the paste plant. All air emissions from the carbon plant are collected and treated in a dry scrubber system. Fig. 1 shows a general scheme of the carbon plant.

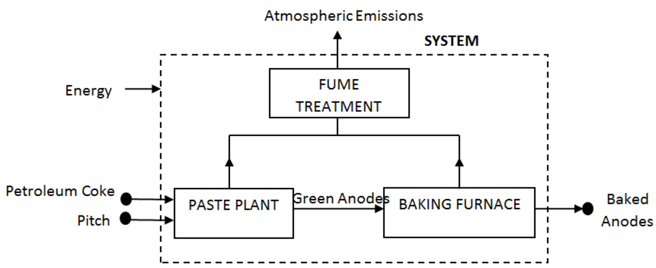

Fig. 1 General scheme of the carbon plant

B. Reduction Plant

The actual aluminum production takes place in the reduction plant. Aluminum is produced by the Hall-Héroult electrolysis process, using the Norsk Hydro reduction technology (HAL 275). This process happens in large steel containers called pots or cells. The Reduction Plant consists of two long parallel buildings approximately 1,150 m long which are called potrooms. Each potroom houses two rows of electrolytic cells known as potlines. Each potline consists of 176 cells giving a total of 352 cells in each potroom [5].

Electricity will flow through the electrolyte from the anode to the cathode, after that it will flow to the anode in the adjacent pot. The white alumina powder (Al_2O_3), is added automatically to the electrolyte which consists principally of cryolite (Na_3AlF_6) and aluminum fluoride (AlF_3). Then molten aluminum is formed by dissolving alumina in the electrolyte. Below the surface of the electrolyte aluminum will form and accumulate at the cathode. The reduction of alumina (Al_2O_3) occurs according to the following equation:

$$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$$

The required carbon in the reaction will be given by the carbon anode. During this process the carbon anodes will be consumed by oxygen and eventually need to be replaced approximately every 3-4 weeks. Produced molten aluminum is collected from the pots and transported to the cast house by special tapping vehicles. All air emissions from the reduction plant are collected and treated in dry and wet scrubbers. In addition fresh aluminum is mixed with fumes produced from the pots to produce fluoride enriched alumina. Fig. 2 shows a general scheme of the reduction plant.

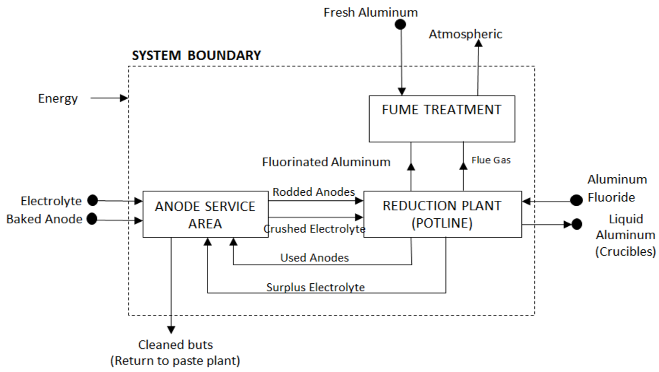

Fig. 2 General scheme of the reduction plant (smelters)

C. Cast House

In the cast house which is the last plant in the process molten aluminum produced from the reduction plant will be converted into extrusion ingots (EI) and foundry alloys (FA), which will be cast as T-bars, standard ingots and mold ingots.

Before casting, specific impurities should be removed from produced molten aluminum this is done in fluxing stations. Fluxing is carried out using aluminum fluoride and argon. Waste called dross will be produced from the fluxing process which will be recycled elsewhere in the plant. To remove moisture some solid aluminum and alloying materials are fed into gas-fired furnaces. The furnaces are then charged with the molten aluminum from the fluxing area. The surface of the metal is then skimmed to remove further dross. The molten metal is then cast into foundry alloys and extrusion ingots. After the casting process aluminum is packed and stored for shipment. Fig. 3 shows a general scheme of the cast house.

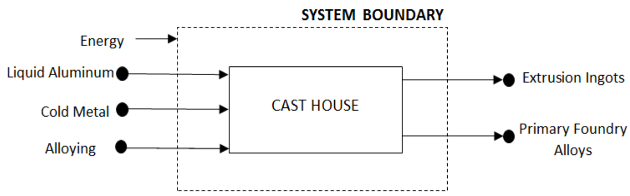

Fig. 3 General scheme of the cast house

III. LCA Study of the Aluminum Supply Chain

Environmental impacts associated with the production of aluminum were evaluated using the LCA method. Emissions to air and water, produced waste, and used energy were estimated for the production of 1 ton of aluminum.

A. Goal and Scope Definition

The overall objectives of the LCA study were to:

- Demonstrate how the LCA method could be a powerful tool in assessing the environmental impacts of a defined system.
- Understand the aluminum production process and quantitatively display where improvements could be implemented in order to reduce the negative environmental impacts.

The scope of the LCA study (system boundary) is defined as follows:

- The system starts with the receiving of alumina and ends with aluminum primary foundry alloys and extrusion ingots as the product.
- The main processes are: carbon plant, reduction plant, and casting plant.
- The power plant which supplies energy to the supply chain is included in each plant.
- Transportation within the supply chain is included in the system.

The modes of transportation within the supply chain are: (i) the delivery of alumina from outside to the refinery by ship. According to the case study most of the imported alumina comes from either South Africa or South America the approximate distance from both areas were estimated and used in the LCA study; and (ii) the delivery of molten aluminum to the casting plant by special tapping trucks from the reduction plant. It was found that the maximum carrying capacity of the used trucks is 8 tons. The travel distance between the reduction plant and the casting plant is approximately 2 km. 2000 tons/day are transferred on this path which makes 250 trucks or 250 times of delivery. Based on the scope of the LCA, the supply chain model is shown in Figs. 4 and 5 show its representation in GaBi5. The model represents a ''cradle-to-gate'' which means the end use of aluminum is not included in the LCA study. Life cycle assessment of the end aluminum product will require a separate study.

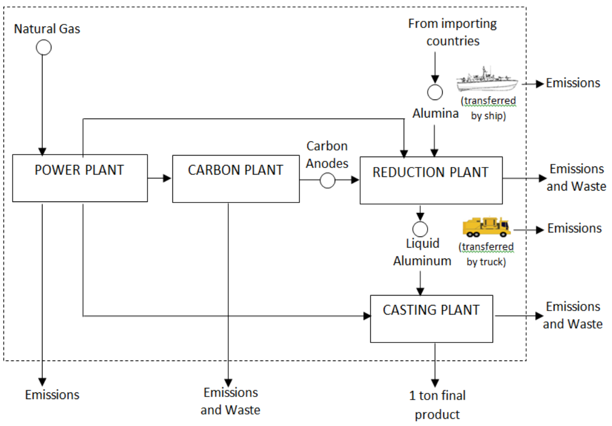

Fig. 4 LCA model of the aluminum supply chain

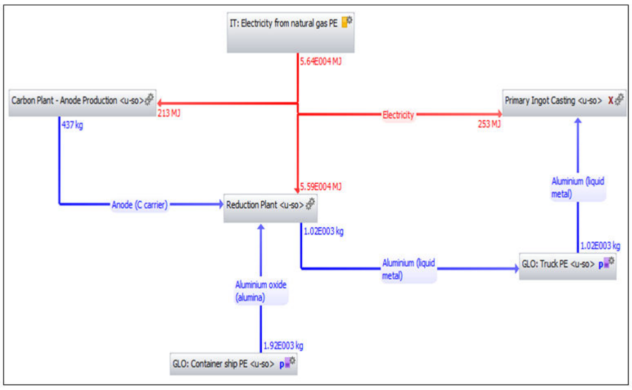

Fig. 5 GaBi 5 model for the aluminum supply chain

TABLE I
LIFE CYCLE INVENTORY FOR SOME OF THE MAIN INPUTS AND OUTPUTS TO THE CARBON PLANT. VALUES ARE PRESENTED PER 1 TON OF PRODUCED ALUMINUM

	Flow name	Quantity	Amount	Unit
INPUT	***Materials***			
	Coke (C carrier)	Mass	373.77	kg
	Cathode carbon	Mass	1074.35	kg
	Pitch	Mass	85.45	kg
	Refractory	Mass	10.82	kg
	Steel sheet part (St)	Mass	4.97	kg
	Cooling water	Mass	4436.30	kg
	Energy and Fuels			
	Electricity	Energy	213.00	MJ
	Thermal energy	Energy	1128.23	MJ
	Natural gas	Mass	138.52	kg
	Diesel	Mass	0.40	kg
	Oil (unspecified)	Mass	14.19	kg
	Flow name	**Quantity**	**Amount**	**Unit**
OUTPUT	***Products***			
	Anode (C carrier)	Mass	437.23	kg
	Waste for Recovery			
	Steel scrap (St)	Mass	3.10	kg
	Refractory	Mass	1.46	kg
	Emission to Air			
	Benzo{a}pyrene	Mass	0.00	kg
	Carbon dioxide	Mass	239.17	kg
	Dust (PM10)	Mass	0.05	kg
	Hydrogen fluoride	Mass	0.00	kg
	Nitrogen oxides	Mass	0.28	kg
	Sulphur dioxides	Mass	2.86	kg
	Polycyclic aromatic hydrocarbons	Mass	3.20E-02	kg
	Emission to Water			
	Fluorides	Mass	2.00E-04	kg
	Oil (unspecified)	Mass	5.02E-05	kg
	Polycyclic aromatic hydrocarbons	Mass	5.52E-05	kg
	Suspended solids	Mass	0.34	kg
	Other Wastes			
	Carbon (unspecified)	Mass	1.70	kg
	Refractory	Mass	6.00	kg
	Sludge	Mass	0.60	kg
	Water	Mass	3737.72	kg

TABLE II
LIFE CYCLE INVENTORY FOR SOME OF THE MAIN INPUTS AND OUTPUTS TO THE REDUCTION PLANT. VALUES ARE PRESENTED PER 1 TON OF PRODUCED ALUMINUM

	Flow name	Quantity	Amount	Unit
INPUT	***Materials***			
	Aluminium fluoride	Mass	16.16	kg
	Aluminium oxide (alumina)	Mass	1915.55	kg
	Anode (C carrier)	Mass	437.23	kg
	Blasting abrasive	Mass	1.04E-01	kg
	Cathode	Mass	2.30E-02	kg
	Graphite	Mass	4.30	kg
	Steel sheet part (St)	Mass	7.67	kg
	Refractory	Mass	25.11	kg
	Cooling water	Mass	16370.39	kg
	Energy and fuels			
	Electricity	Energy	55935.39	MJ
	Diesel	Mass	3.34E-05	kg
	Heavy fuel oil	Mass	2.34E-05	kg
OUTPUT	**Flow name**	**Quantity**	**Amount**	**Unit**
	Products			
	Aluminium (liquid metal)	Mass	1018.50	kg
	Waste for recovery			
	Aluminium oxide (alumina)	Mass	3.58	kg
	Refractory	Mass	7.44	kg
	Smelter recycling by-product	Mass	8.41	kg
	Steel scrap (St)	Mass	5.80	kg
	Emissions to air			
	Carbon dioxide	Mass	1582.72	kg
	Fluoride	Mass	1.18E-01	kg
	Fluorine	Mass	299.12	kg
	Benzo{a}pyrene	Mass	2.70E-03	kg
	Dust (PM10)	Mass	1.19E-01	kg
	Sulphur dioxides	Mass	3.13	kg
	Nitrogen oxides	Mass	0.13	kg
	Polycyclic aromatic hydrocarbons	Mass	0.22	kg
	Tetrafluoromethane (CF4)	Mass	8.70E-02	kg
	Hexafluoroethane (C2F6; R116)	Mass	0.01	kg
	Emissions to water			
	Fluorides	Mass	0.59	kg
	Oil (unspecified)	Mass	6.70E-02	kg
	Suspended solids	Mass	2.30	kg
	Polycyclic aromatic hydrocarbons	Mass	1.79E-04	kg
	Other wastes			
	Carbon (unspecified)	Mass	8.46	kg
	Refractory	Mass	10.67	kg
	Sludge	Mass	12.83	kg
	Water	Mass	12123.25	kg

B. Life Cycle Inventory (LCI)

In the life cycle inventory raw material required in the production process, energy requirements, produced pollutants from each process should be identified and quantified. Data quality and reliability are major issues in a LCA study. ISO standards 14040, 14041 and 14043 each present different methods to measure and analyze data quality. ISO 14041 Section 5.3.6 states "descriptions of data quality are important to understand the reliability of the study results and properly interpret the outcome of the study" [7], [8]. Other important aspects that should be taken into consideration when qualifying data in the LCI include whether the data were measured, calculated, or estimated. In this study data were mainly collected from literature, and collected from GaBi's database. Moreover, data related to the power plants were collected from the extended GaBi5 database. The accuracy of some numbers was tested by different trial and error runs of the model where a small change of that specific number would have an insignificant effect on the final results. To assess the accuracy of each number collected in the LCI to any degree of confidence there is no exact method that could be applied. Care was taken that certain numbers that directly affect an environmental impact, but rather affect several numbers in the system, should be as accurate as possible. An example of that is the amount of a major raw material required in the manufacturing process. This number will affect every upcoming step in the production sequence. Tables I, II and III present the main inventory data that were used in the GaBi model for the Carbon plant, the Reduction plant, and the Cast house, respectively.

TABLE III
LIFE CYCLE INVENTORY FOR SOME OF THE MAIN INPUTS AND OUTPUTS TO THE CAST HOUSE. VALUES ARE PRESENTED PER 1 TON PRODUCTION OF ALUMINUM

	Flow name	Quantity	Amount	Unit
INPUT	***Materials***			
	Aluminium (liquid metal)	Mass	1018.5	kg
	Alloy components [Metals]	Mass	15.05	kg
	Steel sheet part (St)	Mass	32	kg
	Aluminium scrap processed	Mass	108	kg
	Argon	Mass	0.98	kg
	Chlorine	Mass	0.055	kg
	Cooling water	Mass	1400.34	kg
	Silicon	Mass	38	kg
	Refractory	Mass	5.76	kg
	Energy and fuels			
	Electricity	Energy	252.86	MJ
	Crude oil	Mass	7.7	kg
	Diesel	Mass	3.31	MJ
	Natural gas	Mass	20.3	kg
	Thermal energy	Energy	1295	kg
OUTPUT	**Flow name**	**Quantity**	**Amount**	**Unit**
	Products			
	Aluminium DC cast ingot	Mass	1003.4	kg
	Waste for recovery			
	Dross	Mass	18.36	kg
	Filter dust	Mass	0.03	kg
	Steel scrap (St)	Mass	17.26	kg
	Emission to air			
	Carbon dioxide	Mass	68.38	kg
	Dust (PM10)	Mass	0.07	kg
	Hydrogen chloride	Mass	0.016	kg
	Nitrogen oxides	Mass	0.03	kg
	Sulphur dioxides	Mass	0.32	kg
	Emission to water			
	Oil (unspecified)	Mass	0.01	kg
	Suspended solids	Mass	0.02	kg
	Hazardous waste			
	Dross (Fines)	Mass	0.803	kg
	Refractory	Mass	2.91	kg
	Waste (solid)	Mass	0.23	kg
	Water	Mass	500.47	kg

IV. RESULTS AND DISCUSSION

A. Impact Assessment and Interpretation

The primary objective of the impact assessment stage is to transform the long list of Life Cycle Inventory (LCI) results into a limited number of indicator scores. These indicator scores will show the impact of each process on the environment. In this study 8 impact categories were taken into consideration (Table IV).

TABLE IV
IMPACTS CATEGORIES USED

Impact Category	Unit
Acidification Potential (AP)	Kg SO_2-Equiv.
Eutrophication Potential (EP)	Kg PO_4-Equiv.
Global Warming Potential (GWP)	Kg CO_2-Equiv.
Ozone Layer Depletion Potential (ODP)	Kg CFC-Equiv.
Abiotic Depletion Potential (ADP fossil)	Energy-MJ
Terrestrial Eco-Toxicity Potential (TETP)	Kg DCB-Equiv.
Human Toxicity Potential (HTP)	Kg DCB-Equiv.
Marine Aquatic Eco-Toxicity Potential (MAETP)	Kg DCB-Equiv.

The global warming potential is calculated in carbon dioxide equivalents (Kg CO_2-Equiv.). The three gases that were taken into consideration in calculating the GWP are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Each greenhouse gas has a global warming potential (GWP) which shows the impact of 1 Kg of that specific gas on global warming compared to 1 Kg of carbon dioxide. The mass of each global warming gas produced was multiplied by its specific GWP then all potentials were added and were presented as the total GWP (expressed as Kg of CO_2-Equiv.) [3]. From Fig. 6 (a) it can be seen that the impact of the power plant on global warming is the highest among the aluminum supply chain. The second highest impact comes from the reduction plant followed by the carbon plant. Compared to the reduction plant and carbon plant, the global warming potential of the cast plant and transportation processes is very insignificant. If the impact of the power plant was assumed to be 100% then the impact of the reduction plant would be 37% compared to that of the power plant and only 6% would be the contribution of the carbon plant.

Sulfur dioxide and nitrogen oxide and their respective acids are considered the major contributes to acidification. The acidification potential is defined by the ability of certain substances to release H^+ ions which is calculated as sulfur dioxide equivalents (kg SO_2 – Equiv.) [3]. From Fig. 6 (b) it can be seen that the impact of the carbon plant, the power plant and the reduction plant on acidification are the highest among the aluminum supply chain.

The acidification potential of the cast plant and transportation processes is very insignificant. The impact of each plant on a specific impact category depends on the amount of produced pollutants that relate to that specific factor.

The eutrophication potential is calculated in phosphate equivalents (kg PO_4-Equiv.) It can be seen from Fig. 6 (c) that the power plant had the highest impact in this category. The impact of other plants was insignificant which could be due to the fact that nutrients are minimally produced during the production process of aluminum. Furthermore, in the case of the carbon plant the eutrophication potential had a negative sign which indicates a positive impact on the environment, this could be due to the production of fresh water since wastewater is treated on site and recharged into the sea.

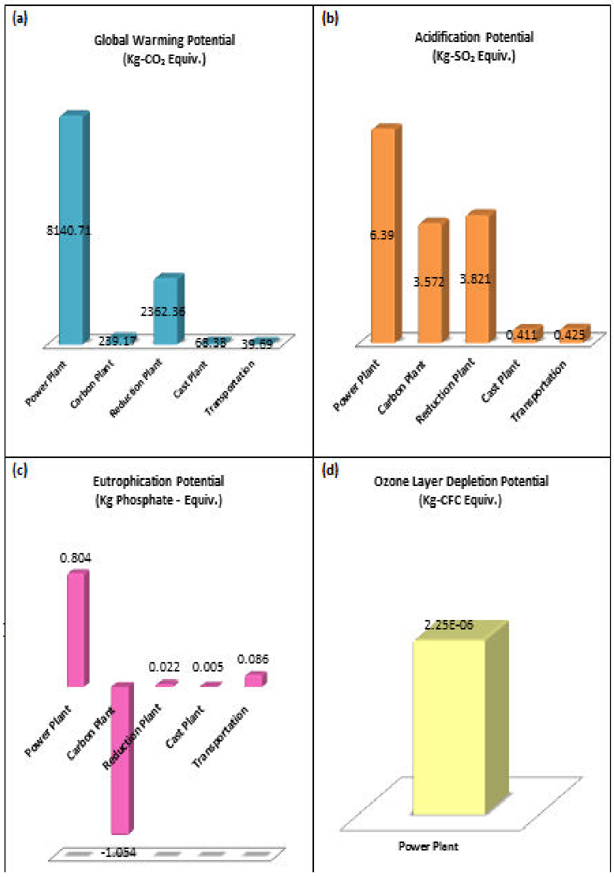

Fig. 6 (a) Global Warming Potential (GWP) (b) Acidification Potential (AP) (c) Eutrophication Potential (EP) (d) Ozone Depletion Potential (ODP)

The substances which have a depleting effect on the ozone and produced by different human activities can be divided into two groups: the fluorine-chlorine-hydrocarbons (CFCs) and the nitrogen oxides (NO_X). The Ozone depletion potential is given (kg CFC Equiv.) [3]. It can be seen from Fig. 6 (d) that the impact of the aluminum production process on the ozone layer depletion is very insignificant. Only a very minimal effect was found from the power plant ($1.5x10^{-9}$ Kg CFC Equiv.)

The Abiotic Depletion Potential (ADP) covers all natural resources as crude oil and natural gas. Abiotic resources are non-living resources that are non-renewable. Therefore, this impact describes the reduction of the non-renewable raw materials. Non-renewable means a time frame of at least 500 years [3]. As shown in Fig. 7 (a) the main source of natural resources depletion is the power plant. The power plant simulated in this study is a natural gas fueled power plant. The impact of different based power plant will be compared and evaluated further in the study.

The Human Toxicity Potential (HTP) estimates the negative impact of a certain process on humans. The eco-toxicity potential aims to outline the negative impact of a certain process on the ecosystem. This is differentiated into terrestrial eco-toxicity potential (TETP) and marine aquatic eco-toxicity potential (MAETP). The potential toxicities (human, terrestrial ecosystems and marine aquatic) are generated from a proportion based on the reference substance 1,4-Dichlorbenzol ($C_6H_4Cl_2$). Thus, the unit is kg 1,4-Dichlorbenzol-Equiv. (kg DCB-Equiv.) per kg emission [3]. From Fig. 7 (b) it can be seen that the reduction plant had the highest negative impact on humans while from Fig. 7 (d) it can be seen that the carbon plant had the highest negative impact on the marine environment. Regarding the terrestrial potential the power plant had the highest impact followed by the reduction plant and then the carbon plant. From Figs. 6 and 7 it could be concluded that the main contributors to the negative environmental impacts in an aluminum supply chain are mainly the power plant followed by the reduction and the carbon plant. The impact of the cast plant and transportation were minimal when compared to the other plants in the chain. Since the power plant had the highest impact in the supply chain it is going to be the core of the benchmarking study.

B. Benchmarking Study

Three main power plants were compared in the benchmarking study, namely, natural gas based (NG), heavy fuel based (HF), and hard coal based (HC). A new model was built only to compare the three power plants. Data pertaining to each power plant was obtained from the extended GaBi5 data base. The impact on the environment of the three power plants was studied by measuring eight environmental impacts. Table V summarizes the impacts of the three power plants on the eight studied categories.

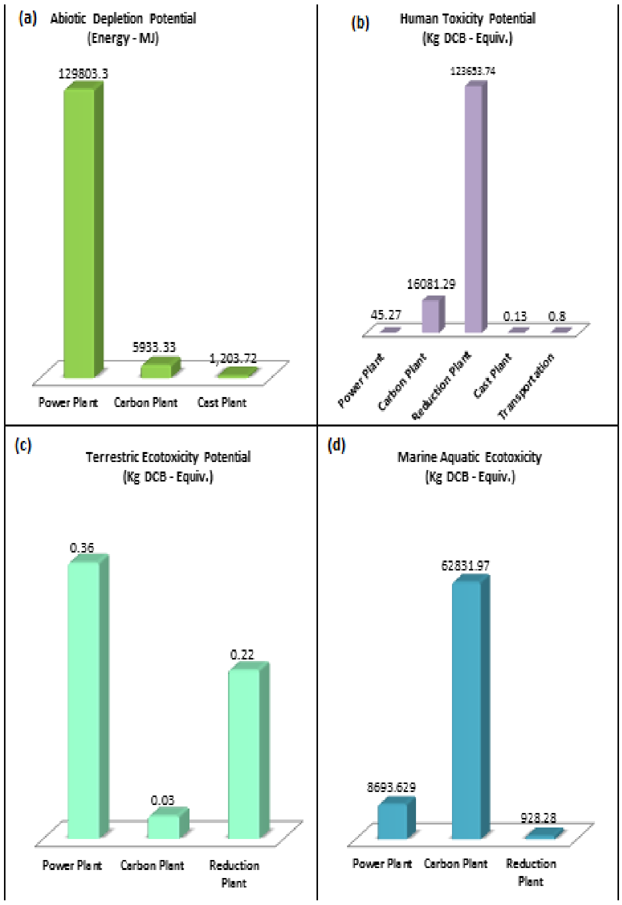

Fig. 7 (a) Abiotic Depletion Potential (ADP) (b) Human Toxicity Potential (HTP) (c) Terrestrial Eco-toxicity Potential (TETP) (d) Marine Aquatic Eco-toxicity Potential (MAETP)

TABLE V
IMPACT OF NATURAL GAS (NG), HEAVY FUEL (HF), AND HARD COAL (HC) BASED POWER PLANTS ON EIGHT ENVIRONMENTAL IMPACT CATEGORIES

Impact Category Power Plant Based	GWP (Kg-CO_2 Equiv.)	AP (Kg-SO_2 Equiv.)	ODP (Kg-CFC Equiv.)	EP (Kg-P Equiv.)	ADP (MJ)	HTP (Kg-DCB Equiv.)	TETP (Kg-DCB Equiv.)	MAETP (Kg-DCB Equiv.)
Natural Gas Power Plant (NG)	0.44	0.0002	2.725E-11	3.92E-5	0.003	0.00037	5.205	5.205
Heavy Fuel Power Plant (HF)	0.74	0.0024	6.28E-11	30.2E-5	0.07	0.002169	37.775	37.773
Hard Coal Power Plant (HC)	1.01	0.00476	5.103E-11	41E-5	0.06	0.001639	58.998	58.998

It can be seen from Table V that the impact of the Natural Gas (NG) based power plant in all eight studied impact categories was the lowest compared to the other two power plants. The impact of the two other power plants was compared to that of the natural gas power plant and results are summarized in Table VI. The values in Table VI were normalized by dividing the numbers of each impact category by that of the Natural Gas based power plant. It could be concluded from Table VI that the natural gas based power plant used in the case study is more environmentally friendly compared to the other power plants. It could be also concluded that the natural gas based power plant will have 8.4 times less negative impact on the environment when compared to the heavy fuel based power plant and 10.7 times less negative impact when compared to the hard coal based power plant.

TABLE VI
BENCHMARKING OF NATURAL GAS (NG), HEAVY FUEL (HF), AND HARD COAL (HC) BASED POWER PLANTS

Environmental Impact	Heavy Fuel Based	Natural Gas Based	Hard Coal Based
Global warming Potential (GWP)	1.7	1	2.3
Acidification Potential (AP)	12	1	23.8
Ozone Depletion Potential (ODP)	2.3	1	1.9
Eutrophication Potential (EP)	7.7	1	10.5
Abiotic Depletion Potential (ADP)	23.3	1	20
Human Toxicity Potential (HTP)	5.9	1	4.4
Terrestric Eco-Toxicity Potential (TETP)	7.3	1	11.3
Marine Aquatic Eco-Toxicity Potential (MAETP)	7.3	1	11.3
Score	67.4	8	85.5
Normalized Score	8.4	1	10.7

V. CONCLUSION

The production of aluminum alloys and ingots – starting from the processing of alumina to aluminum, and the final cast product – was studied using a Life Cycle Assessment (LCA) approach. It was concluded that for most of the studied impact categories the power plant had the highest negative impact on the environment only in the cases of Human Toxicity Potential (HTP) the reduction plant had the highest negative impact and in the case of Marine Aquatic Eco-Toxicity Potential (MAETP) the carbon plant had the highest negative impact. Furthermore, the acidification potential of both the carbon plant and reduction plant was almost the same as that of the power plant. From the benchmarking study it was concluded that the natural gas based power plant had the least impact in all 8 impact categories. The natural gas based power plant had 8.4 times less negative impact on the environment when compared to the heavy fuel based power plant and 10.7 times less negative impact when compared to the hard coal based power plant.

ACKNOWLEDGMENT

This paper was made possible by UREP grant # UREP12-013-2-002 from the Qatar National Research Fund (a member of The Qatar Foundation). The statements made herein are solely the responsibility of the authors.

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