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ENVIRONMENTAL LIFE CYCLE ASSESSMENT ON ALUMINIUM PRODUCTION INDUSTRIES

BY

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ABSTRACT

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Environmental life cycle assessment on aluminum production industries

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This project aims to assess the environmental impact of aluminium production processes using a life cycle assessment approach. The life cycle approach is applied to the product path from the raw material extraction to the time they are disposed or recycled. Several manufacturing processes were presented and their LCI and life cycle impact assessment are outlined and analyzed. The results of the study revealed that energy production is responsible for the highest percentage of emissions since most of the energy demanded results from non-renewable sources. In light of these findings, it was recommended that an improvement in the production technology would reduce the primary energy demand, which in turn would reduce emissions into the environment. Consequently, mitigation of the effect of the emissions on the environment would be achieved. In addition, the promotion of recycling of aluminium products would greatly assist in reducing primary energy demand and hence emissions.

DEDICATION

This master project is dedicated to the best parents in the world for their unwavering support for all past years and their wait for this great moments .i would like to thank my family for believing in me and always be there for me , lastly, I would like to thank my lovely little princess Reema and my little lion Hamad .

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Finally, I would like to confirm that all the work mentioned in this project is done by myself. Also, all the analysis, outcomes, and recommendations are the sole responsibilities of the author.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

With all of the ongoing urbanization and countless project worldwide , industries worldwide have started the industrial race on providing the best products and technology ,especially aluminum industry where its second-most demanded metal worldwide due to its characteristics and durability this study focuses on carrying out a case study to investigate the production of the aluminium industry. To achieve this, the life cycle approach is applied in a bid to cover the system complexity of aluminium production and use. Contrary to using the traditional approach that focuses on compliance and control of the facilities in environment management, life cycle approach covers all the stages of a product during its life cycle except one stage that we will elaborate later further. Some of these stages include, processing of the raw material; designing and production of the product, packing and delivering; maintenance and reuse; disposal or recycling of the product.

1.2 Life Cycle Approach

A life cycle approach is an approach in which the management of the sustainability of the product is done while considering production, use and disposal of the product and their management (AG, 2020). In this approach, shifting problems are avoided such that problems that change in each stage in the product life cycle are eliminated. It overcomes the problems faced by the traditional approach that focuses on a single stage while addressing the economic, social and environmental aspects that are required.

The topics that this assessment will address will include the processes involved in aluminium production, its interaction with flora and fauna and the footprint of unfinished products. In addition, it will provide an update on aluminium product life cycle assessments of the past in this country.

Recent development activities, especially in the construction industry, have impacted aluminium production. The demand and use of aluminium can be attributed to its numerous advantages over other metals: its abundance on the surface of the earth, its lightweight, and its high strength to weight ratio, low cost compared to other metals, properties such as malleability, resistance to corrosion and ability to conduct electricity. Currently, the development of stadiums and other infrastructure everywhere will demand more aluminium production. In addition, countries future visions on sustainability will impact the same industry. Therefore, a life cycle approach in the assessment of aluminium production industry.

1.3 Life Cycle Assessment

Notable LCA studies that have been carried out with aluminium production as the system under study took place in 1992-1993, 1996-1998 and 2007-2010. These studies focused on the cradle to the grave cycle of twelve-ounce beverage aluminium cans, automobile products and a mixture of aluminium cans respectively.

The findings from these studies shed light on the impact aluminium products have on the environment during their cradle to grave life cycles, therefore, supporting informed decision-making processes to take place. In addition, the industry and the stakeholders are able to identify ways in which they can improve or reduce the negative effects of the aluminium products and their residuals on the environment. Moreover, the public is also educated on the use of the products hence are able to make their own strides in a bid to reduce the effect on the environment by these products by adopting environmentally friendly practices such as reusing and recycling.

Life Cycle Assessment (LCA) is a methodology outlined by the International Organization for Standardization (ISO) that is employed in a life cycle approach in the management of the environment. A system approach is employed in LCA to gain knowledge on the effects a product has on the environment, the process used in its production right from the extraction of the raw material until the time the product is disposed of, and the material returns to the earth (KM, 2019). LCA serves to carry out a quantitative analysis, evaluation of the data obtained and seeking out ways of reducing the impact the system being studied has on flora and fauna around it. Life Cycle Assessment has 4 separate parts outlined in the International Organization for Standardization that are interrelated. These include;

a) Life Cycle Scope and Goal Definition: In this phase, the purpose of the study being carried is stated; the exact system to be studied is also defined; statement of how the results will be used and their limitation on usage for other objectives are defined; the quality of the data to be collected; the requirements on the reporting process and the intended process of reviewing the data. In addition, boundaries including geographical and system are defined, rules used for decision making and assumptions to be made are also stated.

b) Life Cycle Inventory Analysis: In this LCA phase, input and output data of the system under study is compiled and quantified throughout the product’s life cycle.

c) Life Cycle Impact Assessment: This phase tries to gain knowledge and evaluates the quality and quantity of the effect the product understudy will have on the environment.

d) Interpretation of the Life Cycle phase: A combination of the facts found in the preceding steps is done here. A cessation is made based on the objects laid out in the first part.

1.4 General Overview of the study

Constant and continuous LCA studies are necessary for Aluminium production since it is a dynamic system where the technology applied is ever-changing. Aluminium industry commitment to carry these studies for the sustainability of the industry, therefore, creates a need for such a study to be carried out at this level. These studies aim to not only information on the subject in question but also serve to update past studies so that the most current and up-to-date information is always available to support decision-making processes.

In view of the above benefits of LCA studies, the structure of the report of the current study will be structured as outlined below in the subsequent chapters:

a) Overview of aluminium production and product systems

b) Definition of research objectives

c) The methodology to be used in collecting data and its subsequent processing

d) Definition of methods to be used in presenting data

e) Inventory analysis and impact assessment of the life cycle of aluminium products

f) Discussion and deduction of a conclusion from these finding

CHAPTER TWO: LITERATURE REVIEW

For over a decade's studies increased drastically on aluminium productions due to its properties and recycling without losing its original properties (RH,2002),and as per Coursol life cycle assessment has significantly been the main driver for an efficient production and has been the driver for other industries(CC,2011), and therefore aluminium industry has begun the race on optimizing their process and reducing their emissions (LM,2012).

2.1. Al Merchandise Life Cycle

The life cycle of Al merchandise starts at the source i.e. the origin on the earth's surface from which the raw material is extracted and terminates at the sepulchre where it is normally disposed of. The termination stage can also be marked by the recycling of the aluminium product (RH,2015). The aluminium industry, in this case, is considered as the industry which is involved in the enclosed stages of the aluminium life cycle either partially or fully. The aluminium industry is involved in producing the aluminium metal, partial fabrication of some of the products and recycling of the already used products.

Aluminium as a metal is produced in two unique ways: it is either extracted from its ore called Bauxite found abundant in some parts of the earth or it is produced from recycled aluminium products i.e., aluminium scrap (CS,2015). Once produced irrespective of the resource used, the resulting aluminium metal has the same properties and hence is applied in similar places. However, the two differ in terms of the impact on the environment. After processing, the metal then undergoes fabrication processes to be turned into useful products that are used for various applications. This phase is called the use phase and it can last for a short period or a long period depending on the use and the conditions of its use. Once the use phase elapses, the product is disposed hence returning it to its cradle or it is recycled to produce a new metal (OEA,2006). Aluminium life cycle is as illustrated in figure 1 below.

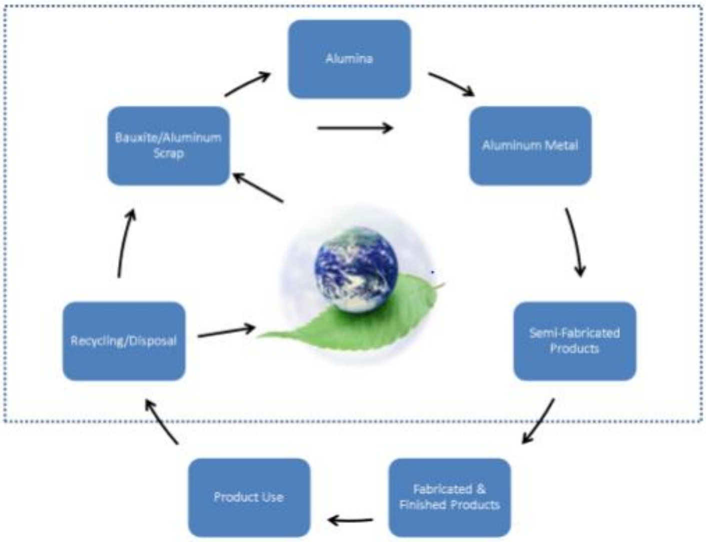

Figure 1: Aluminium products' life cycle “(LA,n.d)

Aluminium products have the largest effect on the environment during extraction, processing of the material from its raw form and fabrication stage to produce a useful product. However, once fabricated, the product has huge economic, social, and environmental positive impacts during its use phase (PE,2010). Its environmental effect during the final stages is low compared to the impact during its entire life cycle.

2.2. Definition of goal and scope of the study

2.2.1. Definition of the goal.

This study is carried out with a major purpose of updating past LCA studies of aluminium products worldwide. It is also intended to generate high quality and reliable data that can be applied in decision-making processes in many sectors that it may be needed, such as consumer durables, packaging and transportation. Updates to existing

LCAs are important since the earlier LCAs get outdated with time and technological evolution making them fail to meet the current needs. The current LCA will have updated details of the market, the current technology and practices used in production.

The findings from this study will, therefore, be used by me and other stakeholders to advise aluminium manufacturers on the best practices that conserve the environment and help track aluminium footprint during the use phase. It will also be used to help manufacturers' and other concerned parties to identify areas that need to be improved in aluminium production. Nevertheless, it will assist in meeting the rising need for information on aluminium to the public, the government and other interested parties.

2.2.2. Targeted Audience of the study.

This study targets the general public, manufacturers, customers, and the concerned arms of the government. Data from this study can be adopted by experts in the field to disseminate information in a manner that is understandable by the public and customers. It can also be used to develop other LCIs intended for particular applications and product development for specific customers.

2.2.3. Intended use of the study.

As previously discussed, the results of this study can be used in diverse applications to achieve specific goals. Possible Ways the results can be used include:

- Establishment of an updated database for aluminium products that can be used by the manufacturers and other parties in various applications that depend on data.
- Provision of information that improves the understanding of aluminium production to the manufacturers, the general public, and all other stakeholders. This information will reveal the impact of aluminium production on the

environment and suggest ways of improving while highlighting the benefits of aluminium production.

- Acting as a driving force for permutation by enabling evaluation of substitute fabrication ways in addition to refining existing fabrication methods by modifying them.
- Supplying facts and figures that can be used in the strategic drafting of plans.
- Assist the industry in building out of sustainability chronicles and correspondence such as EPDs.

2.2.4. Limitations of use in other areas.

I acknowledge the possibility of misuse of data and information from this LCA study since it is an approach that is generated following particular stated assumptions. The use of data or information where it was not intended might turn out to not only be dangerous but also misleading to the intended audience. In view of this, there are a number of uses that the data cannot be applied. These include;

- Raw material and product choice decisions should not be solely based on the findings and recommendations of this report.
- The data herein cannot be used to place claims against aluminium products and the industry as a whole.
- It should not be used by any authorities when making regulations that affect the activities of aluminium production.

CHAPTER THREE: RESEARCH OBJECTIVES AND METHODOLOGY

This chapter explores the objectives of the project, as well as the methodology used. The methodology will include an exploration of the approaches recommended in the aluminium industry. The chapter will entail detailed information on the specific methodology used to gather information for the study. In this case, the results of the research study will be achieved for an effective analysis of the findings.

3.1 Research Objectives

The main aim of this research project is assessing the current aluminium production processes with modern technology and their impact on the environment to succeed in this, the following objectives are achieved:

1. To conduct a life cycle assessment of aluminium products, including the most relevant parts and/or products.
2. To assess current technological advances with regard to the aluminium production practices
3. To include the most important of the aluminium process with the semi-fabricated aluminium study to be more inclusive and covering.

3.2 Research Methodology

This research is mainly involved with the lifecycle analysis and assessment of aluminium. The study, therefore, takes care of LCI and LCIA information to ensure that the necessary final products are obtained within the relevant sites. The LCIA results for each of the aluminium products were provided. This methodology employed in this study follows the standard methodology described in ISO 14040 and ISO 14044 documents. These include parts such as scope definition, collection of data, as well as the impact analysis.

There are other recommendations for the approaches used in the life cycle analysis of aluminium products. One of these approaches is the substitution method. The worldwide metals industries recommended this approach, which can be used with aluminium. This recommendation is due to specific aluminium characteristics. In particular, the aluminium recycling characteristics help the metal preserve its full properties without any quality qualities irrespective of the number of frequencies of it is actually process and reprocessed and recycled. The reprocessing process can be considered a semi-simple closed-loop system that can have the same final product system such as the shape-casted aluminium to a shape-casted product. Additionally, there are other situations where an end product can be used to produce other systems. However, these are dependent on the market forces' efficient quantities of scrap that can be used.

The substitution method is one that is focused on the environmental vision and fundamental sustainability of the metal industry. This focuses on a reduction of the average costs of aluminium production while maximizing on the benefits brought to society as a result of aluminium products. In this way, it would be easy to preserve aluminium metal for longer than its useful life which would be great for future generations. This way of thinking is as illustrated in the figure below.

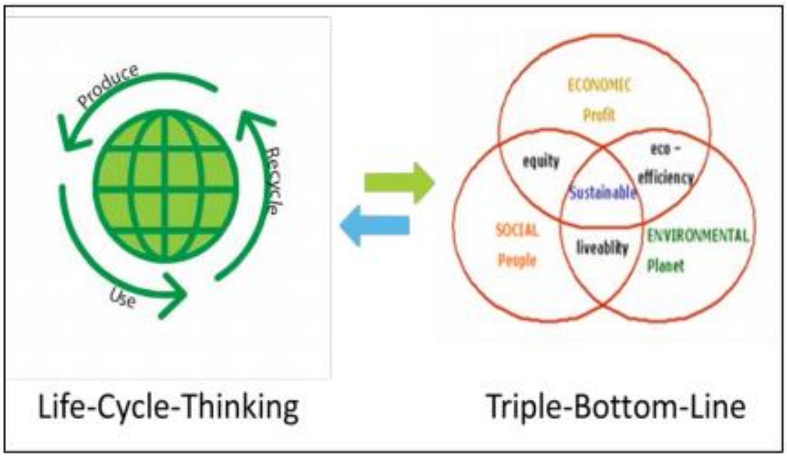

Figure 2: Sustainability vision of aluminium (AS,2013)

Similarly, according to the Aluminium Association, it is reported that there are numerous approaches that can be used to explore the environmental impacts of certain products such as metals during its life cycle. In this case, it is important to provide a comprehensive and transparent approach that can provide information for any user who intends to use their methodology in the analysis of the life cycle of these materials. Generally, the methodologies have to provide relevant information, for instance, content, so as to ensure transparency which provides efficiency within the main sector.

The substitution approach is one that ensures that it follows a perspective that strictly follows a product life cycle. Its system flow chart is, as shown in figure 3 below. The main consideration comes to play when the products are past its usage phase and concentrates on the by-product material final output flaws. Using the substitution approach is necessary to evaluate the environmental impacts of the system. In this way, it will be easier to consider the possible changes that can be made to improve the system. In this case, it is paramount for the material recycled completely before going through the end of life phase. At this stage, the net recovered metal is usually the one substituted by the primary metal indicating that any burdens as a result of the primary metal production are avoided. For any designer using this approach, it is paramount to consider the optimization of product recovery as well as material reliability. Through the facilitation of greater end-of-life recycling, there is an analysis of the material loss after the material has been used. In this way, the general consequences of the product at its end life can be effectively assessed, which in turn helps support an efficient market.

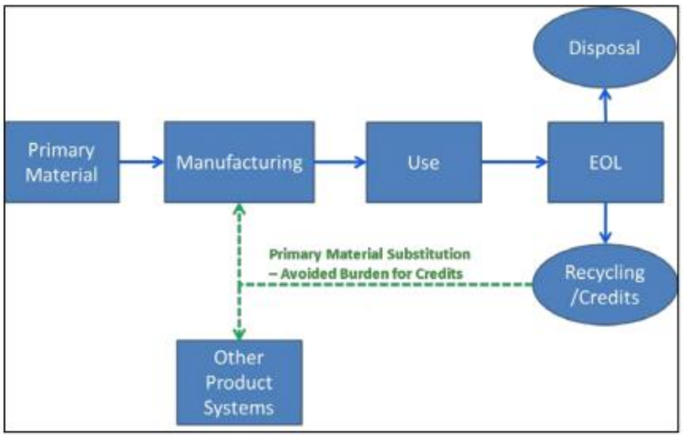

Figure 3: substitution approach process flow chart (AS,2013)

3.3 Data Presentation

For each production unit processes, report results are used to provide the aggregated input and output data. Here, there is a provision of the process descriptions, their boundaries, process model flow charts, as well as the assumptions. Whenever possible, there is an addition of a provision of quality assessments. Within the several sections, there are cumulative LCIs which are provided on the intermediate and final product systems. These include: primary ingots, hot and cold aluminium, and the cast metal, and finally the recycled metal, and the process we will present will be from refining till shaping of casted metal.

Within these processes, there is a gate-to-gate presentation of the datasets which are classified into numerous categories. These include;

- Primary energy demand
- Global warming potential
- Acidification potential
- Smog formation potential
- Eutrophication potential

These impact categories are further explained and discussed to provide their meaning and significance. Using the assessment tool for measuring the impact of environmental and chemical impact called (TRACI), it is possible to calculate the impact results of the impact assessment. TRACI can be considered as one of the most common and used software that is widely accepted when it comes to the application of impact assessment methods in the world today.

3.4 Specification of product systems to be studied.

The product systems to be studied in this project include all the enclosed stages of the life cycle of the aluminium product, excluding the use stage and the fabrication and assembly stages of aluminium product life cycle. I included in this study some of the stages of aluminium products produced like primary and recycled metal or secondary metals; Products that are flat-rolled; products that have undergone extrusion; and Shape-Casted products.

3.4.1 Product System Boundaries.

The system boundaries in this study include the product that has undergone partial/semi-fabrication; however, the products may undergo further processing/ fabrication and/or assembly which is excluded in this report. Therefore, the products to be looked at include products that have undergone extrusion, flat-rolling and shape-casting. the present technology condition is substituted by the traits portrayed by the aluminium merchandise, the procedure used in their production and their market influence. A summary of the boundaries of the system under study including and excluding respectively the stages mentioned earlier are as indicated below:

List of items included in this study:

- Inputs such as fuel and energy
- Process of extracting, processing, and delivering the inputs of energy and fuel.
- Process of extracting and processing auxiliary materials such as lubricants, chemicals, and packaging.
- Metal production and processing to produce the semi-fabricated goods
- Surface treatment of products and their finishing such as coating
- Transporting raw and processed materials and the finished products.
- Recycling of used products
- Treating and disposing of waste materials
- Production facility overhead heating and lighting

List of items excluded in this study:

- Operating and maintaining equipment
- Human labor
- Product use phase

- Maintenance and capital equipment
- Assembling, Fabricating and pre-use stages

2.2.7 Functional Unit and System Function.

The products serve the function of individual components, those of parts, units and/or combined products that are then used for transporting; building and constructing; packaging consumer goods, electrical goods etc. This study's functional unit is modelling one tone of the products for each of the categories of items mentioned in the list of included items previously. These include primary metals, recycled/secondary metals, metals that have been extruded, metals processed through extrusion, metals processed by flat rolling and metals that have been shape-casted.

3.4.2 Coverage

A. Time

This study's time coverage is 2018. It will be used as the datum when the facts and figures of the firms from which facts are taken were producing. A program named GaBi version 6.0 was employed to aid in devising a representation of raw material fabrication and energy production by way of providing more information. Facts and figures for the years of 2015 to 2019 excluding 2018 for some producers were excluded from the study due to either late response or provision of unreliable data. A conjecture that the industry underwent insignificant adjustment in terms of technology and production processes was made to take care of the exclusion made earlier. However, this covers the semi-fabrication facilities only.

B. Technological

An exemption will be made to a single process, i.e. shape-casting. All the other processes will involve all the available technologies that are being used in the production of aluminium merchandise.

3.5 Data Collection, Software, and Database

3.5.1 Data Collection

The study's aim is the generation of LCI data and results that are a representation of the average production capacity currently of the production systems in the production processes that are being studied. To achieve this target, the primary data from the production companies are given priority over secondary and tertiary information. The steps discussed below were taken while gathering the facts and figures required to conduct this study.

A. Procedures

The initial step in this process is to resolve the origin of the facts and figures. The stages in the life cycle of aluminium merchandise that will be covered in this study will include mining of the aluminium ore i.e. bauxite; re-fabrication of the resulting ore; process of generating secondary/ recycled metal; processing of the ore to produce a primary metal; the termination process; managing the termination process of the used product i.e. coming up ways of disposing or recycling of the aluminium merchandise. The most time-consuming part of the study will be the termination process where keen interest is placed on how the products go back to the starting point to complete the cycle. Processing of the ore to produce the primary metal phase data was taken from the Qatalum environmental department database. Qatalum normally gathers information and data from both primary production and aluminium refining facilities around the globe included. This department fact and figure need aggregation before applying them in the study. The remaining data for the other stages such as the process of generating secondary metal can be obtained by my project from the participating firms using various methods that will be outlined in later sections of this project.

Second, since the number of individual stakeholders in this industry is huge, I could not collect data from all the players in this industry. Therefore, I had to go through the relevant organizations to determine the number of manufacturers and other stakeholders around the globe.

Third, the selection of samples of data required for assessment was to be done from the number of stakeholders taken into consideration. To ensure that the industry was represented well, a selection technique that was random was used to make the selections. Consequently, 2 corporations and 5 facilities were selected representing this industry in terms of the production capacity in their individual groups. The selection included both large and small companies that either specialize in the activities of primary production or semi-fabrication processes.

Fourth, carrying out the collection which included, sending emails and meeting them, collecting responses, checking the quality of the data and aggregating the data. Out of all the other steps of collecting data, this is most time and energy-consuming. As a result of the sample size taken is huge and diverse in addition to an economic recession that affected most production facilities, it took a long time to collect the data required. Eventually, acceptable response rates that were a representation of the industry in this country in terms of flat-rolled aluminium, extruded aluminium, and secondary and recycled aluminium production were obtained. Nevertheless, shape-casted aluminium production data was not successful since the responses obtained were not an acceptable representative of the industry. Therefore, the model we used was from the data from the company database shape-casted aluminium production.

B. Data categories

The individual production processes were used to base the Data gathered of operational data such that a list of inputs and outputs characterized each production process unit, as shown in figure 4 below.

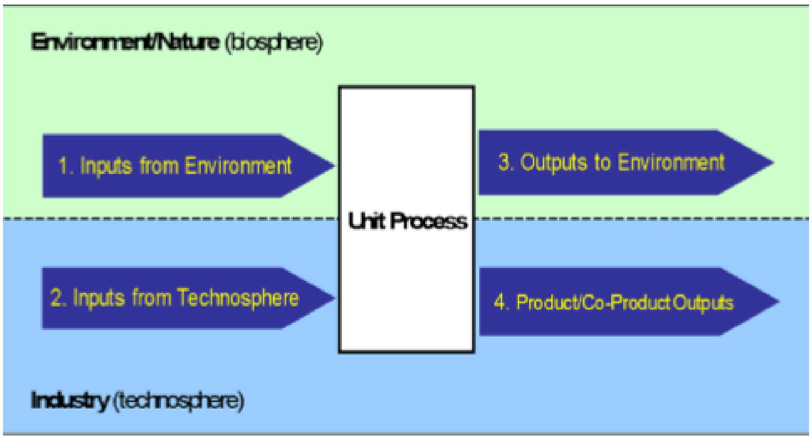

Figure 4: Manufacturing process in individual units(AS,2013)

The Data had various categories defined before being dissemination for collecting facts and figures; these include:

- Water and energy inputs
- Outputs
- Environmental emissions
- Waste management methods

C. data entry Format

Process of aluminium is the same so the companies who share almost the same production process, so it get and evaluate the data, I need to establish a common ground to collect the data and compare each entry in the assessment and for marking concerns, we are committed not to share each company data with others in the assessment. these will help me come up with future tools for conducting similar data collection in the same field.

The product categories showing a representation of the industry coverage were the ratio of the reported tonnage in the data to the total net shipments made by the producer, which might differ from the common definition adopted by other industries such as industries that manufacture materials. Besides, most LCAs carried out by most associations at a geographical region are chosen randomly. In addition, multi-facility or national corporations are normally represented using data from one facility. Consequently, in some industries, the entire industry is normally represented by a few facilities. Hence, this definition by this study was sufficient and conformed to the common practices in the majority of the industries.

3.5.2 Database used and software

Processes of production and auxiliary materials that are critical but are not part of the aluminium industry have been included in the study. Such processes and materials are auxiliary material processing/production, fossil/non-fossil fuel production, electricity generation and subsequent transmission etc. In the same sense, as was indicated in the previous sections, shape-casted aluminium production was excluded from the study since it did reach the criteria for selection of the study categories despite being part and parcel of the industry (Aluminium). In that case, a relevant database was chosen to provide the needed LCI data. Additionally, the need for appropriate software to be used in conjunction with the database arose. Therefore, an appropriate Gabi database and the software itself (GaBi) were selected to conduct the study.

3.5.3 Calculations of Data

Presumptions and computational strategies are applied in the process of updating and correcting the inventory of the industry. These presumptions and strategies aid in the simplification of the entire process that is followed when collating the gathered data. The segments below include a discussion of the particular strategies applied in this study.

A. Reporting Units

The units used in the report conform to assessment reports on impact when converted to metric units and life cycle inventory world convention such that mass is given in kilograms/metric tons, volumes of gases are given in cubic meters; energy is given in mega-joules while volumes of liquids are given in litters. Some other accepted convectional units to denote units of parameters such as electricity, distance, concentration etc. i.e. kilo/megawatt-hours, meter/kilometer and parts per million (ppm) respectively. The data was carried out using the program already selected for use. Mass in kilograms or tones and volume in cubic meters were the parameters used to measure energy inputs. These parameters were then converted to their respective calorific values using the program designated for use in this study.

Aggregation, Integration, and Averaging

To ensure confidentiality of the information/data obtained from particular companies and facilities, aggregation and averaging of the data were done before the presentation. This ensured that I performed their legal duty of protecting disclosure of information from those facilities without their written consent owing to the sensitivity of the data from their operations. Effect analysis and calculations were done after the data underwent all the steps outlined in the previous sections of the report, i.e. aggregation and adjustment to reflect the situation being studied. This was then used in modeling the Life Cycle Inventory through the developer. I made sure that there was no data or summaries of the same included in the report which would compromise the confidentiality of the data from a given company or facility. For instance, data was not revealed in case the less than three companies were involved in a unit production process. For the purposes of data evaluation by a reporting firm, it would disclose the facts and figures used in the study in a concealed manner such that the data reflects the performance of a given industry in a given region.

Data for the primary operation was obtained by the application of combined methods of vertical and horizontal averaging. Owing to the fact that the method of vertical averaging shows the industrial processes much better, its application on the data was more consistent as compared to the other method of averaging. Vertical averaging is such that the figures representing a given company processes at each operation are averaged to obtain an intermediate average at the end of that operation. This process continues at the other successive operations until the final computation of the weighted mean as an average. Figure 5 below illustrates this process.

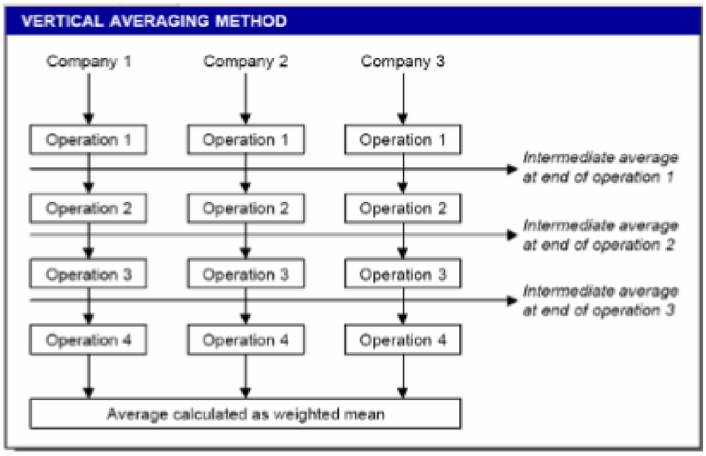

Figure 5: averaging by using the vertical average (AS, 2013)

In some cases where data might be missing from some of the participating facilities/companies, then the method of horizontal averaging was applied. In this method, calculations involving unit fabrication processes are done in a logical sequence that supports unit by unit computational perspective; much more information is gained from each unit about the function/activities in that particular unit. Figure 6 below shows how the horizontal averaging method was used.

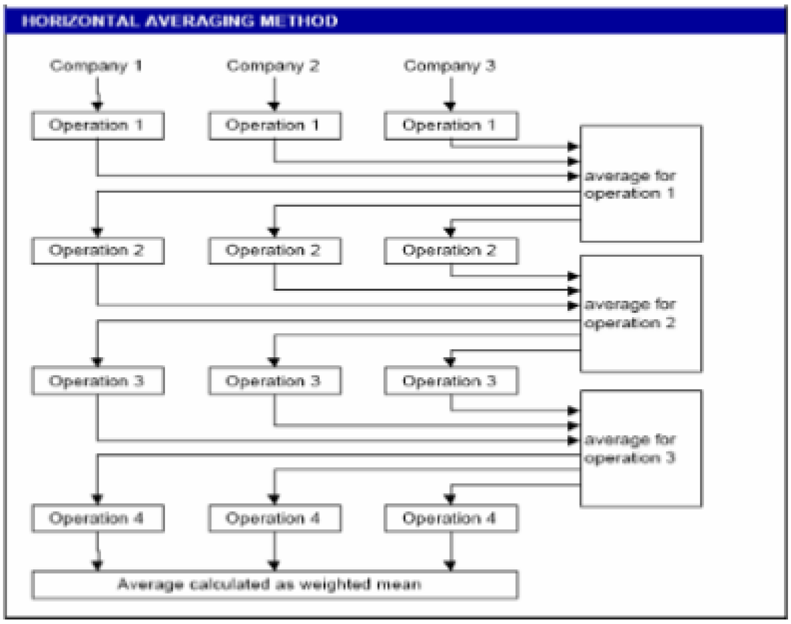

Figure 6: averaging by using the horizontal method (AS, 2013)

In this method, the averages computed at the end of individual operations are taken as inputs during the following operation. However, this was only applied where the data obtained was insufficient or missing.

Allocation

The expansion of the boundaries of the system has enabled the avoidance of allocation as much as possible. Valuable merchandise leaving the system were only two. These were Al ingots and partially-fabricated merchandise. This was done since Al scrap had already been added to the dataset of the study. Therefore, allocation took place where automatic computation for two given auxiliary processes was done by the software used in this study, GaBi software.

These processes include Caustic soda production since Sodium Hydroxide was applied in the processing of alumina used in aluminium production. Thus, sodium hydroxide proportion was allocated in terms of its mass. This was because the Solvay process is used to produce chlorine and sodium hydroxide; exegetic content was used to do allocation in electric production where there was steam co-production. An approach called an Avoided Burden was used to allocate the end of life. Thermal/electrical recovery of energy was used to quantify solid waste incineration provided it was not hazardous. The introduction of this energy to the model of the LCI was done to avoid having to allocate for this energy and a corresponding reduction of input of energy done to the model. However, the input from such energy was minimal constituting < 0.01% of the total energy input.

Elimination Criteria

The standard used for eliminating or including flows that had a significant effect on the environment is as detailed below:

- Mass: If the environmental impact of flow was low enough to be neglected without raising any concerns, it was neglected as long as the summation of its inputs and outputs mass was below 1%.
- Energy: If the environmental impact of flow was low enough to be neglected without raising any concerns, it was neglected as long as the summation of its inputs and outputs energy was below 1%.
- Relevance to the environment: Given that a flow met all the criteria to qualify for exclusion from the study but it had such an impact on the environment such that it could not be ignored, it was re-included in the study. Emissions by the system, i.e. flow of material out of the system were included in the study for assessment if its

impact on the environment was more than one percent of the entire impact of a category of the impact that had already been taken for assessment consideration.

- A percentage of 3% was the value used to determine if a flow that was neglected would be included. To compute the flow re-inclusion, the summation of the flow's energy and mass was done. This sum was maintained below the three percent value.

3.5.4 Review

A review of the study was necessary for under to observe the international standards spelt out in the ISO standards. In particular, ISO 14044 was the clause to which the study had to adhere to. The aims and the extent of the review areas outlined in the ISO standard mentioned above. An independent review panel was used to conduct the critical review process following the ISO standards laid out. In accordance with ISO 14044, the review should make sure that;

- ✓ Methods outlined in the standard were followed in conducting the study.
- ✓ Valid scientific and technical methods were used to conduct the study.
- ✓ Following the study's goal, the data was used appropriately and reasonably.
- ✓ The study's goal and limitations are reflected in the deductions made.

CHAPTER FOUR: DATA GATHERING, RESULTS AND ANALYSIS

In Chapter 4, we will collect all Data from Each aluminium Processes that we need to assess and for each process, we will descript it and will elaborate each unit process and then we will collect each process input and outputs that we require for the assessment.

4.1 Primary product production process

The accompanying sub-areas cover depictions of the procedures being demonstrated, sources of info and yields of the procedures, and introductions 1000kg of aluminium ingots to be assessed by life cycle assessment and life cycle inventory analysis.

4.1.1 description of processes

Sourcing of real crude materials in every one of the unit Part: Inventory Analysis and Results 27 forms depends on measurable creation, shipment, and global exchange information distributed yearly by the Aluminium Association. (AAA,2006) The accompanying sub-segments describe the nonexclusive profiles for every one of the unit creation forms related to essential aluminium and depend on the substance of comparable past investigations completed by the aluminium business (for example (AAA,2006), RH,2015, (DV,2006). The existence cycle phases of essential aluminium ingot generation incorporate the part procedures of alumina refining, metal electrolysis with making anode and baking it inside the plant, and essential ingot throwing.

4.2 Alumina Production process

4.2.1 Description of unit process

Alumina process and refinement is a procedure of producing alumina from bauxite Ore Al2O3 (alumina) utilizing the Bayer procedure. This progression of assembling starts with the preparing of bauxite and closures with the yield of alumina to be in this manner handled in the smelters:

- bauxite granulating, assimilation, and preparing of mixers,
- alumina calcination,
- support and fix of plants and hardware, and
- air processing and treating fluids, and solids.

4.2.2 Energy sources and raw material acquisition

Pure alumina generation incorporates raw material, burning soft drink, Na2CO3, and so on; all bauxite is transported in and the source nations are additionally recorded. Burning soft drinks and sodium carbonate are either locally created or imported.

4.2.3 Modeling the unit process

As per the IAI overview, manufacturing of 1 metric ton of alumina will need 1.992 metric huge amounts of raw material considering the immaculateness of ore metal and misfortunes amid preparing and transferring (IAI, 2013). This is an agent worldwide normal that has been received to demonstrate both the household and the transported in part of the alumina creations for usage. Metallization alumina utilization was evaluated to be 633 hundred thousand metric tons in 2010. Similarly, as with the bauxite is imported from outside, it was accepted that the wellspring of alumina imports is illustrative of the whole Asian continent. The nation's explicit, detailed imports of refined alumina imports to the industry in 2009/2010 is given in figure 7.

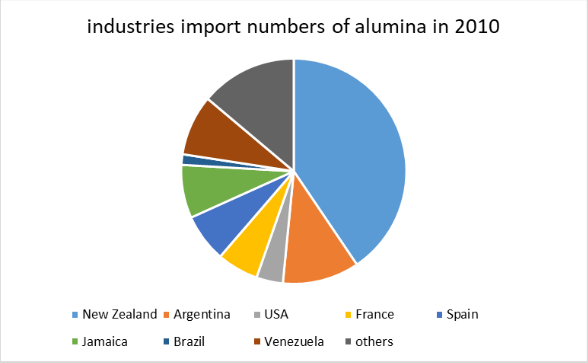

Figure 7: industries import numbers of alumina in 2010

The transportation remove was approximated dependent on the normal nautical separation between a noteworthy port in every one of the bauxites sending out nations in the industry. The transferring of crude material, minerals from the getting raw material imported nations to industries is included in the study to make a mineral import blend demonstrate as appeared in Figure 7.

4.2.4 Process input and output products

Table 1: Alumina production in the process

Flows	Unit	Amount
Inputs		
Materials		
Bauxite	kg	2667
Aux Materials		
NaOH	kg	75.4
Calcium oxide	kg	37.2
Water		
From Sea	kg	573
Dimmed Water	kg	2742
Fossil fuels		
Coal	MJ	785.5
Heating oil	MJ	1.22

Flows	Unit	Amount
Gas turbine power	kWh	143.5
Heavy fuels oils	MJ	1743.6
Steam turbines	MJ	1532
Methane gas	MJ	6231.7
Outputs		
Products		
AL2O3	kg	1000
Waste for recovery		
recycling remaining’s	kg	3.1
residues	kg	6.2
Waste for disposal		
Bauxite tailing	kg	1642
Non-hazardous	kg	7.6
hazardous	kg	9.23
Emissions to air		
Pm matters	kg	0.75
Sodium dioxide	kg	2.64
Nitrogen dioxide	kg	0.86
Hg	kg	0.004
Steam	kg	1300
Emissions to water		
solids particles	kg	0.021

Flows	Unit	Amount
lubricants	kg	0.675
Hg	kg	6.0E-03
Water (treated wastewater released to surface water)	kg	1632

4.3 Production of Anode process

During the electrolysis process of the aluminium, the anode is considered to crucial be element and it is usually consumed in the cause of the process. The anode is made from petroleum and then rod from steel is used to suspend the anode in the cell. The current is forced to pass through the electrolyte made of the mixture of alumina and cryolite. The current cause the mixture breaks down into oxygen gas and aluminium metal. At the anode, CO_2 and CO gas are produced due to the reaction of carbon and oxygen. Also, the reduction of alumina electrolyte contributes big in the consumption of the anode. Carboxyl reaction and dust also contribute to consumptions of the anode. Therefore, there is a need for the production of the node so that can get replaced during the electrolysis of the aluminium. Prebake and Soderberg is the main reductions cell that applied in aluminium production.

Soderberg cell is made of a single anode and more so, used is design to cover the most top part of the cell. As the anode consumed, briquettes are added to the anode and get absorbed in downward through gravitational force. Prebake cell is made of a block of solid carbon which is pre-fired. The bus bars are used to hold the anodes and also used to carry the current from the required electrolyte. The process that is applied in making anodes for both Soderberg and prebake is the same. The carbon from petroleum is heated, grounded and then blended with pitch coal forming briquettes. After the paste is formed, it gets cooled. This process is repeated since the anodes are being consumed in the reduction of cells. The baking furnace is used in the production of the anodes in both technologies since it reduces the net energy consumption. The technology often uses the pits that discharge the volatiles in the air. The furnace has a bigger capacity of the anode production with low refractory mass. The baking furnace also produces the anodes that are homogenous in the baking level. Baking technology is one of the green technologies that is being used to save energy.

Approximately ninety-five percentage of primary aluminium that was produced in these industries in the years 2010 came from prebake technology, and the other five percentage came from Soderberg cells. The operations activities that are conducted in anode production are the recycling of anode materials that are being consumed, preparation of mixture electrolyte, maintenance and repairing and of the plant, equipment among others. Finally, there is the treatment of process liquids, solids and air.

Production of Anodes in these industries may be manufactured internally of getting anode from the overseas. The pitch and coke, which are used as raw material that is used in anode production, are usually available inside the plants. The sources of energy are available. The presentation global average profile has been able to reduce the footprint effect that is being produced from the production of the anode that has consumed in their respective countries.

4.3.1Production of the anodes through the Prebake technology

Petro Coke, hard coal pitch, recycled anode butt, refractory, cooling water and the steel are the material used in anode production. Electric power and thermal are the main sources of energy, and thermal energy comes from light fuel oil, heavy fuel oil and natural energy. After the production of anodes, by-products and the materials that are recycled are steel, refractory and carbon waste. The emissions that are emitted in the process are SO2, gaseous fluorides, NOX, particulates, particulate fluorides, benzo and polycyclic aromatic carbon. Water emitted is treated wastewater release, oil and particle in freshwater. The solid wastes that are getting released in the production are the non-hazardous waste, hazardous waste scrubber sludge, and refractory.

The prebake technology usually targets to produce one thousand kilograms of anode paste in one process. The raw materials are usually prepared in a hot container where then are molded in the required shape. Then the molds are transferred into bake furnace. At bake furnace, the anodes are calcined to a temperature of 1120 degrees Celsius for a maximum of fourteen days. The blocks of carbons are now able to withstand the conditions that are required inside the smelting pots. The rodding room is the last stage of anode production and in this stage, carbon blocks are well fused with a steel rod. Then prebake anodes are ready to be consumed in Aluminium smelting.

4.3.2Production of the anodes through the Soderberg technology

The raw materials are used in Soderberg technology are coke, hard coal pitch and the cooling water. Electric power, thermal energy from heavy oil, light oil and natural gas are the main sources of the energy. The result of the product is anode paste. The recycle element is carbon waste. The air emissions that get emitted in the atmosphere are particulates, SO2, NOx, benzopyrene and polycyclic aromatic hydrocarbon. Water emitted includes treated wastewater, hydrocarbon from freshwater and solids suspended in freshwater. The main solid that is emitted as waste is refractory.

The sub-plants of Soderberg are eliminated in order to form bakes where then are joined together with a block of carbons. The shape of the anode in the Soderberg cell is usually given by the steel container. At the top of the steel container, the paste is fed there, and the bakes are formed. The Soderberg anodes are considered to be of low quality. And thus, most industries prefer the prebake reduction cell than this Soderberg. Also, the prebake cells have higher current and consumed low energy. Furthermore, the emission of air and particulate is very low.

After the transfer of the anode in the electrolysis of the aluminium smelt, converting alumina to molten aluminium is done by the electrolysis process. The electrolysis is the preferred chemical process of producing molten aluminium. The process involves two main steps and the first step is to dissolve the alumina was produced during the refining process. The second step is to pass the electric current in solution and thus, alumina is broken down into oxygen and aluminium metal. Aluminium is produced by the reduction cell and the oxygen gets combined with carbon at the anode. As state in the above discussion, the synthesis aluminium depends on anode involves in the process either in Soderberg or prebake. Most industries have chosen prebake technology as the best process of producing aluminium. During aluminium production, the output starts with producing of the alumina and then ends with molten pure aluminium.

4.4 Aluminium Smelting-electrolysis process

4.4.1 Unit Process Description

Aluminium in its molten form is extracted from alumina after undergoing a series of preheating and passage of electric current through the molten mixture. This particular process involves dissolving alumina Al_2O_3 obtained via several refining steps in a molten cryolitic bath followed by a sequence of electric current passage via the solution causing decomposition of alumina into separate components: aluminium and oxygen. There are two processes of electrolysis that most manufacturers of aluminium use.

These are Prebake technology, Soderberg technology as well as the power mix model. The power mix model, however, due to disclosure and confidentiality of the information provided, I use an averaging method for their convenience .

The efficiency, as well as the emission levels, have been improved by the computerized prebake generic technology reducing the effects of pollutants and emission on global warming. This is achieved by incorporating air pollution control systems to monitor and reduce emissions. With the scrubbers leading the process, the primary is completely absorbed and taken to pots allowing recovery of the scrubbed material. Unlike scrubbers which absorb CO2 that are found in wastewater .

To complete this process, the output should be composed of molten aluminium while the input material is alumina which is later cast into primary ingots to undergo the casting process. Some of the operations linked to the electrolysis process.

4.4.2 Source of energy and material used

Some of the Ore materials for obtaining aluminium after the process are: an anode; AlF; and other used materials.

A previous description dictated that around 52 percent of alumina used in 2011 was produced in each manufacturer's plants in their respective countries industries and the rest imported from outside. Carbon anodes are partly domestically produced as well as partially imported.

4.4.3 Source of energy

Electric surge through the mixture in a process called electrolysis. It is known to serve both as raw material and as an energy provider. The electrons involved electrolysis: The end chemical reaction; the anode reactions and the cathode reactions. The electric provision in this particular process is a vital parameter that causes subsequent environmental processes as a whole. This is therefore proven to be a significant step towards the generation and recording and documenting of the LCIA. Basing an argument on the principles of ISO 14040 Series, one of its fundamental approaches is putting into keen consideration when it comes to matters of the power source generate (electricity) and the following amounts of usage at the process industry covered in this study. Since this process requires permanent and sufficient electrical power supply, the aluminium smelting companies obtain their electricity from a connection of various power sources. Power is purchased from specific power generators or via personal generating power sources. This makes it efficient when running the smelting process smoothly and efficiently. The smelting facility is generally located some distance from the power plant generator. A prolific aluminium production industry is able to establish a power source connection and identify correctly the amount of power that is supposed to be consumed within a specific period of time. The main driver for the industry for the past 5 decades was searching for a cleaner power generation who can replace fossil fuel dependence. The reduction plant that produces molten metal is generally located not that close distance from the powering facility generation.

4.4.4 Domestic Primary Aluminium Consumption Mix

Most internal aluminium usage and consumption is drawn from internal production within the previous ten years. A low percentage of metal is imported metal. There are big players in the globe when it comes to metal importing which are the USA, Norwathe y, China, Bahrain, and UAE.

aluminium smelting-electrolysis is completed by undertaking a unit process model taking into consideration adopted by the information obtained. This information is obtained from several production facilities, and an averaging method has been used for the confidentiality request .

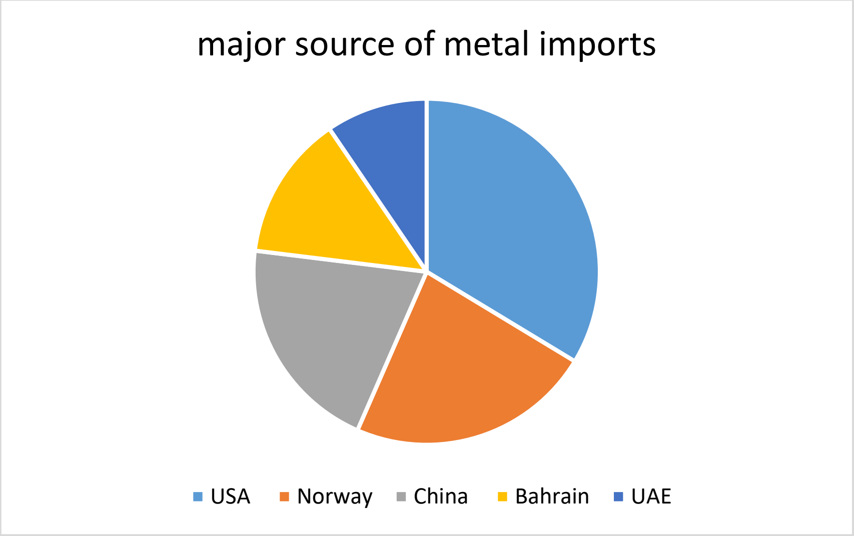

Figure 8: Major source of metal imports

Within the Aluminium smelting-electrolysis process, there are certain production models that are mostly used. In particular, these include; the prebake technology, Soderberg technology and the power mix model. However, the power mix model is normally put to the weighted average exercise in order to ensure that they comply with the regulations required for information disclosure.

4.5 Primary Ingot Casting

4.5.1 Unit process description

The molten metal is sent into a cast house in the smelters. From here, it is then transported to a mixing furnace. Here it is readjusted in accordance with the specifications given by the requested order. In some cases, there may be a need to remove impurities. After the alloying process, the next step is the removal of the impurities as well as the gas content. In general, the fluxing process is used slowly through the slow bubbling of the gases in the material. Alternatively, it is possible to achieve this through the inline degassing technology which provides the same output. In essence, fluxing is responsible for the removal of the impurities in the molten metal.

4.6.2 Raw material and Energy source

The raw used in casting is obtained from the electrolysis process, where molten metal is obtained. Since the casting is done in the same place where electrolysis of metal to give molten metal is done, then the same source of energy for electrolysis is used to provide energy for the casting process. During this process of casting of ingots, some alloys of the metal can be added to improve the features of the final ingot. Consequently, the addition of the alloy materials must be followed by the removal of some aluminium from the original molten metal used to cater to the addition and balance the total process.

4.6.3. Unit Process Model

In order to balance and account for the addition of alloy materials in the model created to represent the process of ingot casting (primary), an equal amount of aluminium products is added in the process as the alloy elements are not considered in the model. Three factors are considered while making the changes i.e., substituting the alloy elements with equal and similar aluminium products. These factors include the variation of alloying elements used in the different processes of casting aluminium ingots which depend on the final application of the manufactured ingot; most manufacturing companies usually withhold information about the alloying elements used in a particular process since this information is included in the company secrets. This is done since these additions usually account for less than five percent of the total materials present in a casting process. This is in a bid to protect the specific amount of additives and the particular elements used; the use of a conservative approach in this study ensures that the substitutions made such alloy elements used in the actual process and substituted with equal amounts of aluminium products. This approach helps to prevent the LCI from undercounting. Therefore this approach can be considered to be conservative to some extent. Table 2 below shows the inputs of the unit process used in the casting of aluminium ingots.

Table 2: Inputs in the unit process of aluminium ingot casting

Flow	Unit	Amount
Input		
Material		
High-temperature molten Al	KG	1000
Alloying component	KG	18.64
Cl	KG	1.432
N gas	KG	1.21
Hydrogen and water cooling system	KG	3488

Flow	Unit	Amount
generations		
Generation of power	kWh	53.77
Power from steam turbines	MJ	44.78
Power from fossil fuel	MJ	119.12

4.7. Primary Ingots of Aluminium Life Cycle Inventory data

The results presented here include those of producing one thousand kilograms of aluminium general Aluminium industries. The model discussed in previous sections was employed in the computation of the inventory data hereby presented. Table 5 below shows the results obtained.

Table 3: Primary Energy demand and Carbon dioxide emission in the production of one thousand Kilogram aluminium

Inventory parameter	Unit	Mining Ore	refining process	Reduction process	Casting process	Total
PED	GJ/ton	2.23	29.42	128.65	3.42	163.72
Energy used	GJ/ton	1.88	0.98	49.21	2.45	54.52
CO2 emissions	T CO2/ton	0.07	2.01	5.67	0.12	7.875

Table 4: LCI data for one thousand kg aluminium production

Inventory category	amount
Energy(MJ)	
Nonrenewable energy	8.83E+04
Resources(KG)	
Alumina ORE	6.16E+03
processing usage water	5.38E+03
Air emissions (KG)	
CO2	6.24E+03
CO	1.46E+02
Cl	2.57E-03
F	7.11E-02
HCl	3.43E-02
HF	5.25E-02
NO2	2.42E+02
N2O	8.76E-01
SO2	5.45E+02
NMVOC	3.15E+03
CH4	2.53E+04
Particulate dust matter 10	2.86E-05
Particulate dust matter 2.5	1.42E+00
Water emissions (KG)	
BOD bio oxygen emission	3.14E-02
COD oxygen chemical emssions	2.75E+03
Metals emissions	7.43E+01

Inventory category	amount
NH3	3.3E-02
Fluorine/fluorides	2.45E+03
PO3	2.13E+02
Solid waste (KG)	
Total solid waste	3316.842

4.7.1. Primary Energy Demand (PED)

This concept of energy demand is the summation of the wholesome total of energy that is extracted in the production of aluminium accounting for all the energy obtained from non-renewable sources such as s fossil fuels respectively. The efficiency of the processes involved and the power used in converting from one form to another is also accounted for. Losses while distributing and transmitting the power are also considered in the computation of the total energy demanded.

There is a fundamental difference between the energy demanded, i.e. PED and the energy consumed that might bring an understanding conflict especially to non-Life Cycle Assessment or non-technical individuals. Consumption (energy) is defined as the total energy that is used by the concerned consumers and is generally measured using a meter in the corresponding units available. For instance, the consumption of electric energy is measured using an electric meter in kilowatt-hours or natural gas in its equivalent units.

Demand, on the other hand, refers to the summation of energy that is responsible for consumption which is measured in its own format as opposed to the usable format used in the measurement of energy consumption. In this way, energy is traced to the starting point i.e. the place where it was extracted. For instance, the primary energy demand of aluminium takes into consideration all the energy used in the primary production activities processes and the energy used in the production of materials used in the primary production activities. The coefficient dictating the efficiency of energy considers the efficiency during the conversion of energy, demand for energy in primary and secondary stages which can be represented in the equation below.

$$\text{Primary Energy Demand } \times \text{Conversion Efficiency } = \text{End Energy}$$

The PED can be broken down into individual demand processes. A total of 2.2 Giga joules of energy from energy sources respectively are required to produce the 1000 kilogram aluminium . 75% of the total PED comprises the energy required in the electrolytic conversion of the metal while about 14% comprises in producing the anode. These two processes constitute the highest energy demand in the production of aluminium in this region and elsewhere in the world. The major source of energy in the first energy-intensive process, electrolysis, is electricity and its source are majorly thermal energy. Accounting for the inefficiency in the production of electricity and other forms of energy.

4.7.2. Carbon (IV) Oxide Emissions

Out of the major greenhouse gases that lead to global warming, CO2 is one of them. This greenhouse gas is normally formed during the process of converting fossil fuels such as crude oil or natural gas into another form of energy such as thermal or mechanical energy. From computation, it was found that CO2 constitutes about 7880 kilograms for every 1000 kilograms of primary aluminium produced. This figure resembles that of the PED discussed in the previous section. They, therefore, form similar curves when plotted on the same graph. Again, the electrolysis process contributes to the largest amount of CO2 released in the atmosphere, accounting for close to 5670 kilograms of greenhouse gases, CO2, for every 1000 kilograms of primary aluminium made. The CO2 emitted during the production of electricity used during the electrolytic process accounts for more than 65% of the total CO2 produced during this process making this process contribute to about 72% of the total CO2 emitted into the atmosphere.

4.8. Life Cycle Impact Assessment results

The LCIA results obtained in producing 1000 kilograms of aluminium are discussed here. In contrast to the LCI results that only shows the single components, Life Cycle Impact Assessment shows the methods used in weighing and bringing several single components together to form 1000 kilograms for possible effects of Life Cycle Inventory that is relevant.

Characterization factors were employed in the computation of the LCIA results presented in this section. Table 5 below shows the life cycle impact assessment results while producing one tone of aluminium.

Table 5: Life Cycle Impact Assessment results in producing one ton of aluminium (primary)

Impact assessment category	Unit	Alumina refining	Electrolysis	Cast house	Total
Primary energy demand	GJ/ton	30.78	104.24	2.04	137.06
Global warming potential	Ton CO2-eq/ton	2.219	6.512	0.128	8.859
Acidification potential	Kg SO2-eq/ton	15.2	40.2	0.6	56
Eutrophication	Kg Nitrogen/ton	15.2	0.526	0.015	15.741
Smog	Kg ozone/ton	188	247	6	441

4.8.1. Acidification Potential

This potential is expressed as an equivalence of Sulphur dioxide in kg represents substances released into the environment with effects that can create acidic components. Oxides of Sulphur and nitrogen form the largest amount of substances released into the environment with acidic effects. Ammonia joins this category of emission too to constitute the largest percentage of acidic emissions. The AP contributed by producing a tone of primary aluminium (ingot) in terms of Sulphur dioxide equivalent is about 56.4 kilograms Sulphur dioxide.

Out of this acidification potential, Sulphur dioxide contributes about 75% of the total acidification potential, while Nitrogen oxide constitutes about 22%. The rest of the acidification potential is contributed by fluorides and chlorides of hydrogen with each accounting for 2 percent and less than one percent respectively.

In terms of the stages at which the emissions are done, once more the electrolysis process takes the lead accounting for close to seventy-one percent of the entire AP. The second-largest contributor process is the refinement of the alumina process, which accounts for about twenty-seven percent of the entire acidification potential.

It can also be observed that the generation of electricity contributes to about seventy-four percent of the total acidification potential. Figure 9 below indicates the acidification potential while generating one tone of primary aluminium ingot.

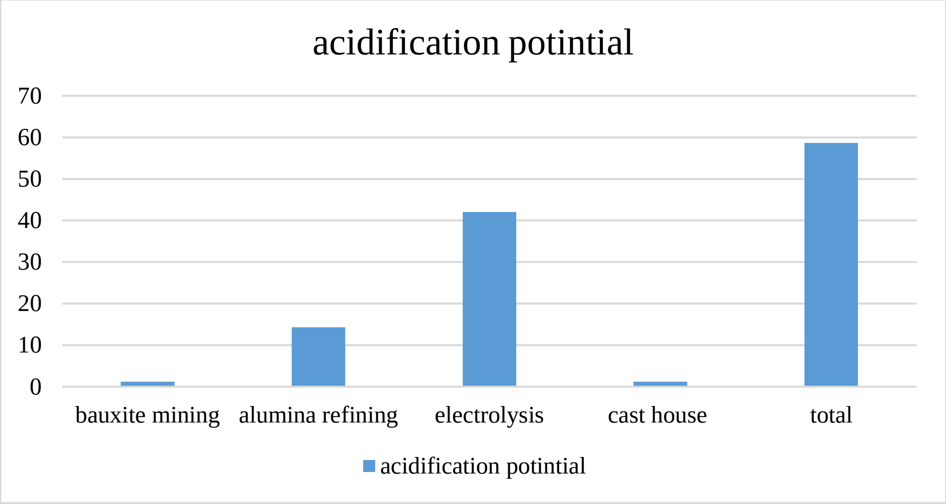

Figure 9: Results of the acidification potential while generating one tone of primary aluminium ingot

4.8.2. Potential of Eutrophication

This potential represented as an equivalent of nitrogen in kilograms is a representation of the substances released into the environment that have eutrophication impacts on the environment. The addition of more than enough nitrogen and phosphorous into the environment has eutrophying effects on aquatic regions. This addition is mainly as a consequence of using excess fertilizer. 0.97 kilograms Nitrogen equivalents are the eutrophication potential during the generation of one tone of primary aluminium. The potential as a result of the emission of oxides of nitrogen in the atmosphere accounts for about eighty-six percent of the total eutrophication potential. The rest of the potential consists of the potential as a consequence of emissions released in water. Water emissions comprise of emissions such as chemical oxygen, nitrogen oxide released in water and nitrates.

In terms of the various stages that contribute to this eutrophication potential. As seen in the previous sections, electrolysis and refinement of alumina processes take the lead, accounting for about ninety-seven percent of the entire eutrophication potential.

Out of the ninety-seven percent eutrophication potential, the alumina refinement process constitutes forty-three percent while the electrolysis process constitutes fifty-four percent. Upstream activities including generation of electricity, contribute to sixty-seven percent of the emissions released into the atmosphere. This is about two-thirds of the total potential with eutrophying effects.

4.8.3. One century Global warming potential (GWP)

This potential, which is represented as an equivalent of carbon dioxide in kilograms is a representation of the total gases with the greenhouse effect released into the environment. Some of the major gases with the greenhouse effect (cause global warming) include Carbon dioxide, methane and perfluorocarbon. These gases accelerate the rate at which the earth absorbs solar radiation and reflects it, thus increasing the warming effect such as the one experienced in a greenhouse.

The generation of one thousand kilograms of primary aluminium results in the production of a GWP of about eight thousand and nine hundred kilograms of carbon dioxide equivalent.

Carbon dioxide emission comprises about eighty-eight percent of the total global warming potential, while components of methane contribute about ten percent. The remaining global warming potential is a consequence of oxide of nitrogen and Hexa-fluoroethane with each comprising of one percent and less than one percent respectively.

Going down to the stages at which the aluminium is produced, again reveals that the electrolysis process takes the lead once more. This process accounts for about seventy-three percent of the total global warming potential. The second-largest source to global warming potential is the process of alumina refinement which accounts for twenty-five percent of the total global warming potential.

Direct release of greenhouse gases accounts for about forty-two percent of the total global warming potential. Indirect releases beat this number to account for about fifty-eight percent of the total global warming potential; this is while considering carbon dioxide emissions alone in upstream processes such as the generation of electricity.

Green House Gases analysis and their breakdown into three scopes

It is imperative to assess the release of greenhouse gases keenly to spot key areas and evaluate the impacts of the greenhouse gas releases from individual stages that comprise the life cycle process. Processed data from this analysis is handy during planning and decision-making processes.

To implement this analysis, the notion of scopes was applied to the results obtained regarding the emission of harmful gases during the generation of aluminium. GHG protocol details this notion of scopes, which was applied in this case. Since the protocol was not originally meant to be used in the analysis of products, the guidelines outlined in the protocol were followed to a satisfactory level to produce the current results. In line with these protocols outline in the International Organization for Standardization (ISO), standard 14044 the three scopes in consideration here were derived. Scope one was in consideration of the greenhouse gases emitted directly, and scope two covered greenhouse gases emitted indirectly while converting energy and scope three covered greenhouse gases emitted elsewhere in the chain of production.

Scope one: Greenhouse gases emitted directly into the environment result from production stages that are possessed or are in the control of the manufacturing company under investigation. Such sources of direct emissions include: boilers or furnaces or movers possessed or controlled by the company; equipment that generate chemicals that are possessed or are in control of the firm.

Scope two: Greenhouse gases emitted indirectly comprise the generation of electricity that the company buys from outside and consumes internally. Electricity that is bought is known as purchased electricity taken to the company boundaries. These greenhouse gases releases take place where the purchased electricity is produced.

Scope three: This includes all other greenhouse gases release that takes place indirectly. This scope permits the inclusions of emissions that were not included in the previous scope where the release of the greenhouse gases occurs indirectly. The emissions in this category are as a result of processes within the company only that the origin is not possessed or controlled by the company. For instance: emission when extracting and generating the raw materials used in aluminium ; emission when transporting fuels that are bought by port and utility department; and consumption of the merchandise that is sold by the company.

4.8.4. Smog Formation Potential/ Photochemical Ozone Creation Potential

SFP or POCP represented in terms of equivalent ozone and represented in kilograms is a representation of the releases of substances into the environment leading to summer smog or smog in small levels. This summer smog is as a result of volatile organic compounds reacting with oxides of nitrogen with UV light acting as a catalyst.

Smog Formation Potential due to the generation of one thousand kilograms of primary aluminium is about four hundred and forty-six kilograms of equivalent ozone. Releases of oxides of nitrogen comprise ninety-nine percent of the total Smog formation potential in primary aluminium production.

Similar to all the other LCI stages, the biggest source of smog formation potential is the electrolysis process which comprises fifty-five percent of the total smog formation potential. Consequently, the second-largest source of smog formation potential is the process of refining aluminium that accounts for forty-two of the total smog formation potential.

The generation of electricity that is needed in the generation of primary aluminium accounts for about seventy percent of the total smog formation potential when the process is broken down in the individual activities involved in primary aluminium production. Figure 10 below shows the smog formation potential during the generation of primary aluminium.

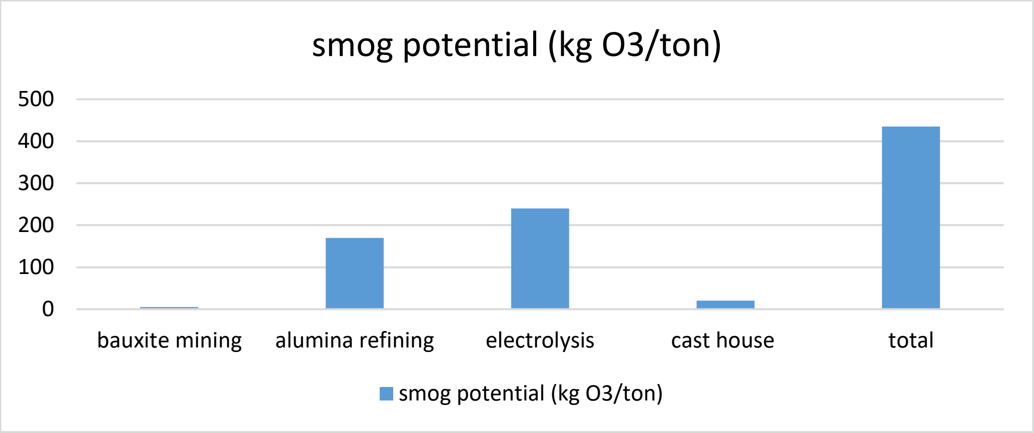

Figure 10: Results of the SFP in generation of primary aluminium.

The electrolysis process accounts for the largest percentage of SFG constituting fifty-five percent of the total smog formation potential. Out of this percentage, seventy percent is associated with the generation of electricity.

4.9. Recycling/ Secondary production of Aluminium

4.9.1. Process Description and Modelling

In the secondary production of aluminium or the process of recycling of this metal, scrap is used (AA, Aluminum Recycling Casebook). The scrap is normally gathered in what is termed as 'mining' then grouped in particular select groups and washed before use in the generation of new aluminium ingots. Aluminium recycling is composed of two processes that are at the heart of this process. One of the major processes is re-melting. The second process is casting.

Aluminium scrap is melted in a rotary or electric furnace to turn it into a molten form. The molten metal undergoes purification and adjustment of the alloy content to the desired level. Finally, the metal is made into a shape that is good enough to allow the next step in the fabrication process. Reverberator furnaces also exist and are used sometimes to melt aluminium scrap. Aluminium scrap which acts the raw material for secondary production of aluminium can either be new or old.

New scrap is formed during the fabrication process of final products using cast or wrought. The processes followed during fabrication of aluminium be it semi or final processes produce scrap aluminium of varying amounts depending on the desired features of the final product and its intended use.

Old scrap, on the other hand, is obtained from aluminium goods that have been used by their intended consumers and have been discarded then collected. Example origin of old aluminium scrap includes motor vehicle parts e.g. body, wheel rims, brake pads, hood etc.; scrap obtained from aluminium used in the construction of buildings; merchandise used by the general consumers including bottles, cans used for beverages, utensils, aluminium covers of some electronics etc.

Another source of aluminium scrap is the waste generated during the generation of either primary or secondary aluminium resulting in waste aluminium called dross/salt cake. The recycling of this kind of aluminium scrap significantly reduces the amount of waste that is witnessed in production hence fulfilling the industry’s commitment to lowering waste.

4.9.2. Collecting of crap and process it

4.9.2.1. Unit Process Description

Scrap is normally found in areas that are highly populated e.g. towns or cities as opposed to the raw material for primary aluminium and it exists as part of a larger object or just as a single piece just lying around on the ground. This is so because the scrap is found from used products hence found where there are a lot of people who are likely to consume the aluminium products.

The people involved in ‘mining’, essentially collection is almost all the people in a given society either as a duty as a good member of the society concerned about the environment or as a result of wanting to gain a monetary reward through the collection. Collection of scrap is mainly taken as part of another process/activity since it results from the occurrence of another activity such as consumption of the aluminium product, demolishing of a construction in which an aluminium product was used, the repair or wreak of motor vehicles etc. For this reason, the activity of collecting the scrap is taken to be a green-collar type of work.

Once the process of collecting the scrap metal is completed, it is then grouped according to alloy content, cleaning is done, and pre-fabrication takes place. Grouping/ sorting of the scrap involves placing the various parts together such that alloy groups are formed. Cleaning involves degreasing, dirt removal etc. Prefabrication involves activities such as cutting it into small pieces, crushing, removal of coatings etc. Prefabrication enables to lower the amount of aluminium in later processing steps and the harmful releases to the environment during processing.

The first step in secondary processing involves transportation of the scrap metal to where it is stored in a given facility. Some of the activities carried out during this first step include:

- Transportation and receiving of the scrap metal once it is collected.
- Separating the scrap into various groups according to the alloy content in each piece of scrap.
- The aluminium scrap is then heaped together
- Parts that are connected to others are disconnected, those that are inside are dismantled, and the scrap metal can also be cut into small pieces or compressed.
- Dirt and grease/oil is then removed from the scrap metal and left to dry
- Paint and coatings are then removed by the use of some heat source and partially melted.
- The parts that can be used are then taken
- The facility is then maintained or repaired
- The matter is then treated.

Once all or some of the above-mentioned activities take place, the resulting scrap is acceptable to proceed in the next steps of processing to act as new aluminium scrap. This scrap is now taken to the facility where recycling of aluminium takes place.

4.9.2.2. The origin of used raw material and used energy

The raw material was for recycling of aluminium is obtained from the facilities that deal with aluminium, other industries and residential areas where waste is normally dumped.

The energy used in recycling and all other pre-fabrication activities such as a collection of scrap comes from the local regions, and the various forms range from electricity to fossil fuels.

4.9.2.3. Inputs and Outputs in a unit process

Table 6 below shows the inputs and outputs that go into producing one tone of aluminium used as a raw material in aluminium recycling.

Table 6: Processing of secondary aluminium inputs and outputs while producing one tone of secondary aluminium raw material.

Flow	Unit	amount
Input		
Material		
Unprocessed aluminium scrap	kg	1040.33
Filter media	kg	0.0013
Hydraulic oil	kg	0.1356
Calcium oxide	kg	0.8861
Lubrication oil	kg	0.0092
Refraction process	kg	0.0733

Flow	Unit	amount
NaSiO2	kg	0.3390
Water	kg	1.4878
Energy		
Electricity	kWh	114.33
Natural gas	MJ	897.34
Output		
Products		
Pre-processed aluminium	kg	1000
Waste for recovery		
Fluff from shredder	kg	4.7334
Steel scrap	kg	4.0022
Scrap from metal	kg	2.6004
Oil usage	kg	0.0401
Waste for disposal		
Particulate matter	kg	1.3782
Dust particles	kg	0.0047
Solid waste	kg	7.1122
Baghouse lime	kg	0.0899
Emission to water		
Water	kg	1.0556

4.9.3. Melting and Casting of the secondary aluminium raw material

4.9.3.1. Unit Process Description

This section covers the processes involved in turning the metal into molten form, adjustment of the alloy metal present in the aluminium raw material and the subsequent shaping through moulding to make it into desired shapes for processing later.

4.6.3.1.1 Melting

Turning the raw material into molten form is carried out at high temperatures above seven hundred degrees Celsius in furnaces which varies in terms of appearance or the source of power, e.g. they could be powered using electricity, they could be rotary or be the crucible types.

Majority of the scrap is melted in furnaces known as reverberated and rotary ones since they are readily available in most melting facilities. They are normally applied in melting of scrap that has multiple grades. The source of energy in these furnaces is gas and can handle scrap ranging between fifteen thousand and one hundred and twenty-five thousand kilograms of scrap aluminium at a go. The first type of furnaces can further be classified into either one or many chambers considering the design of the furnace. The second type is applied in turning scrap that has high oxidation levels into a molten form. When a small amount of scrap needs to be melted, crucible furnaces are employed to carry out this gig. Electric ones are powered using electric energy.

The flux used in covering the scrap while it undergoes the process of melting is salt which is made of a mixture of chlorides of sodium and potassium and other elements. The flux serves to reduce the wastage of the metal when it comes into contact with the air becoming oxidized. It also carries cryolite added to the flux to the edge of the molten metal to remove coatings of the oxides that may have formed. This helps in stockpiling the molten scrap at the bottom of the furnace, therefore, enabling to obtain more metal that is almost pure.

The reverberator furnaces can be applied to supply two or more secondary furnaces that hold the molten metal as it undergoes further processing. This is because these furnaces can handle huge amounts of scrap at ago compared to other types of furnaces. This type of furnace carries out the first steps in the melting process such as melting, fluxing and impurity removal. Then the molten metal is taken the secondary furnace discussed above where further processing is done such as adjustment of the alloy content in the metal to meet the required standard. Contaminants present in the molten metal can be skimmed off from the surface by the use of other gases such as nitrogen to bring them to the surface from the bottom in a bid to meet the requirements made by a given customer. This is done considering the materials that compose given scrap metal.

4.9.3.2. Alloying

Once impurities are removed from the molten metal, alloying necessary to add the needed characteristics in the metal. By alloying/ addition of some elements, the chemical properties of the original metal are adjusted to suit particular requirements. Common elements used to alter the chemical properties of scrap molten metal include magnesium, copper and silicon. The chemical properties are checked at every go, and the process of addition of alloying element and checking is repeated in a cyclic manner until the required mixture is arrived at.

After the processes of melting and alloying to the required specification, the metal can be transported to the next facility for further processing. This can be done while the metal still in molten form or cast into ingots or other similar forms in which the metal can be made such as billet or cones. There are a number of ways in which further processing can be done and the way that is selected is dependent on the final required standards and customer requirements.

4.9.3.3. Casting

This involves pouring the molten metal into molds through which the metal is formed into required shapes for further processing. Through casting ingots are obtained, this can be done directly through DC or through putting the molten metal in prepared molds. The way that is applied is dependent on the intended final application of the metal.

4.9.3.4. Emissions

The facilities that melt and process the scrap usually emit dust and other harmful substances into the environment. VOCs and PAH categorized as part of VOC are usually released from these facilities into the environment. These substances are released to the environment as a result of the vaporization of the flux used, i.e. salt and the removal of impurity coating on the scrap during the melting process. Laws and regulations aimed at Environmental conservation bind the facilities to try as much as possible to reduce these emissions. The full combustion of these substances in a closed circuit is normally carried out in the latest furnaces to reduce emissions and improve how energy is consumed. Control of emissions is achieved through the use of scrubbers. Some of the gases that constitute part of the emissions such as VOCs are trapped using calcium carbonate.

4.9.3.4. Summary of the unit description of the process

In summary, to melt and cast the scrap into ingots, the process starts with transportation of the scrap to the processing facilities where it is first stored once collected. Some of the activities carried out during this step are:

- Transportation and receiving of the scrap metal once it is collected.
- Separating the scrap into various groups according to the alloy content in each piece of scrap.
- The aluminium scrap is then heaped together
- Parts that are connected to others are disconnected, those that are inside are dismantled, and the scrap metal can also be cut into small pieces or compressed.
- Dirt and grease/oil is then removed from the scrap metal and left to dry
- Paint and coatings are then removed by the use of some heat source and partially melted.
- The parts that can be used are then taken
- The facility is then maintained or repaired
- The matter is then treated.

Once this is completed, scrap that has been melted and casted is obtained and taken to facilities where it undergoes further processing.

4.9.3.5 Origin of raw material & Energy

The products of the unit step discussed in the preceding section are the origin of raw material. A facility can choose to process and treat its own scrap or buy one that is already processed and treated from firms that specialize in this kind of activity. Other materials needed in this step come from domestic places.

The major source of energy in most facilities is electricity or gas. Therefore, when electricity is used, the corresponding furnaces are used. In this region, electric energy is not owned nor bought from specialized firms, and it is bought from utility firms that are located in the local region.

4.9.3.6. process inputs and its outputs

Process transformation can involve two separate and distinct activities: recycled and secondary production. The fundamental distinction between these two is that they may or may not involve the process of adding alloy materials and some primary metals. The second activity involves these two processes while the first one doesn’t. The reason for separating the two is to give facts and figures that are specific to particular facilities clearly and distinctively. I advise the users of the information in this to employ their distinctions while employing this information in specific areas.

The formats adopted here include those of recycling and secondary production, these two formats serve to enable the users to carry out LCAs, compute origin to death inventory and analyses the environmental impacts of the processes. Recycling ensures all the three functions are achieved while secondary production assists with the achievement of the first two functions.

4.9.4. Recycling of Dross & Salt cake

4.9.4.1. Unit Process Description

Dross is formed during melt and cast process of scrap when the molten metal is oxidized by air forming and oxide of aluminium. The conditions surrounding the melting and processing of scrap aluminium dictates the amount of dross formed as a consequence. The amount of aluminium contained in dross can vary depending on conditions surrounding its formation; it can be as little as five percent or as much as eighty percent.

When salt is used as a flux during the melting of aluminium scrap, some of it reacts with oxygen to form an oxide and a mixture with other contaminants forming what is known as Salt cake. The amount of aluminium metal in slat cake ranges between three and five percent and is collected when it floats on the melting scrap.

There are two statuses through which recycling salt cake and dross can be done, and these are: hot and cold. The hot status is done in a facility that has the capability of carrying out this kind of processing such that after skimming it during melting of scrap aluminium, it is processed immediately before it cools down thereby using less energy. On the other hand, cold status is where the skimmed dross or salt cake is left to completely cool down before it is taken for reprocessing in a completely different facility. The cold status always consumes more energy since it requires to be reheated as compared to the hot status. When cooling to achieve the cold status, the molten metal is cooled using a rotary device with an inert gas such as argon is applied to prevent reaction with oxygen present in the air.

During this recycling process, concentration is done such that the material with much content of aluminium is brought together and impurities such as salt and others can be removed from them main molten metal. The dross is crushed, milled and screened to separate larger and smaller metallic parts since the former has a high content of aluminium compared to the latter pieces. The larger particles are then taken for melting in a furnace or other fabrication processes while the smaller particles which are mainly composed of salt is taken for processing to extract salt which is also used again in the process of melting.

The dross is taken for melting and undergoes the same process that scrap metal undergoes. Furnaces that can rotate or tilted are used in the process of melting the dross or salt cake. In order to remove impurities from the molten metal, salt is added in the mixture the same way in which it is done during processing scrap metal. The by-products in the process of melting dross or salt cake are materials that are not metallic in nature; hence they are disposed of in a designated site or can be used as inputs in some kilns.

To summarize, the process of recycling the by-products of scrap melting, i.e. dross or salt cake starts by the transportation of the by-product and other required materials to where they are stored. The major steps involved in this process are:

- Transportation and storage of the dross/salt cake and other necessary materials;
- The by-product is crushed, milled and screened to remove contaminants from the needed metal;
- The processed byproduct is melted and refined and purified;
- Melting in furnaces is done in batches, and then the resulting metal is casted;
- Removal of salts from the remaining molten metal;
- Packing to prepare for dispatch;
- The plant is maintained and/or repaired;
- Significant parts are treated.

The final product from the entire process is processed aluminium that can be in shapes such as ingots that are packed and shipped for further fabrication processes.

4.9.4.2. Inputs and Outputs

Table 7 below shows the inputs and outputs in the process of recycling dross to produce one tone of aluminium. It indicates the number of inputs and inputs in terms of energy, emissions etc. that go in and out while producing one tone of aluminium from dross or salt cake i.e. By-products of scrap melting.

Table 7: Recovery of one tone of aluminium from dross inputs and outputs

Flow	Unit	Amount
Input		
Material		
Concentrated dross and salt cake	KG	2676.654
Argon	KG	17.667
Sodium chloride	KG	155.321
Potassium chloride	KG	52.456
Cryolite	KG	3.1455
Refractory	KG	0.7543
Quicklime	KG	17.245
Energy		
Electricity	kWh	220.5
Fusil fuels	MJ	6021.456
Outputs products and wastes		
Output Products		
Aluminium ingots (recycled)	KG	1000

Flow	Unit	Amount
Used oil	KG	0.1211
Output Waste for disposal		
oxidized waste of aluminium	KG	111.245
Particulate matters filtration	KG	64.5677
Refracturing by product	KG	2.7313

4.9.5. Life Cycle Inventory on recycling production and secondary production results

In this section, a presentation of the most relevant life cycle inventory results of recycling and secondary production of aluminium results is done.

4.9.5.1 Primary Energy Demand (PED)

A huge chunk of the primary energy demand is taken up by the melting of scrap metal which accounts for about seventy-nine percent of the total PED. Of this percentage, the main source of energy is non-renewable sources of total primary demand.

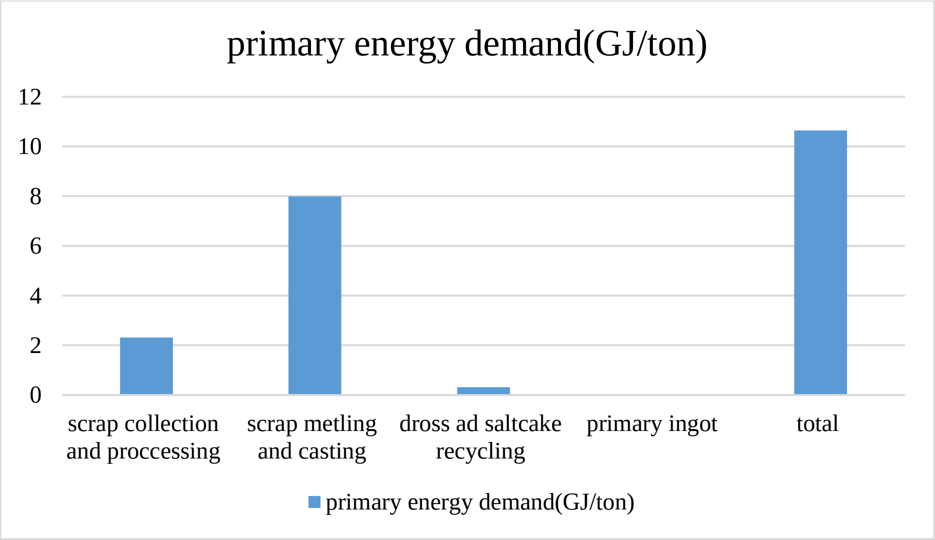

Figure 11: PED of recycling and secondary production of aluminium to produce one tone of aluminium

4.9.5.2. Emission of Carbon IV Oxide

In a similar manner to primary energy demand, the largest amount of carbon dioxide released into the environment is a result of melting and casting aluminium scrap. Emission of carbon dioxide during this process accounts for about eighty percent of the total carbon dioxide released into the environment. This is seen in the process of recycling aluminium.

In the process of secondary production of aluminium, adding primary metal accounts for forty-four percent of the total carbon dioxide released into the environment. In a similar manner, the process of melting and casting of the processed metal accounts for forty-four percent of the total carbon dioxide releases into the environment.

4.9.6 Life Cycle Impact Assessment Results

Table 8 next page shows the results of the life cycle impact assessment in the production of one tone of secondary or recycled aluminium.

Table 8: Life Cycle Impact Assessment results in the secondary production or recycling of one tone of aluminum

Impact assessment category	unit	Amount of collecting scrap	Melting the scrap and recycling it	Recycling the dross	Primary ingot	Total
PED	GJ/ton	2.21	8.43	0.42	0	11.06
Global warming potential	Ton CO2/ton	0.12	0.42	0.037	0	0.577
Acidification potential	Kg SO2/ton	0.312	1.678	0.025	0	2.015
Eutrophication	Kg Nitrogen/ton	0.021	0.004	0.045	0	0.07
Smog	Kg monoxide/ton	3.54	21.43	0.43	0	25.4

CHAPTER FIVE: RESULTS, CONCLUSION AND FUTURE STUDIES

The study carried out in this project serves to not only update existing life cycle inventory, and life cycle impact assessments carried out in the world but also give the first LCA and LCIA and provide information to concerned stakeholders for proper planning and decision making. Various processes in the production of aluminium products have been discussed and their LCI and LCIA results presented in the previous chapter.

It was noted that a: -

- A higher percentage of emissions to the environment is related to energy. This was mainly in the generation since most of the energy used comes from non-renewable sources such as fossil fuels.
- Based on the data obtained in the recycling of aluminium, that recycling should be encouraged to reduce the aluminium product footprint in the environment after use, consequently reducing the energy demand.
- A reduction in energy demand reduces emissions and their impacts on the environment.
- The electrolysis process has been the main contributor to most of the indicators, and this will be the focus of future sustainability studies.

In conclusion, an improvement in the technology used in production will increase the energy efficiency of the processes, in turn, this reduces the demand for energy consequently reducing the emissions. This will help mitigate the effects of these emissions. In addition, recycling should be encouraged in order to assist in reducing the primary energy demand in production. For future study, it is highly recommended to integrate bot sustainability with quality control for a better achievement of sustainability goals and maintaining high quality of product outputs in the metal industry. Using advanced quality monitoring techniques such as univariate, multivariate control charts are crucial to maintain high level of product and process outputs (KA 2018; GA 2019; JK 2019). These tools would provide the management with a data-driven framework for achieving sustainability thought the reduction of material and energy waste.

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