

LIFE CYCLE ENGINEERING CASE STUDY: SULPHURIC ACID PRODUCTION

J. A. Adeniran^{1*}, R.O. Yusuf¹, M.A. Adetoro¹

¹Department of Chemical Engineering, University of Ilorin, P.M.B. 1515,
Ilorin, Kwara State, Nigeria

Article History: Received 6.10.2016; Revised 1.6.2017; Accepted 19.9.2017

ABSTRACT

Sulphuric acid is an essential basic chemical in the world. This chemical is used in different industries, and is mainly sold as intermediates applied in a range of products. This study investigated the life cycle assessment of sulphuric acid production in commercial scale in Nigeria by identifying the processes that contribute significantly to the hotspots and the impact the product has on climate change. The data gathered for the study represents operations at a major plant in Nigeria. System boundaries were established using a cradle to gate approach, based on primary data from the plant. Secondary data was obtained from the US database. Sulphuric acid plant process simulation was done using Aspen HYSYS 2006-aspen ONE from ASPENTECH. GaBi life cycle assessment (LCA) software, (PE International) was used to evaluate the environmental impact of the process. The work was done in accordance with ISO 14040 series LCA standards. The weak point analysis identified the raw material stages as areas of weakness in the sulphuric acid model. The assessment in this study identified the raw material stage; elemental sulphur at plant as the main contributor to the carbon footprint with emission to air amounting to 4×10^7 kg. The total CO₂ emission the sulphuric acid model is 1.24×10^7 kg with approximately 0.66% direct emission from fuel combustion in the plant. The opportunity for improvement in terms of emission reduction is in reduction of energy consumed by replacing fossil based material with bio-based material. An advantage of this study is that the methodology applied can serve as a means for determining the carbon footprint of other sulphuric products. This study has shown that life cycle assessment has a potential to identify hotspots of a product to find strategies to sustain the environment.

KEYWORDS: Sulphuric Acid, Life Cycle Assessment, Greenhouse Gas, Inventory, Emissions

1.0 INTRODUCTION

Drastic measures to reduce greenhouse gas emissions (GHG) are needed to tackle the current global environmental challenge. There is high consumption rate of sulphuric acid around the world due to its wide application. Increase in consumption of this chemical

* Corresponding e-mail: adeniran.ja@unilorin.edu.ng

cannot be dissociated from the serious environmental deterioration potentials the manufacturing process may portend across the globe. Technological improvements in energy efficiency have not decreased energy use as a result of increased total production such that per capita consumption continue to rise drastically including constantly growing greenhouse gas (GHG) emissions (Lenzen and Shauna, 2001; Rood *et al.*, 2003; Hauschild *et al.*, 2013). Currently in Nigeria, there are two sulphuric acid industries in operation. Its wide use has prompted the need to expand the sulphuric acid industry to conserve the nation's foreign exchange by reducing importation of materials or products that requires this chemical in their production. It is estimated that emissions in developing countries may surpass those of developed countries due to the rapid rate of urbanization and thus necessary to examine the steps involved in the life cycle of a product system as this will help in addressing environmental issues without compromising developmental needs and priorities.

Sulphuric acid is one of the most important chemicals in the world. It is an essential basic chemical widely used in different industrial sector, the prosperity of a nation can be measured by the amount of sulphuric acid used annually (Chowdhury *et al.*, 2012). Sulphuric acid is the parent substance of modern chemical industry. The major use of sulphuric acid either directly or indirectly is in the production of phosphate fertilizers, explosives, dyes and pigments, other acids, purification of petroleum, pickling of metals. It is also used in electroplating, non-ferrous metallurgy in the production of rayon and film, as a laboratory reagent, storage batteries. Sulphuric acid plants are a significant source of sulphur dioxide, as well as nitrogen oxide, particulate matter, volatile organic emissions and other pollutants which are associated with certain health and environmental impacts. SO₂ is also a primary contributor to acid deposition, or acid rain. Nitrogen oxides (NO_x) contribute to a variety of health problems and adverse environmental impacts, such as ground-level ozone, acid rain, global warming, water quality deterioration, and visual impairment (USEPA, 2015).

The need to evaluate environmental and energy burdens associated with the entire life cycle of the process is important so as to have a clear understanding of the emissions emerging from the production of sulphuric acid and devise means of environmental improvement. A method put in place to examine the environmental impact of a process, product or service from a life cycle perspective by identifying the material and energy use, and the waste discharged into the environment is called life cycle assessment (Jacquemin *et al.*, 2012; Hauschild *et al.*, 2013).

The assessment discloses the demand in resource, process and product emissions and waste and then allocates these to environmental impact categories (ISO, 2006). These categories could include acidification, global warming potential, ozone layer depletion, human toxicity, freshwater aquatic ecotoxicity depending on the method used in the impact assessment.

A subset of life cycle assessment data is the carbon footprint calculation, which specifically describes the total amount of GHG emissions caused directly or indirectly by an individual, organisation, activity or product (Carbon Trust, 2012; Padgett *et al.*, 2008; Sinha and Cass, 2009). Carbon footprint is synonymous to the calculation of the global

warming potential (GWP), computed by summing the emissions resulting from every stage of a product or service's lifetime which include material production, manufacturing, use phase, and end-of-life disposal (Centre for Sustainable Systems, University of Michigan, 2013).

Few life cycle assessments studies have been reported on the manufacturing process of sulphuric acid. The assessment by Kennecott Utah Copper Corporation (2006) focused more on life cycle assessment of sulphuric acid originating from their operations by quantifying four main impact categories: Primary energy demand, Global Warming Potential, Acidification Potential and Photochemical Oxidant Creation Potential. Combustion of fossil fuels to generate electricity on-site and off-site and emissions from the acid plant were identified as key areas for environmental improvement.

The emission inventory guidebook (2006) studied emissions released from sulphuric acid production while taking into account emissions released from all process steps but did not indicate that life cycle assessment was used for the analysis. This paper covers both the GWP and the other environmental impacts. The impetus for this work lies in the fact that there has been little or no work on life cycle assessment of sulphuric acid production in Nigeria. The published life cycle assessment studies in this area were case- or site-specific; they are based on inventory from industry at a specific site, which in many cases limits the validity of the conclusions of those life cycle assessments to those sites only. The goal of this study is to estimate the environmental impact of sulphuric acid production from cradle to gate by determining the areas which account for the greatest share of the company's operational emissions, in accordance with ISO 14040 series life cycle assessment standards.

2.0 DESCRIPTION OF THE PRODUCTION PROCESS OF THE CASE STUDY

2.1 Production of Raw Materials

To simplify the analysis, it was assumed that Drury industry sulphuric plant uses elemental sulphur recovered from petroleum refining and natural gas in operation at the plant's location. Hence, there was no need for data on transportation of natural gas and petroleum products for power generation. Recovered elemental sulphur are primarily produced to comply with environmental regulations that applies directly to emissions from the processing facility or indirectly by restricting the sulphur content of the fuels sold or used by the facility.

2.2 Manufacturing Process

Moist air is dried in the drying tower using 98% sulphuric acid. Elemental sulphur is fed into the melting pit and is melted by means of the heat provided through steam coils. Molten sulphur is pumped to the pressure leaf filter and the purified sulphur along with the dry air is pumped into the sulphur burner to produce sulphur dioxide. The sulphur dioxide is converted to sulphur trioxide by passing through 4 converter beds (Figure 1). The

sulphur dioxide from the sulphur burner is passed through 1st and 2nd waste heat boiler to lower the temperature before and after entering the 1st converter bed respectively. Between each of two consecutive converter beds, there are economizers (heat exchangers) for the same purpose.

Finally, the outlet gas from the 4th converter bed is passed through an economizer. This cool gas, containing sulphur trioxide, is fed to an absorption tower where it reacts with 98% sulphuric acid to form 99.0% sulphuric acid. The gases emitted through the stack from the absorption tower consist predominantly of nitrogen. The 99.0% sulphuric acid is fed to circulation tank along with demineralized water and, 98.0% sulphuric acid which comes from the drying tower. The resulting concentration of the sulphuric acid exiting from the circulation tank is 98.5%, which is split into two portions. One portion is cooled using heat exchanger and recycled back to the absorption tower. The other portion is also cooled and further split into two portions; one of which is the final product (98.5% sulphuric acid) and the other portion is recycled back to the drying tower. The block diagram of the sulphuric acid plant is shown in Figure 1. The simulation using HYSYS^R shown in Figure 2.

2.0 METHODOLOGY

Sulphuric acid plant process stimulation was done using Aspen HYSYS 2006-aspen ONE. The software is an optimal choice for simulating the processes involved in the production of sulphuric due to its excellent property databanks, which are required to model all thermodynamic interactions (Aspen HYSYS, 2006). COM thermo was selected as advanced thermodynamics databank in the fluid package in order to simulate the process as accurately as possible. In model phase selection NRTL was selected for liquid phase and Peng-Robinson was selected for vapour phase. Some process operational data of the sulphuric acid plant of Drury industries were used for stimulation. GaBi software from PE international was used to evaluate the environmental impact of the product. The simulation of the production process using HYSYS^R is shown in Figure 2. Figure 3 shows the life cycle assessment methodology used for this study.

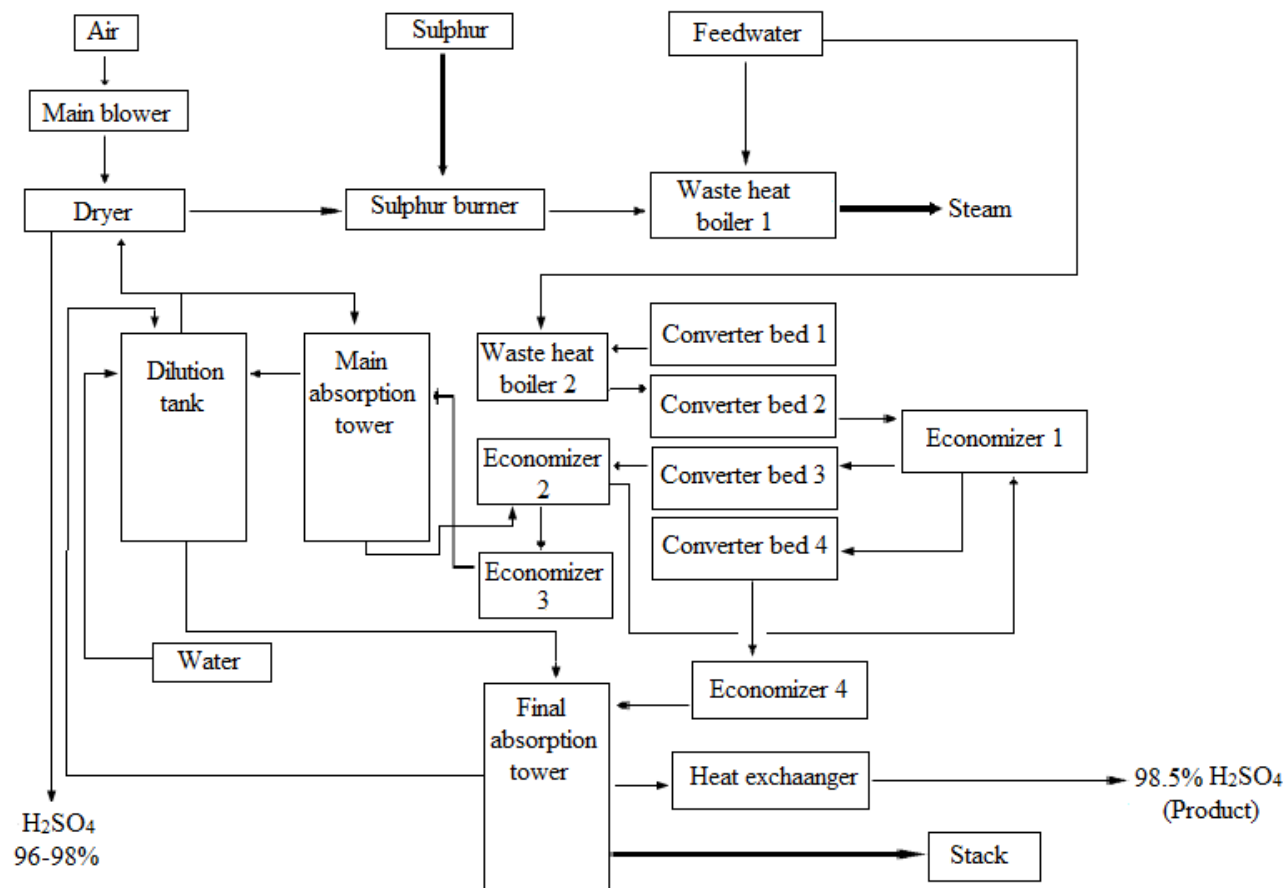


Figure 1: Block diagram of sulphuric acid production

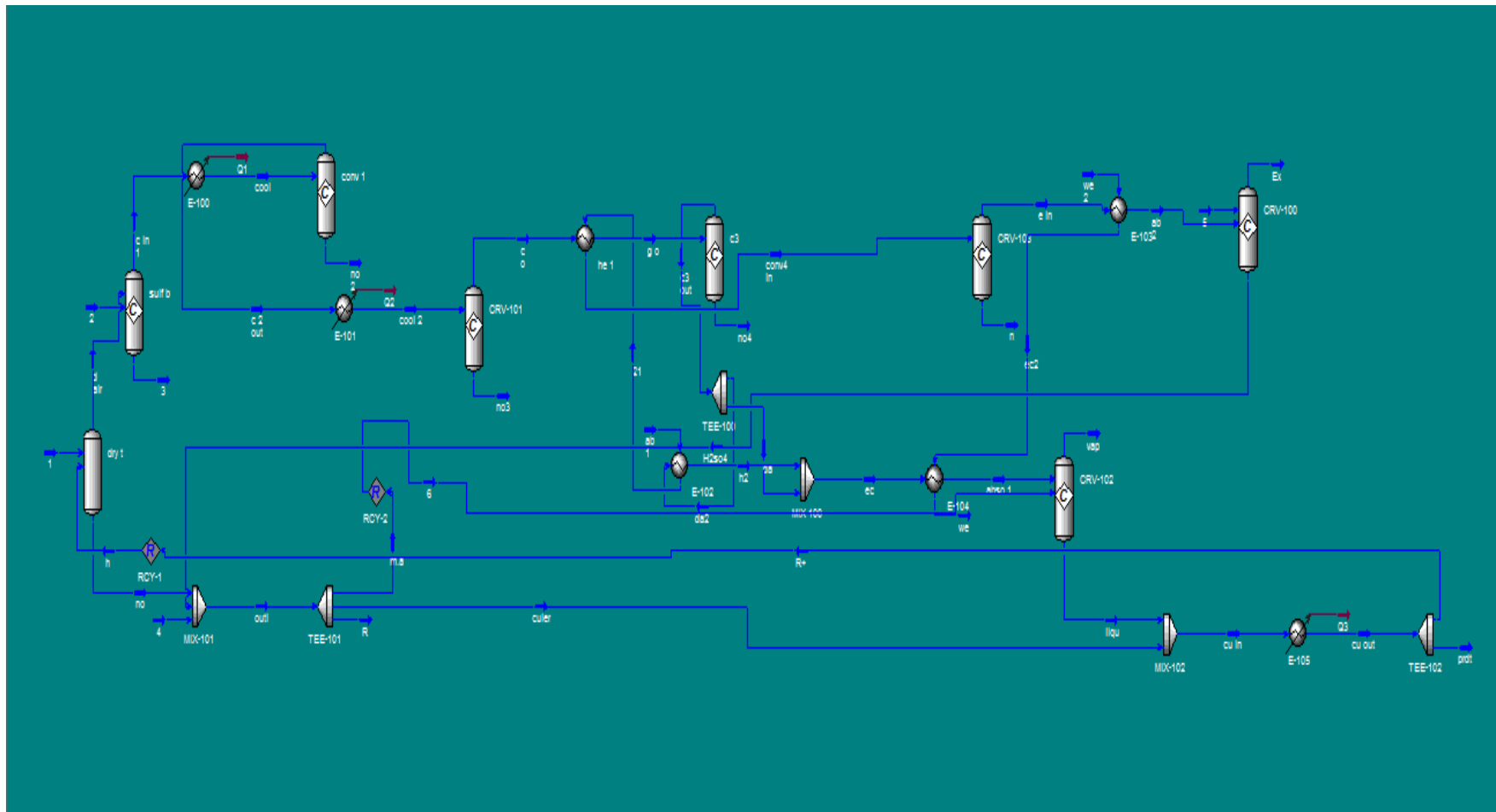


Figure 2: Simulation of sulphuric acid production process

3.1 Goal of the Study

The intended use of the study is to identify environmental hotspots in the life cycle of sulphuric acid production. The purpose of carrying out the life cycle assessment is to estimate the carbon footprint of sulphuric acid produced in Nigeria and identify the stages that contribute majorly to the hotspots. The results are then interpreted and used to make more informed decision in addressing environmental issues related to the process without compromising developmental needs.

The life cycle assessment study is undertaken for academic research purpose; the target audience for this report is my school's department internal staff (internal knowledge generation). This work was done in accordance with ISO 14040 series life cycle assessment standards (ISO, 2006a; ISO, 2006b) for a project not making product comparisons for public disclosure. The data gathered for the study represents operations at Drury industry plant in Nigeria during year 2010.

3.2 Scope of the Study

The scope of this lifecycle assessment is to evaluate the environmental impact of sulphuric acid with respect to its life cycle analysis. The purpose of this study is to estimate the carbon footprint. The system considered would be from cradle to gate. Distribution, use and disposal phase is beyond the scope of this analysis. The study covers all lifecycle activities associated with the extraction and processing of raw materials and energy input into the process as well as production processes within the process system boundary.

The end of life and disposal phases of the product was not taken into consideration in the system boundaries because sulphuric acid is mostly an intermediate product used in large number of end product and there is significant uncertainty as to the uses and disposal phases of the product. To estimate the carbon footprint of sulphuric acid plant, this paper considers Drury industry plant- a sulphuric acid plant in Nigeria as case company.

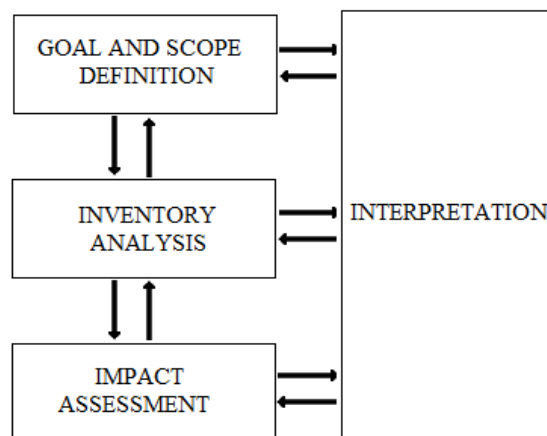


Figure 3: Interactions between life cycle assessment stages as defined by the international ISO 14040 and 14044 standards. Source: Masanet *et al.* (2013)

3.3 Functional Units

In a life cycle study, products are compared based on providing the same defined function called the functional unit. The functional unit in this analysis is to provide a grade quality of 98.5% of 1kg for one year. The reference flow is sulphuric acid aq. (98%) - 1 kg (Mass). The model in GaBi was later scaled up to 50000 metric tonnes per annum.

3.4 System Boundary

The assessment is conducted by defining product systems as models that describe the key elements of physical systems. The system boundary defines the unit processes to be included in the system. The criteria used in setting the system boundary are important for the degree of confidence in the results of a study and the possibility of reaching its goal. The system boundary used in this study is according to ISO 14040.

This study's lifecycle assessment used a cradle to gate approach. Thus the sulphuric acid product system investigated includes the materials and processes from raw material extraction/recovery through the production phase (gate of the factory). The distribution, use and reuse, and end of life stage were excluded. The system boundaries are defined so that all inputs and outputs from the system are either elemental flows or materials or energy entering another product life cycle. Therefore, the study quantifies all energy and materials used, starting from extraction of resources, and the emissions from the two life cycle stages. Figure 3 shows a simple flow diagram, which defines the system boundaries for the study.

In defining the production system, it is necessary to specify the particular unit processes or flows that are excluded from the system boundaries. We apply what are known as "cut off" rules in our system boundaries to make the life cycle assessment feasible from a time and resource perspective, since it's impossible to trace back every flow. In this study, the flows associated with manufacturing capital equipment, transportation equipment, or manufacturing plants were excluded.

3.5 Allocation Procedures

Allocation which refers to the process of choosing which flows to attribute to a product system when such flows are shared with other product systems. Product life cycle systems occasionally yield other products or services as well as the functional unit. The international standard ISO 14044 (ISO, 2006) gives a stepwise procedure for the allocation of material and energy flows as well as environmental releases when this occurs. Allocation should preferably be avoided either through an increase in system detail or through system expansion, where the product system is credited with the avoided burdens delivered by its co-products.

The product system is assumed to produce a single product, so no allocation is needed. In addition, the project scope and boundaries do not include all the things that might influence energy use such as pumps, compressors, shell, ambient temperature, consumer behaviour.

3.6 Data Quality Requirements

A detailed product life cycle assessment requires primary data on the materials, energy, waste and emissions specific to the production, use and disposal of the product. The inventory is mainly based on industry data and is completed, where necessary, by secondary data. This data set is based on primary data from internationally adopted production processes. The primary data from Drury industry sulphuric acid plant used in this project include the material types, weights and process conditions to manufacture sulphuric acid.

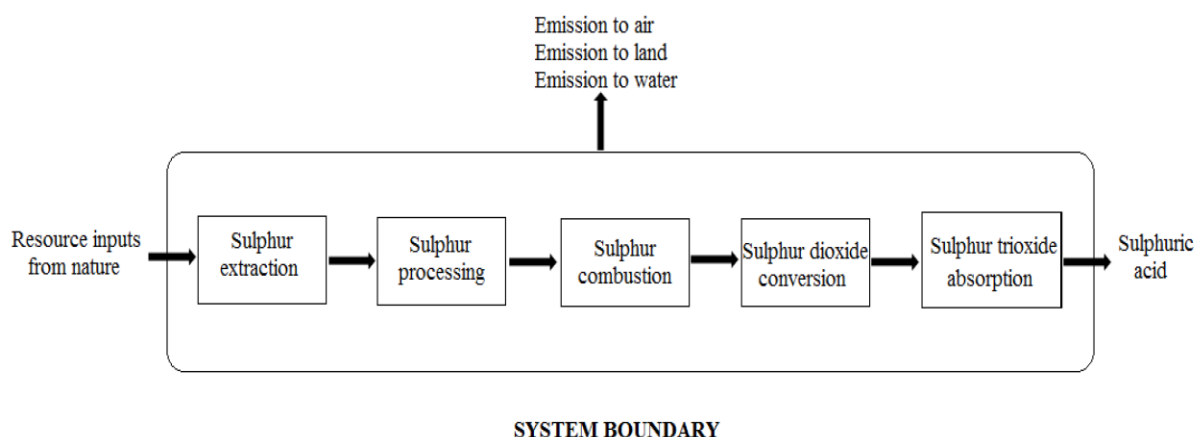


Figure 4: System boundary diagram of the unit processes within sulphuric acid product system

Secondary data from US database and GaBi, a commercial life cycle assessment database was used for the production of raw materials, waste process emissions and energy supplied to the product system where specific data were not available. Secondary data was used because there was no direct access to data in the raw material acquisition stage of sulphuric acid life cycle and also because the study is an exploratory one with limited resources.

3.6.1 Geographical Coverage

The goal of this study is to assess the life cycle environmental impacts of sulphuric acid produced in Nigeria. The amount of energy used and the efficiency of these production processes are still based on commercial database. The raw materials are assumed to be produced in Nigeria at the location of sulphuric acid plant, due to the high cost of importation from other countries and to avoid the cost of transportation of raw materials.

3.6.2 Time-Related Coverage

A time-related coverage of the year 2010 was set for the datasets and assumptions at the commencement of the project. The datasets used for the manufacture of sulphuric acid are from year 2010. The datasets from *GaBi* database for raw material production and energy generation are representative of the USA and for the year 2008.

3.6.3 Technology Coverage

The primary and secondary data used for this study is consistent with the current process configurations, operation and performance in Nigeria and it agrees with the process configurations and conditions at the time of data collection. Nonetheless, the secondary data used represent country rather than region-specific technologies.

3.6.4 Consistency

A quantitative consistency check was not included in this study. Qualitatively, the use of a small number of data sources was believed to allow collection of primary data with consistent age, quality and detail. All primary and secondary data are from operation in Nigeria, US database and *Gabi ts* database respectively.

3.7 Life Cycle Inventory Analysis (LCI)

The process of conducting an inventory analysis is iterative. As data is collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data collection procedures, so that the goal of the study will still be met. In some cases, there is revision to the goal or scope of the study. After all the data were collected, the LCI was created. The LCI is essentially a table listing all of the material and energy inputs and outputs. The following sections outline the data and assumptions used to model the raw materials and production processes of the sulphuric acid plant considered. Inventory data were taken from the *GaBi ts* database.

3.7.1 Data Collection and Sources

The product system determines the unit processes from which it is necessary to collect and quantify data. Consequently, it was necessary to collect and combine datasets including primary data from the company under study and emission data databases.

3.7.2 Allocation of Emission

In order to calculate the environmental impact of sulphuric acid product, a balance between the mass and energy input entering a process and mass and energy outputs derived from the process. A mass balance is required because the environmental impact of a process is divided between each product produced based on their individual mass. To evaluate raw material consumption, energy consumption, emission sources and amount by stage of production for each functional unit, the database was employed.

3.8 Life Cycle Impact Assessment (LCIA)

This study considers only the carbon footprint of sulphuric acid. According to PAS 2050, data needs to be recorded in relation to greenhouse gas emissions (GHG) within the system boundary of the product. Two types of data are needed for the carbon footprint calculation: activity data and emission factors. The sulphuric acid lifecycle modelled in Gabi is shown in Figure 4.

The carbon footprint of all activities was calculated by multiplying the activity data (e.g., kWh electricity consumed) by the emission factor for that activity (e.g., kg CO₂e per kWh electricity) (BSI, 2011). The total CF is calculated by then summing the individual CFs for all activities within the specified life cycle as outlined in Equation (1):

$$\text{Carbon Footprint} = \text{Activity data} \times \text{Activity emission factor} \times \text{GWP} \quad (1)$$

The following environmental impact categories: global warming potential (GWP) (excluding biogenic carbon), abiotic depletion (elements) (AD(e)), abiotic depletion (fossil) (AD(f)), acidification potential (AP), ozone depletion potential (ODP), eutrophication potential (EP), Human toxicity potential, Ecotoxicity potential, water depletion, Ground level ozone creation potential (POCP) and Photochemical oxidant formation potential (POFP). The impact assessment was carried out using the CML 2001 method, November 2010 version.

4.0 RESULTS AND DISCUSSION

This section also presents the distribution of emissions between the inputs and outputs of the life cycle stages of the cradle-gate assessment, thus identifying the hotspots and magnitude of the impact.

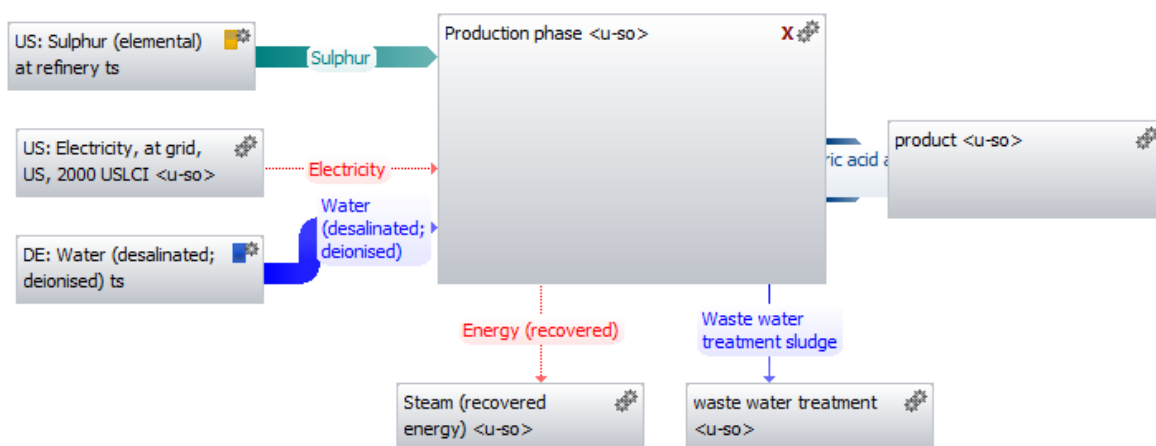


Figure 4: Life cycle model of sulphuric acid (cradle to gate)

This information can be considered when making decisions concerning sulphuric acid production. Data could not be gotten for each of the unit process inventories. The impact assessment stage of this study involves the calculation of the global warming potential (GWP) of all the activities based on the inventory data and other environmental impacts.

Table 1: Input and output flows associated with sulphuric acid production (cradle to gate)

Flow	Category	Flow type	Amount/Units
Inputs			
Electricity, at grid, US, 2008	Utilities/Fossil Fuel Electric Power Generation	Product flow	6.61e-02 kWh
Sulphur, at plant	Chemical Manufacturing/All Other Basic Inorganic Chemical Manufacturing	Product flow	3.30e-01 kg
Water (deionised)		Product flow	3.50e-01 m ³
Particulates, unspecified	air/unspecified	Elementary flow	1.00e-03 kg
Outputs			
Waste water treatment	water/unspecified	Elementary flow	6.00e-04 kg
Sulphuric acid, at plant	Chemical Manufacturing/All Other Basic Inorganic Chemical Manufacturing	Product flow	1.00e+00 kg
Steam (energy recovered)	Chemical Manufacturing/Petrochemical Manufacturing	Product flow	1.98e+00 MJ

Table 1 summarises the input and output flows used in modelling the life cycle assessment of sulphuric acid production in Gabi. It describes the type of flow, the categories of each flow and the amount required to produce 1kg of sulphuric acid product. The model was later scaled up to 50,000 tonnes per annum using 365days as worst-case scenario.

The characterized impact for each category is shown in Sections 4.1–4.9. The total CO₂ emission the sulphuric acid model is 12482763.42 kg with approximately 0.66 % direct emission from fuel combustion in the plant. Table 2 presents a survey of the overall LCIA results for the sulphuric acid model; the total emission and the contribution of the processes.

4.1 Global Warming Potential (GWP)

This section examines the global warming potential (100 years) of sulphuric acid product in Nigeria. It confirms the difficulty involved in comparing the results found here with other studies in literature due to the little consistency in system boundaries and methodology used in life cycle inventory and carbon footprint studies. Previous studies also differ in geological scope,

production and allocation method. The total carbon footprint for the life cycle inventory of the product studied is presented in terms of kilograms of carbon dioxide equivalents (kg CO₂e). The assessment in this study identified the raw material stage; elemental sulphur at plant as the main contributor to the carbon footprint with emission to air amounting to 4E+007 kg. The study shows the processing stage as a contributor mainly due to the energy required for sulphuric acid production at plant. Demineralised water used for the production of sulphuric acid was also identified as a significant contributor to emission of air which is primarily due to energy required to deionise the process water. Figure 6 presents the distribution of global warming potential on the sulphuric acid model. Global Warming Potential was majorly created by the combustion of fossil fuels to generate electricity on-site and off-site.

Table 2: Distribution of environmental impact between the inflows into the sulphuric acid model

Environmental impact category	Units	Total value	Production of elemental sulphur	Production of deionized water	On-site processes
Global warming potential (GWP)	kg CO ₂ -Equiv.	1.35E007	1.34E007	8.63E004	
Abiotic depletion (elements) (AD(e))	kg Sb-Equiv.	6.1	5.35	0.745	
Abiotic depletion (fossil) (AD(f))	MJ	4.85E008	4.84E008	9.94E005	
Acidification potential (AP)	kg SO ₂ -Equiv.	2.18E005	6.16E004		1.57E005
Ozone depletion potential (ODP)	kg R11-Equiv.	6.44e-4	6.4e-4	3.34e-6	
Eutrophication potential (EP)	kg Phosphate-Equiv	6.9E003	6.43E003	39.6	435
Human toxicity potential	kg 1,4-DB eq	7.9E005	7.87E005	2.64E003	
water depletion potential	m ³ water	1.85E006	1.69E006	1.6E005	
Ground level ozone creation potential (POCP)	kg Ethene-Equiv.	1.3E004	6.71E003	15	6.29E003
Photochemical oxidant formation potential (POFP)	kg NMVOC	5.09E004	3.77E004	159	1.3E004

Elemental sulphur from plant has the greatest environmental impact having relative contribution of 99.29% and followed by deionised water with a 0.71% relative contribution. Carbon dioxide released from energy consumption was seen to be the main contributor to the global warming potential by 92.03%; 0.53 % of deionised water and 91.5% from elemental sulphur from plant respectively. Another contributor to the global warming potential was methane released during

crude oil production with relative contribution of 6.64% and 6.62% from deionised water and elemental sulphur respectively. Minimal nitrous oxide emissions were obtained from deionised water and elemental sulphur had 0.63% and 0.62% respectively.

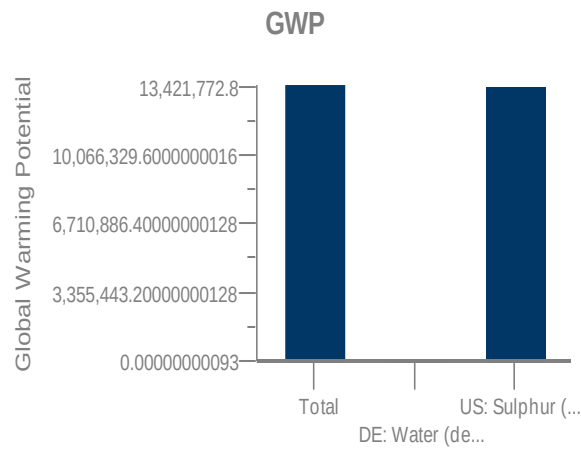


Figure 6: Distribution of global warming potential (GWP) on the sulphuric acid model

4.2 Acidification Potential (AP)

Emissions contributing to acidification potential were as a result of SO_x remaining after processing and the production of electricity. The major contributor to AP as is seen in Figure 7 is direct emission from the plant with relative contribution 72% as the processes that take place on-site involve an acidic product which releases pollutant into the atmosphere. The other contribution is from elemental sulphur production with relative contribution 28%.

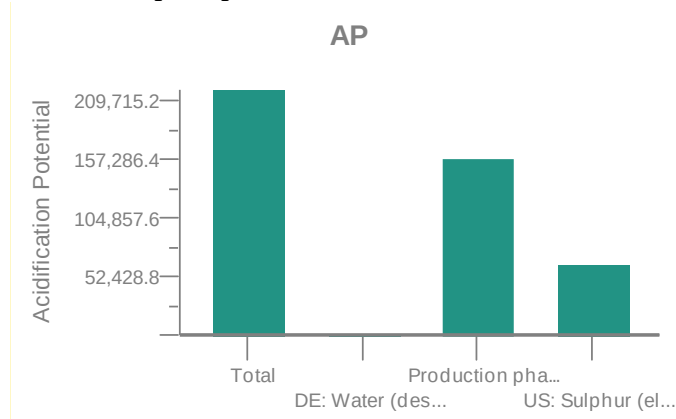


Figure 7: Distribution of Acidification potential (AP) on the sulphuric acid model

4.3 Eutrophication Potential (EP)

Figure 8 shows the process contribution with elemental sulphur production having the largest contribution of 93.2% to the EP. Other contributors are the production phase for the product and the demineralised water production. The productions contribute 6.3% and 0.5% to EP respectively.

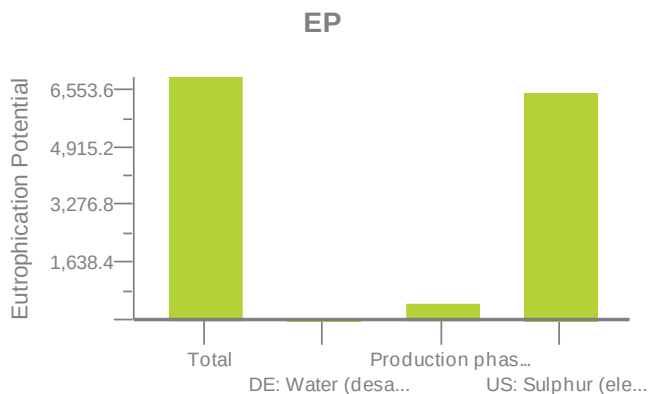


Figure 8: Distribution of Eutrophication potential (EP) on the sulphuric acid model

4.4 Ozone Depletion Potential (ODP)

The major contributor to ODP is direct emission from elemental sulphur production processes with relative contribution 99.4%. The other contribution is the demineralised water production with relative contribution of 0.52%. Figure 9 shows process contribution to ozone depletion.

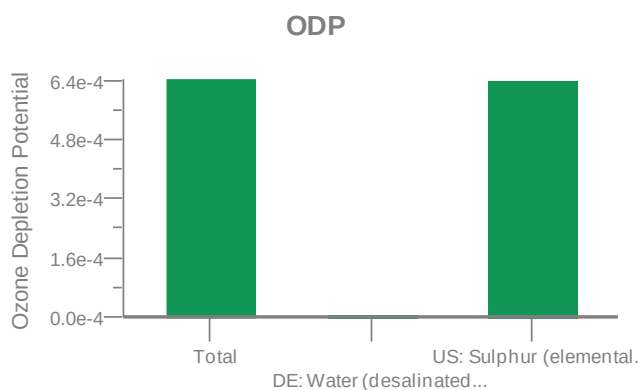


Figure 9: Distribution of ozone depletion potential (ODP) on the sulphuric acid model

4.5 Ground Level Ozone Creation Potential (POCP)

Elemental sulphur shows a contribution of 51.6% in POCP. The major contribution to POFP is direct emission from the plant. The second major contribution is from on-site production, contributing 48.4%, followed by demineralised water with relative contribution of 0.12%. Figure 10 shows the impact of the processes in the sulphuric acid model on ground level ozone creation potential (POCP).

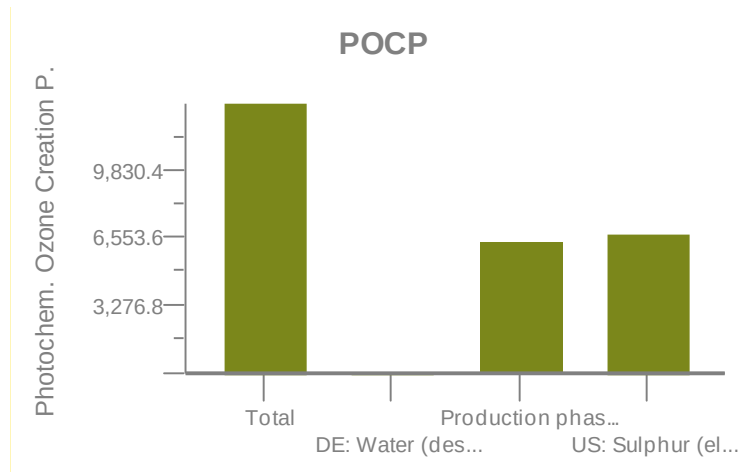


Figure 10: Distribution of Ground level ozone creation potential (POCP) on the sulphuric acid model

4.6 Abiotic Depletion Potential (ADP)

The production of elemental sulphur has the largest contribution followed by demineralised for the plant as a result of the energy associated with the processes. The process contribution shows that elemental sulphur emission contributes 87.7% and the demineralised water production contributes 12.2%. In Figure 11, the processes are distributed for Abiotic depletion potential (ADP) (elements).

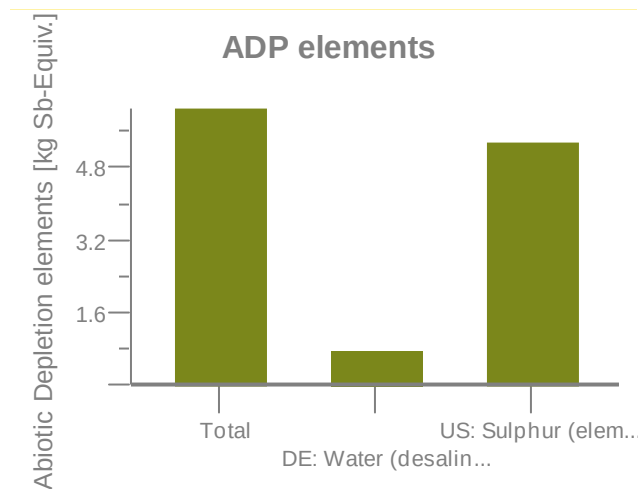


Figure 11: Distribution of Abiotic depletion potential (ADP) (elements) on the sulphuric acid model

4.6 Abiotic Depletion Potential (fossil)

The major contributor to ADP (fossil) is direct emission from the production processes with relative contribution of 99.8%. Demineralised water production contributes 0.2%. Figure 12 presents the impact of the processes on Abiotic depletion potential (fossil).

4.7 Human Toxicity Potential

The major contributors to total HTP are from the on-site infrastructures which contribute 99.6% as shown in Figure 13. This increase is as a result of corrosive nature and concentration of the sulphuric acid product produced at the plant. The second contribution is the demineralised water infrastructure contributes 0.33% to the total HTP.

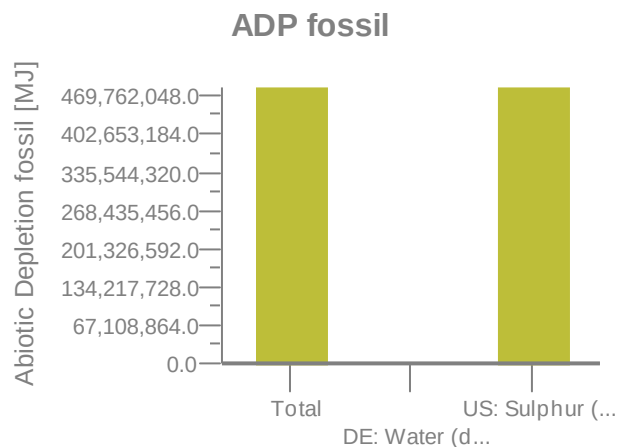


Figure 12: Distribution of Abiotic depletion potential (fossil) on the sulphuric acid model

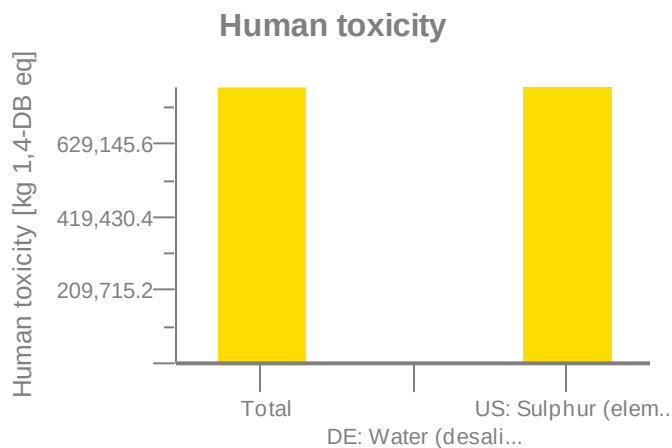


Figure 13: Distribution of Human toxicity potential on the sulphuric acid model

4.8 Photochemical Oxidant Formation Potential (POFP)

The major contribution to POFP was from direct emissions from the acid plant. Elemental sulphur shows a contribution of 74.1% in POFP. The second major contribution is from on-site production, contributing 25.5%, followed by demineralised water contribute 0.003%. Figure 14

displays the distribution of Photochemical oxidant formation potential (POFP) on the sulphuric acid model.

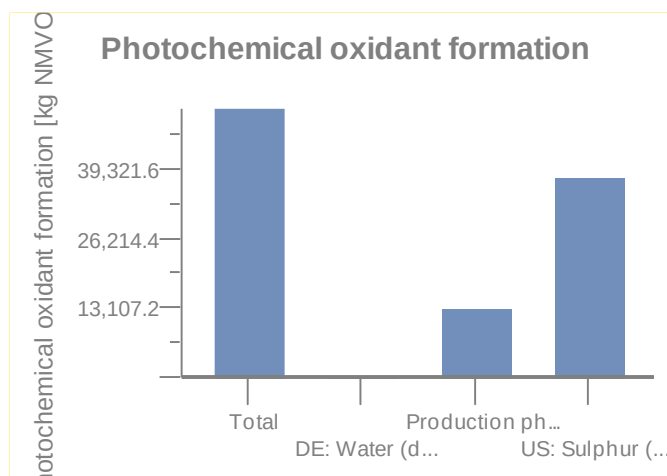


Figure 14: Distribution of Photochemical oxidant formation potential (POFP) on the sulphuric acid model

4.9 Water Depletion Potential

The major contributor to water depletion is direct emission from the production processes with relative contribution of 91.4%. Demineralised water production contributes 8.6%. Figure 15 shows the impact the processes have on water depletion.

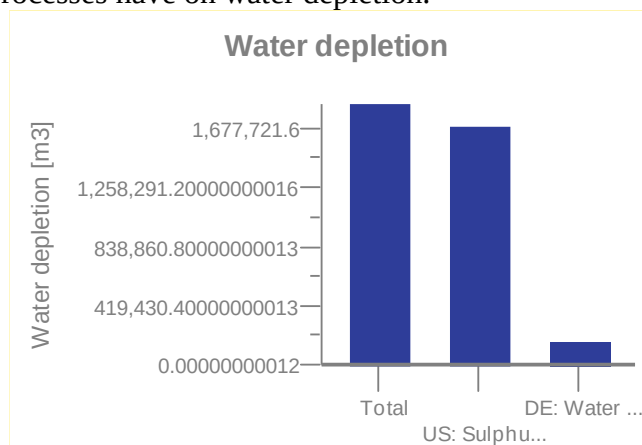


Figure 15: Distribution of Water depletion potential on the sulphuric acid model

Reductions in emissions could be achieved by substituting fossil based raw materials with bio-based raw material provided that the environmental impact of the processes used to produce the latter does not exceed the former. This reduction only holds true if biogenic CO₂ emissions do not contribute to global warming potential. Also, the use of biomass could have negative consequences for land use. In an life cycle assessment study, end-of-life scenarios should always be considered. This methodology does not include the end of life of the product and this approach is recommended.

This model has the same limitations as life cycle assessment studies: There is variation when defining the system boundaries and selecting data sources, as necessary data may not always be accessible. These factors influence reliability of the data and the quality of the final results (Hermann *et al.*, 2007; Rebitzer, 2005). The use of inventory data from commercial database to determine emission is not without setbacks as the data are not always representative of specific conditions or processes under study and the consistent quality of data is not always guaranteed; hence, the reliability and quality of the results.

As regards to future studies, consideration should be given to the whole value chain. Although the upstream and on-site are important, processes involving the use of the product outside the industry may have a significant impact on the environment. It should be noted that the type of processes used for producing the sulphuric acid product, the location is of relevance and the environmental impact figures and strategies may vary and should not be adopted.

Data and methodology are appropriate for the product considered in this report. It isn't appropriate for other approaches; data should not be used for other products. It's essential that all conclusions in an life cycle assessment study reflect the stated goals of the study, and take into account any study limitations that were documented as part of the study. Methods such as sensitivity analysis and scenario techniques are recommended.

Furthermore, proper life cycle assessment isn't quick and easy; life cycle assessment requires a lot of planning and careful attention to detail. They also require lots of data, flexibility, and documentation. Reliable data and documentation, contribute more sound life cycle assessment studies which will lead to more informed decisions about how to address the sustainability challenges and to anticipate and manage any possible environmental trade-offs.

5.0 CONCLUSION

The application of life cycle assessment to evaluate the environmental impact associated with sulphuric acid production will help understand the entire product system and thus determine ways to reduce environmental impacts of the product. The results obtained from life cycle assessment can also help policy makers make a well-informed decision when putting down public policies and incentives by addressing environmental issues without compromising developmental needs and priorities.

There has been little or no work on environmental impact of life cycle stages of sulphuric acid in Nigeria. This study presents the cradle-to-gate environmental impact of sulphuric acid in the western part of the country. The environmental burdens of the overall system of sulphuric acid product were evaluated, from a product-related functional unit perspective, across all the environmental impact assessment categories. This study shows how life cycle assessment discloses the distribution of the environmental impact among the inflows and processes, thus providing a means of identifying possible areas for improved approaches and flows to be targeted by strategies. Weak point analysis methods offer the opportunity to identify environmental improvement possibilities. The results show that energy consumption on-site and

off-site and emissions from the acid plant are key areas for environmental improvement. The results of this study can serve as a base for future research.

ACKNOWLEDGEMENTS

Authors are grateful to PE International for providing GaBi Education Network License used for this study.

REFERENCES

- Ashar N.G. and Golwalkar K.R. (2013). *A Practical Guide to the Manufacture of Sulphuric acid, Oleums, and Sulfonating Agents*, Springer International Publishing, Switzerland DOI: 10.1007/978-3-319-02042-6_2
- Berg, S., & Karjalainen, T. (2003). Comparison of greenhouse gas emissions from forest operations in Finland and Sweden. *Forestry*, 76(3): 271-284.
- BSI (2011). British Standard Institution. Carbon Trust, Department for Environment Food and rural Affairs. PAS 2050: 2011. Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services. BSI standard, London, UK.
- Centre for Sustainable Systems, University of Michigan (2013). "Carbon Footprint Factsheet." Pub. No. CSS09-05
- Chowdhury, N. B., Hasan, Z., & Biplob, A. H. M. (2012). HYSYS Simulation of a Sulfuric Acid Plant and Optimization Approach of Annual Profit. *Journal of Science (JOS)*, 2(4): 179-182.
- Emission Inventory Guidebook (2006). Processes in inorganic chemical industries, B441: Activity 040401, 105.09.10, 2 B 5. Otto Rentz, Dagmar Oertel, University of Karlsruhe, Germany.
- Garcia, R., & Freire, F. (2014). Carbon footprint of particleboard: a comparison between ISO/TS 14067, GHG Protocol, PAS 2050 and Climate Declaration. *Journal of Cleaner Production*, 66: 199-209.
- González-García, S., Feijoo, G., Widsten, P., Kandelbauer, A., Zikulnig-Rusch, E., & Moreira, M. T. (2009). Environmental performance assessment of hardboard manufacture. *The International Journal of Life Cycle Assessment*, 14(5): 456-466.
- Hauschild, M.Z., Goedkoop, M., Guinée, J., Heijungs, R., Huijbregts, M., Jolliet, O., Margni, M., De Schryver, A., Humbert, S., Laurent, A. and Sala, S., (2013). Identifying best existing practice for characterization modeling in life cycle impact assessment. *The International Journal of Life Cycle Assessment*, 18(3): 683-697.

- Hermann, B. G., Kroeze, C., & Jawjit, W. (2007). Assessing environmental performance by combining life cycle assessment, multi-criteria analysis and environmental performance indicators. *Journal of Cleaner Production*, 15(18): 1787-1796.
- ISO (International Standard Organisation) (2006). ISO 14040: Environmental Management, Life Cycle Assessment, Requirements and Guidelines. International Organization for Standardization, Geneva, Switzerland.
- Kennecott Utah Copper Corporation (2006): Sulphuric acid environmental profile. *Life Cycle Assessment*
- Lenzen, M., & Murray, S. A. (2001). A modified ecological footprint method and its application to Australia. *Ecological economics*, 37(2): 229-255.
- Jacquemin, L., Pontalier, P. Y., & Sablayrolles, C. (2012). Life cycle assessment (LCA) applied to the process industry: a review. *The International Journal of Life Cycle Assessment*, 17(8): 1028-1041.
- Masanet, E., Chang, Y., Gopal, A.R., Larsen, P., Morrow III, W.R., Sathre, R., Shehabi, A. and Zhai, P., (2013). Life-cycle assessment of electric power systems. *Annual Review of Environment and Resources*, 38:107-136.
- Padgett, J. P., Steinemann, A. C., Clarke, J. H., & Vandenberg, M. P. (2008). A comparison of carbon calculators. *Environmental impact assessment review*, 28(2): 106-115.
- Pang, M. M., Pun, M. Y., Chow, W. S., & Ishak, Z. A. M. (2014). Carbon footprint calculation for thermoformed starch-filled polypropylene biobased materials. *Journal of Cleaner Production*, 64 : 602-608.
- Rebitzer, G. (2005). Enhancing the application efficiency of life cycle assessment for industrial uses. *The International Journal of Life Cycle Assessment*, 10(6): 446-446.
- Rood, G. A., Ros, J. P. M., Drissen, E., & Vringer, K. (2003). A structure of models for future projections of environmental pressure due to consumption. *Journal of Cleaner Production*, 11(5): 491-498.
- Sinha, P., & Cass, D. M. (2009). Tools for Carbon Management: Potential Carbon Footprint Reduction Through Fuel Switching. In *Proceedings of the 2007 National Conference on Environmental Science and Technology* (pp. 227-231). Springer New York.
- The Carbon Trust (2012). Management guide: Carbon Footprinting, pp. 1-5.
- U.S. Environmental Protection Agency (EPA) (2015). Acid plant new source review enforcement initiative. Retrieved August, 2015 from <http://www2.epa.gov/enforcement/acid-plant-new-source-review-enforcement-initiative>

U.S. Life Cycle Inventory Database (2012). National Renewable Energy. Laboratory, 2012.
Accessed February 19, 2015: <https://www.lcacommons.gov/nrel/search>