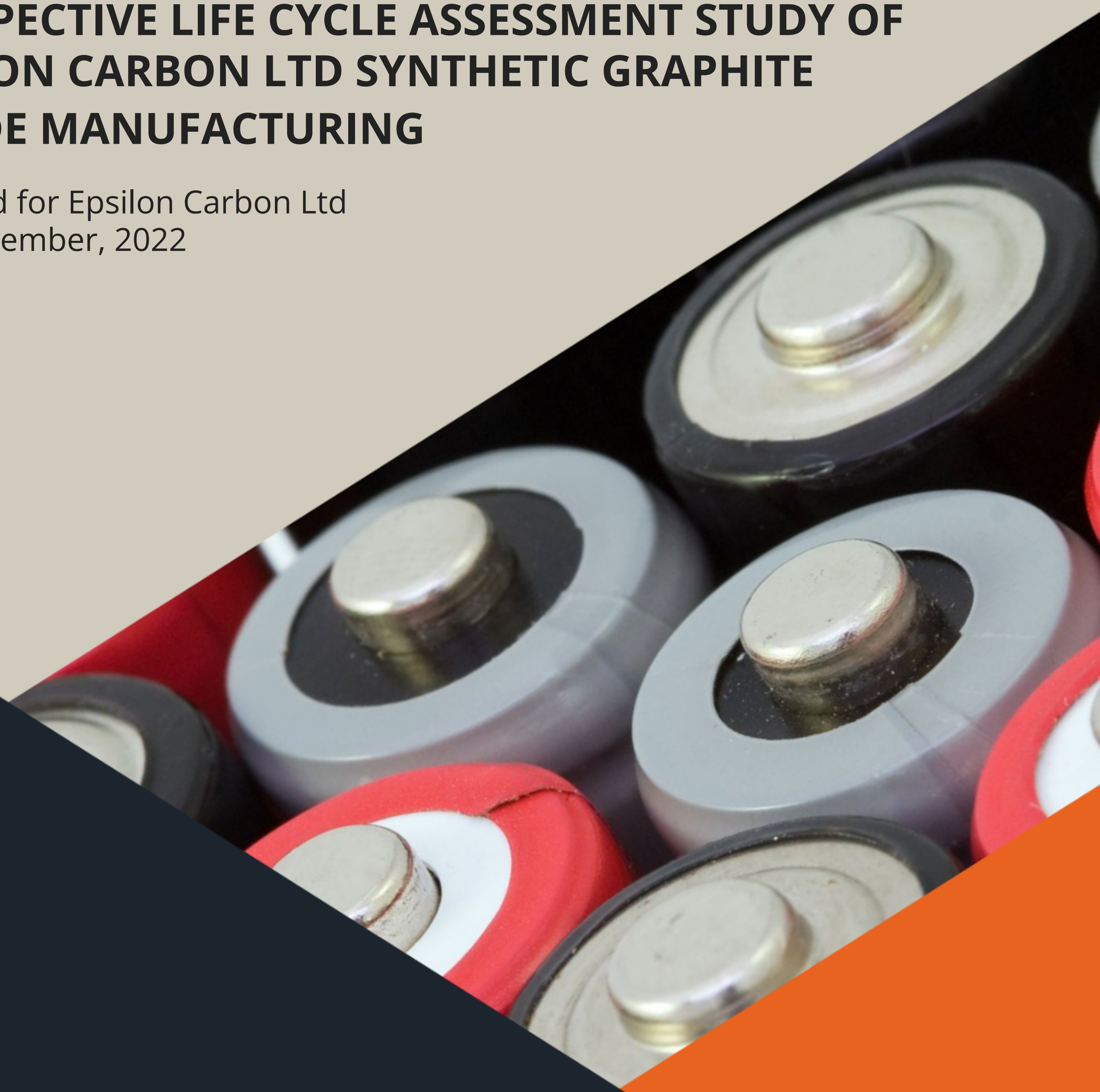
PROSPECTIVE LIFE CYCLE ASSESSMENT STUDY OF EPSILON CARBON LTD SYNTHETIC GRAPHITE ANODE MANUFACTURING

Prepared for Epsilon Carbon Ltd
14th September, 2022



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Our Statement

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Life cycle assessment is an environmental accounting method with an inherent level of uncertainty, and it should not be seen as having the same level of precision as financial accounting. Life cycle assessment requires a very large amount of data, particularly to calculate all the inputs and outputs for every step.

Primary data is collected from the 2021 - 2022 detailed engineering studies. Databases are often used for secondary data since it is impractical to collect all the necessary data from the original sources.

The report does not claim to be exhaustive, nor does it claim to cover all relevant products. While steps have been taken to ensure accuracy, the listing or featuring of a particular product or company does not constitute an endorsement by Minviro.

Epsilon Carbon (Epsilon) commissioned Minviro Ltd. as a life cycle assessment practitioner in January 2022 to produce a life cycle assessment for the production of synthetic graphite at the Epsilon Graphite Ltd plant in Vijayangar, India.

The life cycle assessment was conducted using the best available data taken from Epsilon's 2021 - 2022 detailed engineering studies. The intended application of this life cycle assessment is to assist in project development and improvement. The results will be used for long term strategic planning.

Table 1. Document Details

Document Details	
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Executive Summary

Minviro was appointed by Epsilon Carbon (Epsilon) to conduct a cradle-to-gate life cycle assessment on the production of the synthetic graphite anode at the Epsilon facility in Vijayangar, India for reference year 2022. The project consists of six distinct areas: (1) precursor production, (2) soft pitch, (3) zero Qi, (4) bulk mesocoke granules, (5) bulkmesocoke powder, and (6) synthetic graphite anode production. For each of these sites, technological and economic data was developed as part of Epsilon's 2021-2022 detailed engineering studies. The studies were based on synthetic graphite anode production, with the purpose of the end product to be sold to the lithium-ion battery industry. The production process produces a series of co-products within each stage. Due to the production of these co-products, allocation of the environmental impacts are conducted on a step-wise approach between the primary product of each stage and the co-products using economic allocation and system expansion. Three functional units are addressed in this study:

1. One kg of bulkmesocoke granules
2. One kg of bulk mesocoke powder, and
3. One kg of synthetic graphite anode

The feed material for this process is coal tar, produced by Jindal Steel Works (JSW) located at the same site as Epsilon's facility in Vijayangar, India. The results of the life cycle assessment results for each product are presented in Table 3. Six impact categories were evaluated: global warming potential (GWP), fossil fuel depletion, photochemical ozone formation, freshwater eutrophication, and acidification potential. The impact categories are based on the Environmental Footprint 3.0 methodology.[1] These impact categories were chosen to understand the environmental value proposition of synthetic graphite anode production compared to alternative processing routes. International acceptance exists for these impact categories.

Table 1. Results Summary of Life Cycle Assessment Study

Impact Category	Bulkmesocoke Granules (per kg Bulkmesocoke Granules)	Bulkmesocoke Powder (per kg Bulkmesocoke Powder)	Synthetic Graphite Anode (per kg Synthetic Graphite Anode)	Unit

Global Warming Potential	0.3	1.7	5.2	per kg CO_2 eq.
Resource Demand - Fossil Fuel Depletion	3.6	6.3	8.83	MJ
Photochemical Ozone Formation	-0.19	-0.40	-0.32	kg NMVOC eq.
Freshwater Eutrophication Potential	7.3E-3	1.3E-2	1.3E-2	kg P eq.
Acidification Potential	3.2E-2	5.7E-2	7.9E-2	Mol H^+ eq.

The total global warming potential for producing Epsilon's synthetic graphite anode is 5.2 kg CO_2 eq. per kg synthetic graphite anode, with the main impact drivers being as a result of the consumption of electricity from the Keralan grid for the graphitisation stage, and the consumption of coking coal, used to produced the coal tar precursor material. This trend is also common throughout the remaining impact categories quantified within this LCA, apart from the photochemical ozone formation.

It should be noted that credits are assigned within this LCA for the consumption of blast furnace and mixed tail gas used for heat, due to these gasses being sourced from waste gas streams. As a result of the recycling of these waste streams into the JSW and Epsilon's processes, the photochemical ozone formation impact category has a negative result, meaning that the formation of the photochemical ozone is reduced as a result of Epsilon's synthetic graphite anode being formed.

Comparison scenarios were conducted to understand the difference in global warming potential between Epsilon's synthetic graphite anode and anode grade graphite (natural and synthetic) produced in Heilongjiang Province, China, and Inner Mongolia, China, respectively. Overall, Epsilon's synthetic graphite anode product indicates a lower environmental impact than the equivalent products produced in China.

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List of Acronyms

Acronym	Meaning
CO_2	Carbon dioxide
DFS	Definitive feasibility study
DQR	Data quality rating
eq.	Equivalent
GWP	Global warming potential
H_2SO_4	Sulphuric acid
HCl	Hydrochloric acid
IPCC	Intergovernmental Panel on Climate Change
kg	Kilograms
L	Litres
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
m^2	Metres squared
m^3	Metres cubed
MJ	Megajoules
mol H^+	Moles of protons equivalent (units of acidification potential)
NaOH	Sodium hydroxide (caustic)
Na_2CO_3	Sodium carbonate (soda ash)
N	Nitrogen
NO_x	Nitrogen oxides (NO, NO_2)
PEA	Preliminary economic assessment
PEF	Product Environmental Footprint
PFS	Pre-feasibility study
P	Phosphorous
RPM	Rate per Minute
SO_x	Sulphur oxides (SO, SO_2, SO_3)
t	Metric tonne(s)

1. Introduction

Epsilon Carbon Ltd (Epsilon) has retained Minviro to model the environmental performance of manufacturing their mesocoke granules, mesocoke powder and synthetic graphite anode product at the Epsilon Graphite facility in Vijayanagar, India, using life cycle assessment (LCA). The results will be used to improve production processes and for long-term strategic planning. This chapter is a summary of the methodology applied by Minviro in the LCA.

1.1. Project Description

Epsilon Advanced Materials was established in 2018 as a subsidiary of Epsilon Carbon Ltd, to mark its entry into the lithium-ion battery (LIB) space by developing and producing high performance and quality carbon products for anode components of LIB's. Epsilon currently has a small commercial scale operation producing anode precursor materials, and a pilot plant producing mesocoke powder and synthetic graphite anodes.

Epsilon's proposed process produces synthetic graphite anode from coal tar. The coal tar is produced at the Jindal Steel Works (JSW) facility as a by-product of metallurgical coke production. The coal tar is transported 800 km by freight train from the JSW facility to Epsilon's facility. The coal tar goes through a series of processing stages to produce mesocoke granules, mesocoke powder and anode-grade synthetic graphite. Co-products produced within each stage are either recycled back into Epsilon's process or sold as a co-product. Allocation between primary and co-products of each stage are shown in section 2.4. Relevant project production estimates from the detailed engineering studies, published in March 2022, are given in Table 2.

Table 2. Epsilon Synthetic Graphite Anode Production Overview

Production Parameter	Value	Units
Epsilon Plant Location	Epsilon Carbon and Graphite Plant, Vijayanagar, India	-
Precursor Plant Locations	JSW Steel Works, Vijayanagar, Karnataka, and ARCL, Dovi - India	-
Life of Project	20	years
Precursor Coal Tar Production	446,951	tonnes/year

Bulk Mesocoke Granules Production	74,000	tonnes/year
Bulk Mesocoke Powder Production	41,814	tonnes/year
Synthetic Graphite Anode Production	50,153	tonnes/year

Epsilon's process has been designed to produce zero waste products. The waste water is treated within the water treatment plant, located on site, then either released into the environment, or recycled back into Epsilon's process.

1.2. Scope of Assessment

The goal of this LCA is to determine the major project and process parameters contributing to the environmental life cycle impact of the production of synthetic graphite anode at Epsilon's facility in Vijayanagar, India. International acceptance exists for the selected impact category indicators. Additionally, comparison scenarios were completed to compare the environmental impact of:

- Epsilon's synthetic graphite anode, with synthetic anode-grade graphite produced in Inner Mongolia.
- Epsilon's anode-grade synthetic graphite with natural anode-grade graphite produced from natural flake graphite in Heilongjiang Province, China.

These routes were chosen at the interest of the client, to understand the environmental impact of traditional and emerging production routes that could supply graphite to the same market to which Epsilon is aiming to supply graphite. Efforts are made to ensure the system boundaries of the processes benchmarked are comparable to the system boundary defined for the Epsilon process. This is described further in section 5.

The LCIA results of global warming potential (GWP), fossil fuel depletion, acidification potential (AP), freshwater eutrophication potential, and photochemical ozone formation, will be presented, following the Environmental Footprint 3.0 LCA methodology.

2. Life Cycle Assessment Methodology

This LCA study was conducted according to the requirements of the ISO-14040:2006 and ISO-14044:2006 standards.[1,2] LCA has four fundamental steps: (i) goal and scope definition, (ii) inventory analysis, (iii) impact assessment, and (iv) interpretation, as presented below.

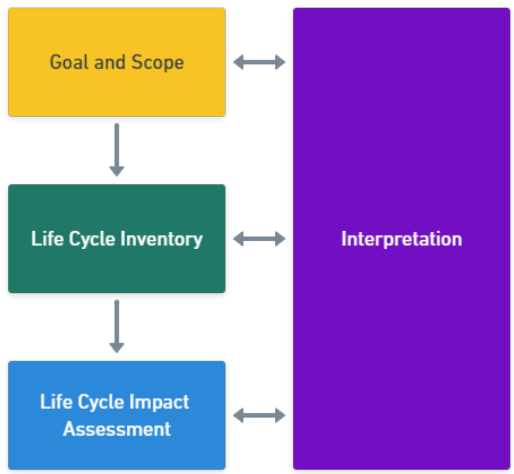

Figure 1. General Phases of a Life Cycle Assessment as Described by ISO 14040, Extracted from ISO 14040 (2006)

The life cycle impact assessment (LCIA) was carried out with a combination of data provided by Epsilon and Ecoinvent databases of characterization factors. Ecoinvent version 3.8 provides a well-documented process for products supporting the understanding of their environmental impacts.[3] The Ecoinvent database comprises inventory data for most economic activities. The consistency and cohesion of this background life cycle inventory (LCI) dataset increases the credibility and acceptance of the LCA. The baselines of this database are LCI datasets that consider human activities and their interactions with the environment. It must be noted that although Ecoinvent's database is extensive, it is critical to understand the uncertainty, technological and geographical relevance of the data points.

LCA is a method to assess the environmental impacts associated with all stages of a product, process or activity.[4] Importantly, LCA makes it possible to evaluate indirect impacts that occur in the development of a product or process system over its entire life cycle, providing information that otherwise may not be considered. A wide range of environmental impacts can be captured both scientifically and quantitatively. The holistic approach generates results on how decisions made at one stage of the life cycle might have consequences elsewhere, ensuring that a balance of potential trade-offs can be made and avoiding shifting of the environmental burden.[5,6] It must be noted that LCA is a suitable method for determining impacts on a global scale however, the methodology is less suitable for determining local impacts.

2.1. Goal and Scope

This study assesses the life cycle impact of the production of 1 kg of synthetic graphite anode produced from coal tar at JSW's plant in Vijayanagar, India. The total production chain includes:

- **Precursor production -** coal tar production from coking coal at JSW plant. The coal tar is a by-product of JSW's metallurgical coke production. The coal tar produced is transported from JSW Vijayanagar and Dovi plants, to Epsilons plant, via tanker.
- **Soft pitch production -** at Epsilon's facility, coal tar is processed to produce soft pitch, by removing the excess oils from the coal tar. Multiple oil-based products are produced within this stage, which are sold to the market.
- **Zero QI production -** soft pitch is mixed with solvents composed of kerosene and wash oil to produce zero QI.
- **Bulk mesocoke granules -** the zero QI pitch is loaded into a furnace, where the residual heavy pitch oil from the zero QI pitch is vaporised and collected. The remaining product is the bulk mesophase coke granules.
- **Bulk mesocoke powder -** the bulk mesocoke granules are further refined into a powder form by grinding and processing. Within the processing stage, the coke powder and agglomerated coke powder is separated from the pitch oil and agglomerated pitch oil, which are collected and sold.
- **Synthetic graphite anode -** the coke and agglomerated coke powder are milled/shaped, then undergoes graphitisation, to produce the final anode-grade synthetic graphite product. This product is transported to market.

The first objective is to understand the life cycle impact of producing synthetic graphite anode at Epsilon's Vijayanagar facility. The preceding steps to precursor production are included. This LCA is a cradle-to-gate study, meaning the product life cycle impact is being assessed from the point of resource extraction (cradle) to the end-gate (a set point at the end of processing). The end-gate has been set to synthetic graphite anode produced at Epsilon's facility and transported to Chennai Port, India. The use of the product in battery manufacturing and end-of-life is outside the scope of this LCA study. The data generated during these studies provides estimates on the technical parameters for precursor production, processing and refining and transport associated with the production of synthetic graphite anode. To understand the full life cycle impact of synthetic graphite anode from cradle-to-grave or cradle-to-cradle requires the extension of the system boundary into the use-phase and the end-of-life phases.

The comparison scenarios included in this report are natural and synthetic anode-grade graphite produced in Heilongjiang Province and Inner Mongolia, China, respectively. These are cradle-to-gate studies, with the end-gate set to the anode-grade graphite product. Therefore, for the comparison scenario section, the transport of Epsilon's graphite product to market has been removed to align the end-gate and overall system boundary to those of the comparison scenarios. The scope boundaries for each process result in coverage of a comparable set of processes, which is discussed further in section 5. For the comparison route, the use and end-of-life management of the products derived from the products are not included in this LCA. Data generated during these alternative routes are obtained from Minviro's internal database, which is based on public studies.[7,8] The primary objective of carrying out this comparison scenario is to quantify the GWP of the alternative production route.

This study has been conducted according to the requirements of ISO-14040:2006 and ISO-14044:2006. The intended audience for this study includes parties that are interested in the graphite value chain, ranging from investors to customers and end-users. This study is not intended to communicate comparative assertions to the general public. This LCA study has not been critically reviewed by a critical review panel. It is recognised that the data provided by this LCA study may be used by others for comparative assertions in separate future studies. These comparisons should be made on a product system basis only and carried out in accordance with ISO 14040 and 144044 standards.

2.2. Functional Unit

LCA uses a functional unit as a reference to evaluate the components within a single system or among multiple systems on a common basis. The **functional unit** is the quantitative reference used for all inventory calculations and impact evaluations.

2.2.1 Bulk Mesocoke Granules

The **functional unit** for this study is defined as **1 (one) kilogram of bulk mesocoke granules from coal tar at Epsilon's Vijayanagar facility, India.**

The reference flow, to which all other preceding flows in the process are normalised, is the output of 74,000 tonnes of bulk mesocoke granules.

2.2.2 Bulk Mesocoke Powder

The **functional unit** for this study is defined as **1 (one) kilogram of bulk mesocoke powder from coal tar at Epsilon's Vijayanagar facility, India.**

The reference flow, to which all other preceding flows in the process are normalised, is the output of 41,814 tonnes of bulk mesocoke powder.

2.2.3 Synthetic Graphite Anode

The **functional unit** for this study is defined as 1 **(one) kilogram of synthetic graphite anode at Epsilon's facility in Vijayanagar, India, produced from coal tar provided by JSW.**

The reference flow, to which all other preceding flows in the process are normalised, is the output of 50,153 tonnes of synthetic graphite anode.

2.3. Epsilon's Synthetic Graphite Anode System Boundary

This LCA models the production of anode-grade synthetic graphite from raw coal. The system boundary for the LCA study covering these stages is presented in Figure 2. The life cycle impact of six distinct stages of the process is modelled, considering the different flows relating to the specific co-products.

The coal is sourced from JSW, a by-product of their metallurgical coke production. Raw coal is pressed into coal cakes that undergo high-temperature carbonisation within the coking chamber. The coke is quenched using nitrogen gas, followed by cooling and screening to produce metallurgical coke and coal tar by-product. The coal tar is transported 10 km to the Epsilon Graphite plant via tankers. The metallurgical coke is used as the blast furnace feed at the JSW plant. Additional products produced in this stage are sulphur, coke breeze, and coke oven gas emissions. The waste gas emissions are recycled back into the JSW process to be used for heating. It is assumed the recycling of the waste coke gas emissions has an efficiency of 95%. The sulphur and coke breeze co-products are sold to the market. The heat source for the JSW process is sourced from captured waste gas. Electricity is sourced from JSW's combined power plant (CPP) on site. The nitrogen gas is burden-free, due to being captured waste gas emitted from the oxygen plant located on the JSW site. The life cycle inventory includes electricity required to capture the nitrogen gas.

The coal tar is transported from the JSW plants in Vijayanagar and Colvi, India, to the Epsilon graphite site by tanker. The tanker is assumed to be a >32 metric tonne EURO3 lorry. Following this, the coal tar is processed to produce soft pitch. This is done by removing moisture, anthracene oil, industrial and refined naphthalene, wash oil, carbon black oil, light oil, residual oil, phenol oil, impregnated zero QI, and sodium sulphate in dehydration, pitch column and fractioning column respectively.

The third stage consists of the soft pitch being mixed with a solvent composed of kerosene and wash oil to separate the zero QI pitch from the soft pitch. The solvent is recovered and reused by distillation. Two by-products are produced in this process: high QI pitch and anthracene oil. The anthracene oil and high QI pitch are sold to the market. The remaining high QI pitch is used within the coke mesocoke powder production process.

Within the fourth stage, the zero QI pitch is loaded in crucibles under metered conditions by a pump to feed into the carbon furnace. The furnace is divided into four zones: (1) entry chamber, (2) heating zone, (3) intermediate zone, (4) exit zone. The inert atmosphere within the carbon furnace is maintained using nitrogen gas. This reduces the oxidation of the feed material. The heat used is generated from electrical heaters. During this process, the residual heavy pitch oil from the zero QI pitch is vaporised and collected at several drain points at the bottom of the furnace. The remaining product is the bulk mesophase coke granules. A proportion of the pitch oil collected is recycled back into the process. The rest is sold as a by-product.

Stage five consists of the bulk mesophase coke granules (2 - 6 mm) which are further refined into a carbon fines powder (15 - 20 μm) by processing at a high rate per minute (rpm). Electricity and cooling water are the only inputs required at this stage. The primary product produced is coke powder, with pitch oil, agglomerated pitch oil, agglomerated coke powder, and bagged filter fines being produced as co-products.

The final stage consists of the agglomerated coke powder and coke powder being milled/shaped then loaded into a copper vessel, on crucibles, where graphitisation takes place. The coke powder mixture is heated to 2,850 ℃. Calcined petroleum coke, carbon black, lime and silica are added within this process. The used calcined coke, crucibles, and carbon black are then sold to the market. Gypsum is also another by-product produced within this stage that is sold into the cement industry. The final anode-grade synthetic graphite product is then transported to Channai port, in India, via trucks.

The energy required in stages 2 and 3, in the form of heat, is sourced from captured waste gases on site. The composition of the waste gas is carbon monoxide (19%), carbon dioxide (13.2%), hydrogen (29%), methane (8.8%), nitrogen (25.4%), oxygen (3.9%), and ethane (1%).

Power is sourced from a captive power plant (CPP) on Epsilon's site. The power plant produces electricity and steam, consumed within each stage of Epsilon's process. The CPP uses waste tail gas from Epsilon's site to power the CPP. The composition of the waste gas captured is carbon monoxide (14%), hydrogen (13.5%), carbon dioxide (1.9%), nitrogen (37.5%), acetylene (0.7%), and moisture (32%).

Electricity required for the graphitisation stage is sourced 80% from renewable power, composed of 72% wind power and 8% solar power. The remaining 20% is sourced from the Keralan grid.

Transport of consumables to the site is included in this study. The coking coal is transported by rail, using a diesel-powered freight train and ship via a freight container ship. Empty return trucks are not included. Reagents to the Epsilon site are transported by road transport using a >32 metric ton EURO3 freight lorry. The zero QI pitch, water and pitch oil are transported around the Epsilon site using a pipeline. The transportation of all co-products, at each stage, to their respective markets, are included.

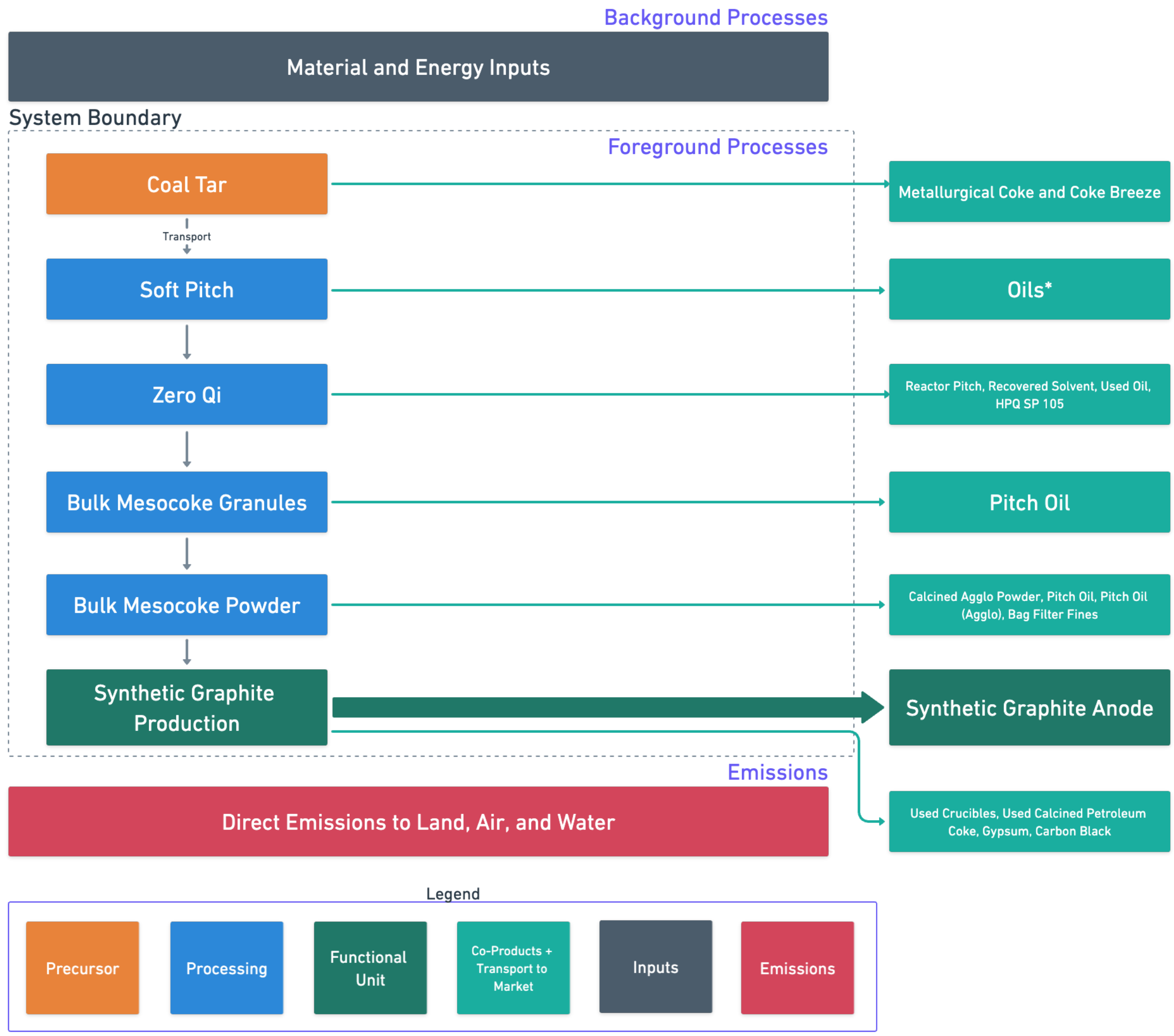

Figure 2. System Boundary Applied to the Life Cycle Assessment Study
**The oil-based co-products include industrial naphthalene, refined naphthalene, wash oil, carbon black oil, light oil, residual oil, zero QI impregnated pitch, phenol oil, reactor pitch, tricanter sludge, and used oil.*

2.4. Multi-Output Allocation

In LCA, it is critical to ensure that environmental impacts are divided among the different products of a process operation in a way that is scientifically valid and best practice.

Following the guidance provided in ISO-14044:2006 standards, it is recommended to avoid allocation as much as possible.[4,6]

Wherever possible, allocation should be avoided by either:[4,6]

- Dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes;
- Expanding the product system to include the additional functions related to the co-products.

If allocation is required, it is recommended to allocate the impacts following the physical relationships between the products before any alternative allocation methodologies are used. Two common alternative allocation methodologies include mass-based and economic allocation, in which the relative mass or economic value of the different products is used to allocate the impacts among them.

This LCA was conducted on a step-wise basis, with the environmental impacts being allocated between the primary and secondary products (co-products) within each stage. System expansion is not deemed appropriate for metallic-based products, due to variability in processing routes, there are currently no appropriate global averages for these products. Therefore, the impacts are divided between the primary product and the co-products of each stage using mass or economic allocation.

For non-metallic co-products, system expansion is the preferred approach, as alternative production routes are often available for non-metallic co-products.[6] System expansion assumes that the co-product will replace an equivalent of that product on the market. For that replacement, credit is given to the production processes of the primary product. The following allocation procedures used within each stage of Epsilon's process are as follows:

2.4.1 Stage 1 - Coal Tar Production

Economic allocation between coal tar (2.9%), metallurgical coke (96.8%), and coke breeze (0.3%). The breakdown of mass and economic allocation is presented in Table 3.

Table 3. Mass and Economic Allocation of Coal Tar Production

Product	Product (t/year)	Price (INR/MT)	Mass allocation	Economic allocation

Coal Tar	446,951	33,459	4.2%	2.9%
Metallurgical Coke	10,247,026	48,000	95.6%	96.8%
Coke Breeze Output	30,175	48,000	0.3%	0.3%

2.4.2 Stage 2 - Soft Pitch Production

The environmental impact of stage two, for soft pitch production, was allocated via market value. Economic allocation is the most appropriate allocation method to use here, due to the number of products produced being less variable than the fluctuation in market prices. Soft pitch accounts for 62.8% of the environmental impacts generated at this stage, with the remaining 37.2% of impacts distributed between the co-products. The breakdown of mass and economic allocation is presented in Table 4.

Table 4. Mass and Economic Allocation of Soft Pitch Production

Product	Product (t/year)	Price (INR avg.yr per MT product)	Mass allocation	Economic allocation
Soft Pitch	250,946	57719	58.7%	62.8%
Anthracene Oil	85,771	42424	20.1%	15.8%
Ind Naphthalene	21,862	80360	5.1%	7.6%
Refine Naphthalene	10,140	88881	2.4%	3.9%
Wash Oil	37,523	42403	8.8%	6.9%
Carbon Black Oil	3123.4	40606	0.7%	0.6%
Light Oil	2,054	37401	0.5%	0.3%
Residual Oil	1,174	41181	0.3%	0.2%
Phenol Oil	8,120	33947	1.9%	1.2%
Zero Qi/Impregnated pitch	2,666	1467	0.6%	0.0%
Phenol Oil from Na-Ph Process	3,576	33947	0.8%	0.5%
Reactor Pitch	339	75069	0.1%	0.1%
Tricanter Sluldge	226	33459	0.1%	<0.1%
Used Oil from Process	2	1530	<0.01%	<0.01%

2.4.3 Stage 3 - Zero QI Production

Economic allocation is used to distribute the environmental impacts between the zero QI production (48%) and the co-products. The breakdown of mass and economic allocation is presented in Table 5.

Table 5. Mass and Economic Allocation of Zero QI Production

Product	Product (t/year)	Price (INR avg.yr per MT product)	Mass allocation	Economic allocation
Zero QI product (IMP SP 110 and SP 85)	140,539	77,339	56.5%	58.7%
HQP SP 105	92,789	75,069	37.3%	37.6%
RAO - Recovered Solvent	14,629	42,424	5.9%	3.4%
Reactor Pitch	769	75,069	0.3%	0.3%
Used Oil from Process	1.28	990	<0.01%	<0.01%

2.4.4 Stage 4 - Bulk Mesocoke Granules Production

For stage 4, economic allocation is used to distribute the environmental impact between the bulk mesocoke granules (77.5%) and pitch oil (22.5%). The breakdown of mass and economic allocation is presented in Table 6.

Table 6. Mass and Economic Allocation of Bulk Mesocoke Granules Production

Product	Product (t/year)	Price (US$ per MT)	Mass allocation	Economic allocation
Bulk Mesophase Coke Granules	74,000	1,450	55.0%	76.3%
Pitch Oil	60,545	552	45.0%	23.8%

2.4.5 Stage 5 - Bulk Mesocoke Powder Production

For bulk mesocoke powder, four additional co-products are produced. These will all be sold to other industries. Using economic allocation, 67.2% of the environmental impacts are allocated to calcined coke powder, with the remaining 32.% of the impacts being allocated to the co-products, based on their economic values. The breakdown of mass and economic allocation is presented in Table 7.

Table 7: Mass and Economic Allocation of Bulk Mesocoke Powder Production

Product	Product (t/year)	Price (US$ per MT)	Mass allocation	Economic allocation
Bulk Mesocoke Coke Powder	41,814	2,000	58.8%	67.1%
Calcined Agglomerated Coke powder (Agglo)	14,498	2,000	20.4%	23.3%
Bag Filter Fines - Total	8,876	975	12.5%	6.9%
Pitch Oil	4,743	552	6.7%	2.1%
Pitch Oil from Agglo	1,187	552	1.7%	0.5%

2.4.6 Stage 6 - Synthetic Graphite Anode Production

For the final stage, synthetic graphite is produced, as well as four additional lower value co-products. The environmental impacts of this stage are distributed amongst the primary product (81.5%) and co-products (18.5%) using economic allocation. The breakdown of mass and economic allocation is presented in Table 8.

Table 8: Mass and Economic Allocation of Synthetic Graphite Anode Production

Product	Product (t/year)	Price (US$ per MT)	Mass allocation	Economic allocation
Synthetic Graphite Anode (EMG + EAG)	50,153	9,000	28.4%	81.3%
Used Crucibles	13,667	949	7.7%	2.3%
Used Calcined petroleum Coke	94,201	949	53.4%	16.1%
Gypsum	15,872	22.1	9.0%	0.1%
Carbon Black	2,635	390	1.5%	0.2%

2.5. Life Cycle Inventory

This study was desk-based, meaning that all data was either provided by Epsilon, collected from public sources, or assembled from public and private databases. Background data was used from Ecoinvent 3.8. Assumptions and limitations for this study are discussed in section 2.8. An LCI summary is included in Appendix A. An analysis of the material and energy flows within the system boundary were made and all major material and energy flows related to the precursor production, processing and refining of coal tar to produce synthetic graphite anode and its intermediate products have been included in the LCI and included in the life cycle impact assessment. This includes materials consumed, energy consumed, and transport of materials.

2.6. Cut-Off Criteria

Cut-off criteria is used in LCA to decide which inputs should be included in the assessment based on mass, energy, or environmental significance. Whilst all flows provided by Epsilon were considered in the LCA study, as this study is based on data from detailed engineering studies, cut-off criteria inherent to the data itself have been applied. Examples include upstream transport of reagents, consumables like pipes, wear plates, gravity separation trays, reagent packaging materials, light vehicle use, ancillary services, and staff transport and/or accommodation.

It is possible that cut-off effects have been applied to the background flows from Ecoinvent 3.8 due to missing flows in the background dataset. Life cycle inventories related to the manufacturing of equipment, maintenance, packaging, and infrastructure have been excluded in this LCA. The reason for excluding these flows is that they are often minimal compared to flows of reagents or energy consumed in the process over decades of operation.

2.7. Life Cycle Impact Assessment

The LCIA categories selected for this study include global warming potential (GWP), resource demand (fossil fuel depletion), photochemical ozone formation, acidification potential, and freshwater eutrophication potential. These impact categories were chosen for this project as these will provide quantitative insights into the relevant impacts for anode production. The LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risks.

2.7.1. Global Warming Potential

Baseline model of 100 years based on IPCC 2013[9]

Climate change can be defined as the change in global temperature caused by the greenhouse effect of “greenhouse gases” released by human activity. There is now scientific consensus that the increase in these emissions is having a noticeable effect on climate. Climate change is one of the significant environmental effects of economic activity and one of the most difficult to control because of its global scale.[10] The environmental profiles' characterization model is based on factors developed by the UN’s Intergovernmental Panel on Climate Change (IPCC). Factors are expressed as GWP over the time horizon of different years, the most common historically being 100 years, measured in the reference unit, **kg CO_2 eq.**

The Greenhouse Gas Protocol identifies three “scopes” of GHG emissions which have been included in this study; however, it should be noted that scopes of emissions are not a framework inherent to LCA. The GHG Protocol defines scopes of emissions as:

Scope 1: Direct GHG emissions (e.g. furnace off-gas, combustion of fuels)
Scope 2: Indirect GHG emissions from consumption of purchased electricity, heat, or steam (e.g. emissions embodied in grid power or embodied in steam at an industrial park)
Scope 3: Other indirect emissions such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g. T&D losses) not covered in scope 2, outsourced activities, and waste disposal. Scope 3 emissions can be either “upstream” or “downstream”. In a cradle-to-gate LCA, “upstream” scope 3 must be included.

2.7.2. Resource Consumption - Fossil Fuel Depletion

Scarcity with relation to ultimate reserves

This impact category quantifies the depletion of natural resources from the earth based on: the concentration of reserves; deaccumulation rate; quantity of fuels; ratios of annual production to available reserves; and damage to resources based on the increased cost of extraction. Characterisation factors are given for minerals and metals collectively, and for fossil fuels as a separate impact category. In this LCA, we use both categories to describe the impacts the project in question has on global reserves. [16]

Regarding fossil fuel depletion of global fossil fuel reserves, this is calculated using the CML 2002 methodology.[16] Resource depletion for this midpoint indicator is measured in megajoules (MJ) per functional unit, and this represents the potential common energy output of all fossil fuels consumed as part of the embodied impacts of any given material or energy input.

2.7.3. Photochemical Ozone Formation

Photochemical Ozone Creation Potential

Photochemical ozone formation assesses the formation of ground-level ozone. Radiation from the sun and the presence of nitrogen oxides and hydrocarbons incur complex chemical reactions, producing aggressive reaction products, one of which is ozone. Nitrogen oxides alone do not cause high ozone concentration levels. Hydrocarbon emissions occur from incomplete combustion and from the evaporation of petroleum products or solvents. High concentrations of ozone arise when the temperature is high, humidity is low, air is relatively static, and there are high concentrations of hydrocarbons. Photochemical ozone formation for this midpoint indicator is measured in **kg NMVOC eq.** per kg functional unit.[11,12]

2.7.4. Acidification Potential

Accumulated Exceedance

Acidic gases such as sulphur dioxide react with water in the atmosphere to form "acid rain", a process known as acid deposition. When this rain falls, often a considerable distance from the original source of the gas, it causes ecosystem damage to varying degrees depending upon the nature of the ecosystem. Gases that cause acid deposition include ammonia (NH_3), nitrogen oxides (NO_x), and sulphur oxides (SO_x). Acidification potential is expressed using the reference unit **mol H^+ eq.** per kg functional unit. The model does not take account of regional differences in terms of which areas are more or less susceptible to acidification. It accounts only for acidification caused by SO_x and NO_x. This includes acidification due to fertiliser use, according to the method developed by the

Intergovernmental Panel on Climate Change. CML has based the characterization factor on the RAINS model developed by the University of Amsterdam.[13,14]

2.7.5. Freshwater Eutrophication Potential

Accumulated Exceedance [14,15]

Eutrophication is the build-up of a concentration of chemical nutrients in an ecosystem, which leads to abnormal productivity. This causes excessive plant growth like algae in rivers, which causes severe reductions in water quality and animal populations. Emissions of ammonia, nitrates, nitrogen oxides and phosphorus to air or water all have an impact on eutrophication. Direct and indirect impacts of fertilisers are included in the method. The direct impacts are from the production of the fertilisers and the indirect ones are calculated using the IPCC method to estimate emissions to water causing eutrophication. Eutrophication potential is divided into three subcategories.

With respect to freshwater eutrophication, phosphorus is the limiting factor; therefore, only P-compounds are provided for assessing freshwater eutrophication. The reference unit is expressed as **kg P eq per kg functional unit**. This category is based on the work of ReCiPe2008.

2.8. Assumptions and Limitations

The primary limitation of this study is the uncertainty associated with the level of definition of a project at the detailed engineering stage compared to an operational facility. This has been addressed by assigning a 15% uncertainty to the data.[16]

2.8.1 Energy-Related Assumptions

- Diesel produced in different countries is likely to have varying impacts. The characterisation factor used in this study is not regional, it is based on a global characterisation factor.
- Heat required to run the JSW coal tar production and Epsilon's soft pitch production processes is sourced from captured waste gas streams that are released into the atmosphere at atmospheric temperature and pressure. Credit is given to the waste gas used within the process for heat generation. This is due to the fact that this gas

would have otherwise been released into the atmosphere. The composition of the waste gas is carbon monoxide (19%), carbon dioxide (13.2%), hydrogen (29%), methane (8.8%), nitrogen (25.4%), oxygen (3.9%), and ethane (1%). The calorific value of the waste gas is 750 GCal/m^3. The density of the waste gas is assumed to be 0.91 kg/m^3.

- Electricity is sourced from combined power plants based on the JSW and Epsilon plant sites. The CPP uses captured tail gas as the heat source. The composition of this waste gas used at the CPP's is: carbon monoxide (14%), hydrogen (13.5%), carbon dioxide (1.9%), nitrogen (37.5%), acetylene (0.7%), and moisture (32%). The calorific value of the waste gas is 750 GCal/m^3. The density of the waste gas is assumed to be 0.91 kg/m^3.
- Electricity required for the graphitisation stage is sourced 80% from renewable power, composed of 72% wind power and 8% solar power. The remaining 20% is sourced from the Keralan grid.
- High-pressure steam is a co-product of Epsilon's CPP. This is formed from recovering condensate from the Epsilon process and is tunnelled into the boiler at the CPP, where the production of electricity occurs and high-pressure steam within a steam turbine. This steam generated is then redirected back into the Epsilon production process. It is assumed there are minimal losses of steam.
- It is assumed the CPP has a life of 20 years. The initial electricity source to start the CPP is imported from a natural gas conventional power plant off-site. From this point, the electricity to run the CPP is provided by the CPP itself.
- It's assumed that JSW's CPP has the same environmental impact as Epsilons CPP.

2.8.2 Water Treatment Assumptions

- For the water treatment plant, the steam condensate co-product is assumed to be burden free, as the steam produced is recycled into Epsilon's CPP on site.
- For the water treatment process, the antiscalant and antioxidant reagents required are defined as a meta-phenylene diamine and trisodium phosphate, respectively.

2.8.3 Process Related Assumptions

2.8.3.1 JSW's Coal Tar Production

- The coal tar produced at JSW's Dolvi facility, is assumed to have the same exact production process as the Vijayanagar facility, therefore is assumed to have the same environmental impact.
- Nitrogen gas is consumed within the coal tar production process and is assumed to be burden-free, due to being a waste gas produced from the oxygen production plant on the JSW site. The nitrogen gas is captured and redirected to the coal tar plant. The electricity requirements to capture the waste nitrogen gas are included in the LCIA.
- Coke oven gas emissions are generated during coal tar production. It is assumed that 95% of these emissions are captured and recycled back into JSW's processes. 5% of the emissions are assumed to be lost to the atmosphere.
- JSW uses compressed air within its process for cleaning purposes. It is assumed that the compressed air unit has a gauge of 392 kPa, with an average pressure of 4 kg/cm^2 of air.

2.8.3.2 Epsilon's Synthetic Graphite Anode Production

- The effluent treatment chemicals in stage 2 (soft pitch production) are DAP, Urea, and Hypo. These are characterised as di-ammonium phosphate, nitrogen-based ammonium phosphate, and sodium sulfate respectively.
- Ecoinvent 3.8 does not have a characterisation factor for aluminium phosphate, therefore a proxy data point of aluminium sulfate was used.
- Anthracene oil and wash oil consumed within zero QI production are assumed to be burden free, due to these two inputs being produced as co-products in the previous stage (soft pitch production).
- Stages 4 - 6 are fully electrified processes, therefore there are no direct CO_2 emissions.
- Blowdown water required within Epsilon's process is burden-free, due to being sourced from condensate production and continuously recycled through the process. It is assumed 100% of the blowdown is recycled.
- It is assumed that the electricity required to capture atmospheric air that is used in the graphitisation process (stage 6) has been incorporated into the electricity

requirements of the process.

- It is assumed that all co-products produced within Epsilon's production process are to be sold to their respective markets. This is addressed in section 2.4.

2.8.4 Transport Assumptions

Transport of material inputs and all products are included within the LCA. The following assumptions include:

- Transported by rail - a diesel-powered freight train.
- Transport by ship - freight container ship.
- Transport by road - using a >32 metric ton EURO3 freight lorry. Empty return trucks are not included.

2.9. Interpretation

The results were interpreted with reference to the goal and scope, comparing the impacts associated with the identified process routes, geographic regions, and technology implemented. Contribution analysis, sensitivity analysis, and uncertainty analysis were carried out to support the interpretation of the LCA.

2.9.1. Data Quality Review

The key data criteria used to evaluate the quality of the LCI used for this LCA study were:

- Technological, time, and geographical representativeness: data is representative if it matches geographical, temporal, and technological aspects of the goal and scope of the study. By utilising representative data for all foreground processes, the study can be made as representative as possible. When primary data are not available, best-available proxy data is used, ideally from databases or academic LCA literature.
- Completeness: a dataset is judged based on the completeness of inputs and outputs per unit processes and the completeness of the unit processes. The goal is to capture all relevant data in terms of unit processes.
- Precision: measured primary data is considered to be of the highest precision, followed by calculated data, data from the literature, and estimated data. This study

is carried out using measured and calculated data from the 2021 - 2022 detailed engineering studies. It must be noted that measured data can be precise but inaccurate. Accuracy can be obtained by cross-validation of measured data.

- Methodological appropriateness and consistency: data is considered appropriate and consistent if the differences between data reflect actual differences between distinct product systems, and are not due to inconsistencies in data collection or modelling.

Table 9 presents the grading system of data quality indicators.[12] An evaluation of the data quality for this LCA on Epsilon's synthetic graphite anode can be found in later chapters of this report.

Table 9. Grading Guidelines for Data Quality Assessment as Environmental Footprint 2.0 Pedigree Matrix[12] (PEF = Product Environmental Footprint)

Data Quality Indicator	Very Poor	Poor	Fair	Good	Very Good
Technological Representativeness	Old to dissimilar technology used	Technology dissimilar to what is used	Generic technology average	From technology specific to the application	All technology aspects of data have been modelled
Time Representativeness	The dataset is older than 8 years	The dataset is less than 8 years old	The dataset is less than 6 years old	The dataset is less than 4 years old	The dataset is less than 2 years old
Geographical Representatives	Data represented is from a distinctly dissimilar region of project location	Similar regions are represented in data	Global average is represented in data	Country of interest is represented in the data	Region of interest is fully represented in data
Completeness	Unknown coverage	Data is from small parts of the target region	Data is less than 50% from the target region	Data is more than 50% from the target region	Data is representative of the entire target region
Precision	Rough estimate with known deficits	Estimates based on calculations not checked by the reviewer	Estimates based on expert judgement	Estimates based on measured and prior values	Measured and verified values with <7% uncertainty
Methodological Appropriateness and Consistency	Attribution process-based approach and following none of the three method requirements of the PEF guide: dealing with multi functionality, end of life modelling, and system boundary	Attribution process-based approach and following one out of three method requirements of the PEF guide: dealing with multi functionality, end of life modelling, and system boundary	Attribution process based approach and following two out of three method requirements of the PEF guide: dealing with multi functionality, end of life modelling, and system boundary	Attribution process based approach and following three method requirements of the PEF guide: dealing with multi functionality, end of life modelling, and system boundary	Full compliance with all requirements of the PEF guide

Minviro assigned a data quality assessment of 1-5 for every life cycle inventory item provided by Epsilon and data quality assessment of each area of the LCA. An assignment of 1 corresponds to a "very good" data quality, while an assignment of 5 corresponds to a "very poor" data quality. Typically, Minviro assigns data qualities to life cycle inventory items with the levels of process and project definition shown in Table 10, but the exact assignment depends on the specific situation and expert judgement.

Table 10. Data Quality Assignment According to Level of Process Definition

Very Poor	Poor	Fair	Good	Very Good
Back-of-the-Envelope Calculations	Scoping Study or Preliminary Economic Assessment	Pre-Feasibility Study or Definitive Feasibility Study	Detailed Design and Engineering	Operating Facility

The data quality rating of the life cycle inventory item was calculated using the following equation.[12]

$$DQR = (TeR + GR + TiR + C + P + M + 4*X_w)/(i+4)$$

Where:

"DQR" is the data quality rating

"TeR, GR, TiR, C, P, and M" are acronyms for the data quality indicators in Table 9:

TeR = Technological Representativeness

GR = Geographical Representativeness

TiR = Time Representativeness

C = Completeness

P = Precision

M = Methodological Appropriateness and Consistency

“X_w“ is the lowest data quality assignment in the set of data quality assignments for the life cycle inventory’s different data quality indicators

“i” is the number of data quality indicators which were assigned values (in this LCA, six data quality indicators were used for assessing data quality)

2.9.2. Critical Review

A critical review of this study has not been conducted.

3. Results

The results for the five impact categories quantified in this LCA are shown below. For each environmental category reported, the figures aggregate the contributors to each impact category worth less than 1% of the total environmental impact as 'other' for visualisation. These small contributors are still included in the overall result.

3.1. Global Warming Potential

3.1.1. Global Warming Potential - Total

The total global warming potential for Epsilon's synthetic graphite anode is 5.2 kg CO_2 eq. per kg synthetic graphite anode according to the LCA model produced by Minviro. The total global warming potential is presented, broken down by stage of the LCA in Figure 3.

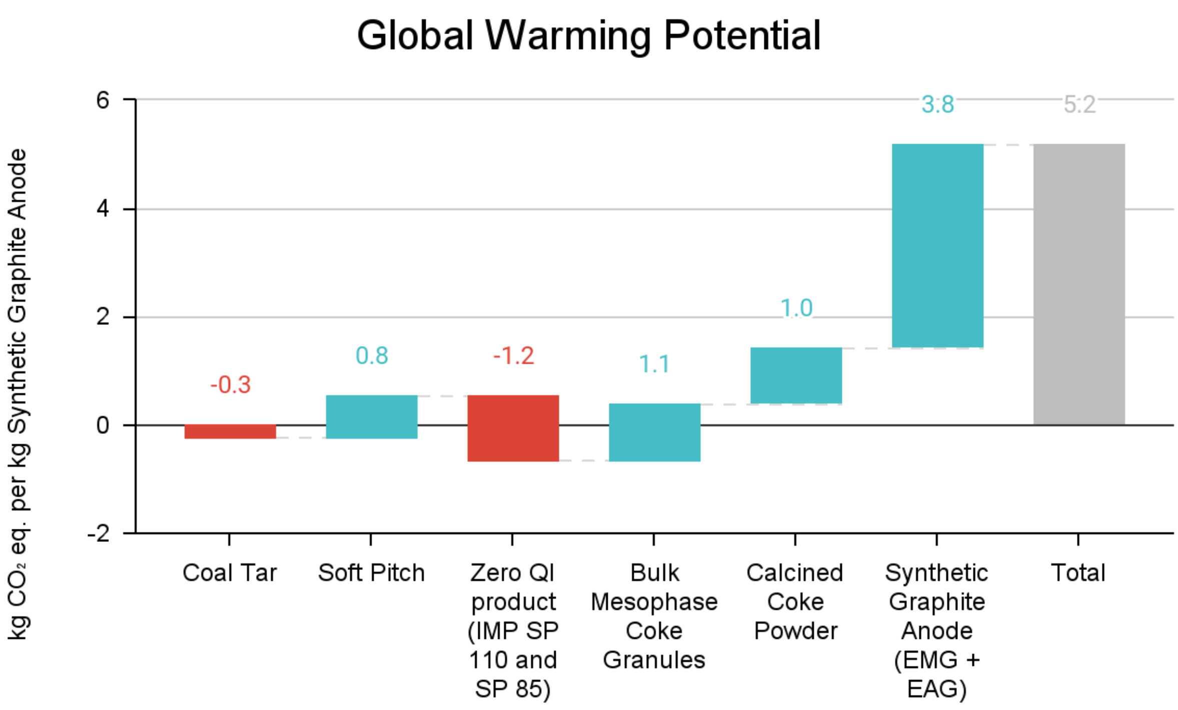

Figure 3. Total Global Warming Potential

3.1.2. Global Warming Potential - Contribution Analysis

Contribution analysis of the GWP is presented in Figure 4. The top three most significant contributors to GWP in the production of Epsilon's synthetic graphite anode are:

- 3.0 kg CO_2 eq. per kg synthetic graphite anode associated with electricity sourced from the grid for the graphitisation stage.
- 2.8 kg CO_2 eq. per kg synthetic graphite anode associated with electricity required to capture nitrogen within the precursor production.
- 2.7 kg CO_2 eq. per kg synthetic graphite anode associated with coking coal in precursor production.
- -9.7 and -1.0 kg CO_2 eq. per kg synthetic graphite anode associated with the credit given for the consumption of waste blast furnace gas and waste coke gas, respectively. These waste gases are captured on-site and used as the heat source for coal tar production.

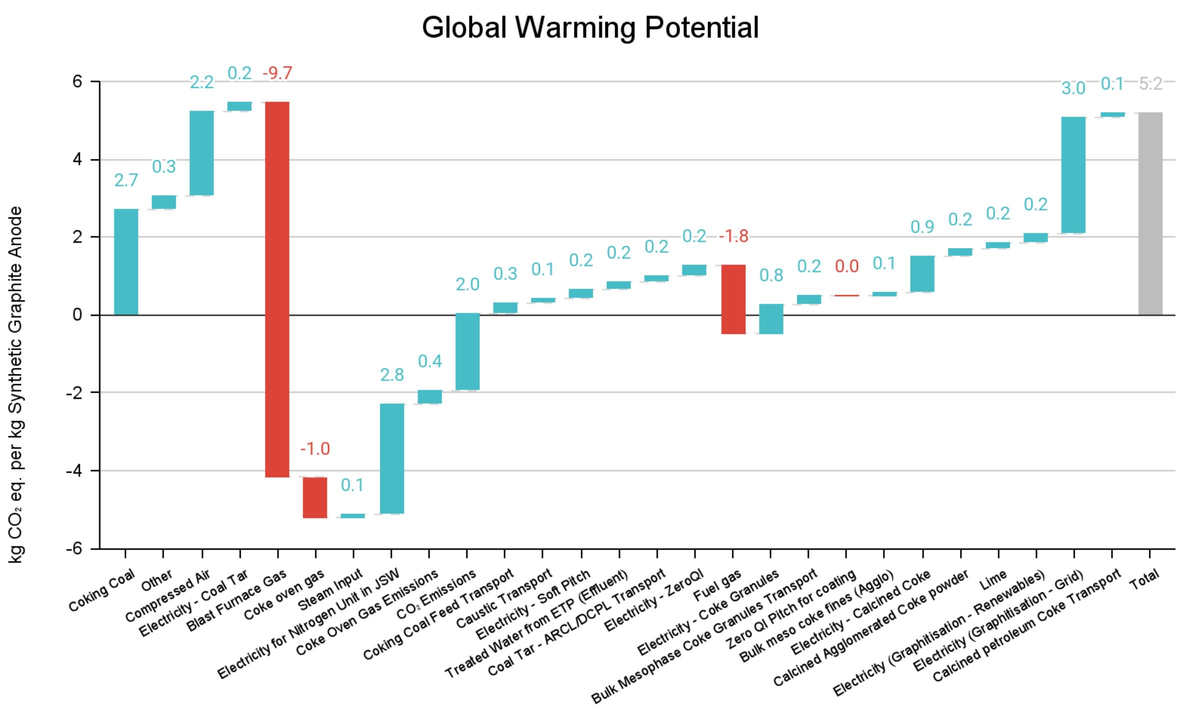

Figure 4. Global Warming Potential Contribution Analysis

3.1.3. Global Warming Potential - Total Breakdown by Scope

GWP impact is classified into scope 1, 2, and upstream scope 3 emissions (defined in section 2.7.1). The total GWP impact is 5.2 kg CO_2 eq. per kg synthetic graphite anode. The GWP broken down by scopes (1, 2 and 3) is presented in Figure 5.

Scope 1 emissions, which reflect direct emissions associated with the combustion of fossil fuels on-site (e.g. diesel), total 6.7 kg CO_2 eq. per kg synthetic graphite anode. These emissions come from direct CO_2 emissions produced on-site.

Scope 2 emissions are the embodied emissions from imported thermal and electrical energy. These total 3.2 kg CO_2 eq. per kg synthetic graphite anode. These emissions come from the importation of electricity within the graphitisation phase.

Upstream scope 3 emissions reflect the embodied impact of consumables. Total scope 3 emissions equate to -5.3 kg CO_2 eq. per kg synthetic graphite anode. This negative scope 3 value mainly comes from the consumption of waste blast furnace gas and waste coke gas.

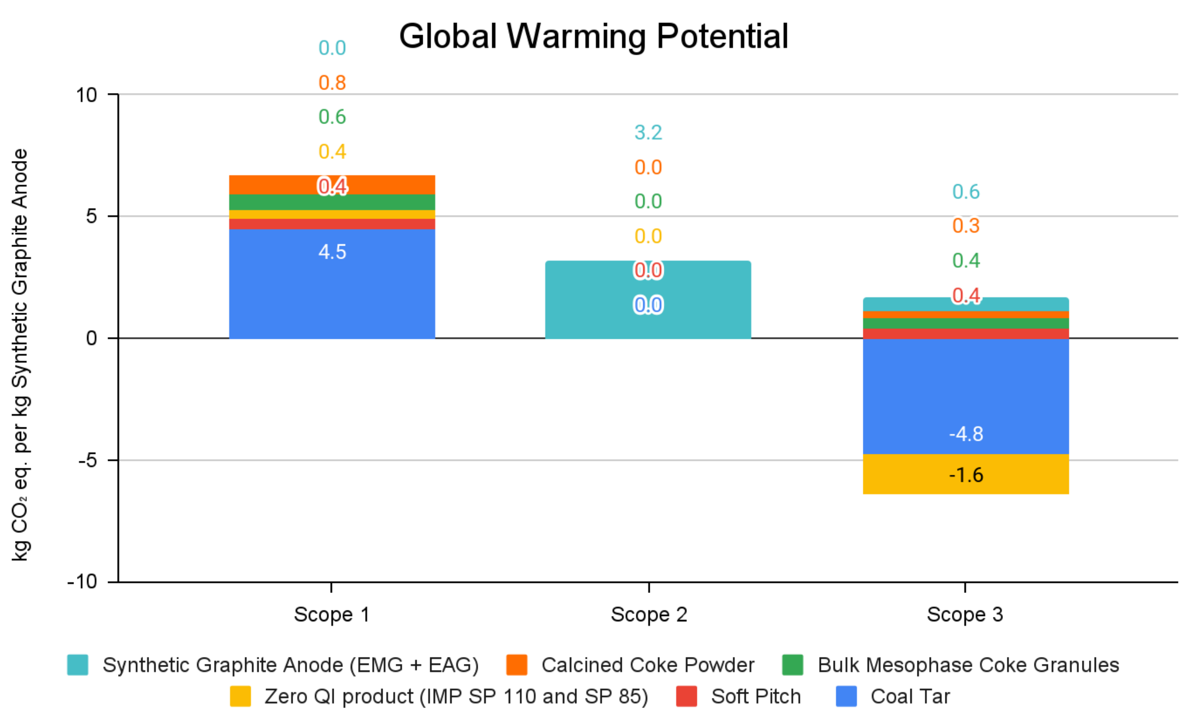

Figure 5. Global Warming Potential Contribution Analysis by Scope of Emissions

3.2. Resource Demand - Fossil Fuel Depletion

3.2.1. Fossil Fuel Depletion - Total

The total fossil fuel for Epsilon's synthetic graphite anode is 8.8 MJ per kg synthetic graphite anode, according to the LCA model produced by Minviro. The results are presented in Figure 6.

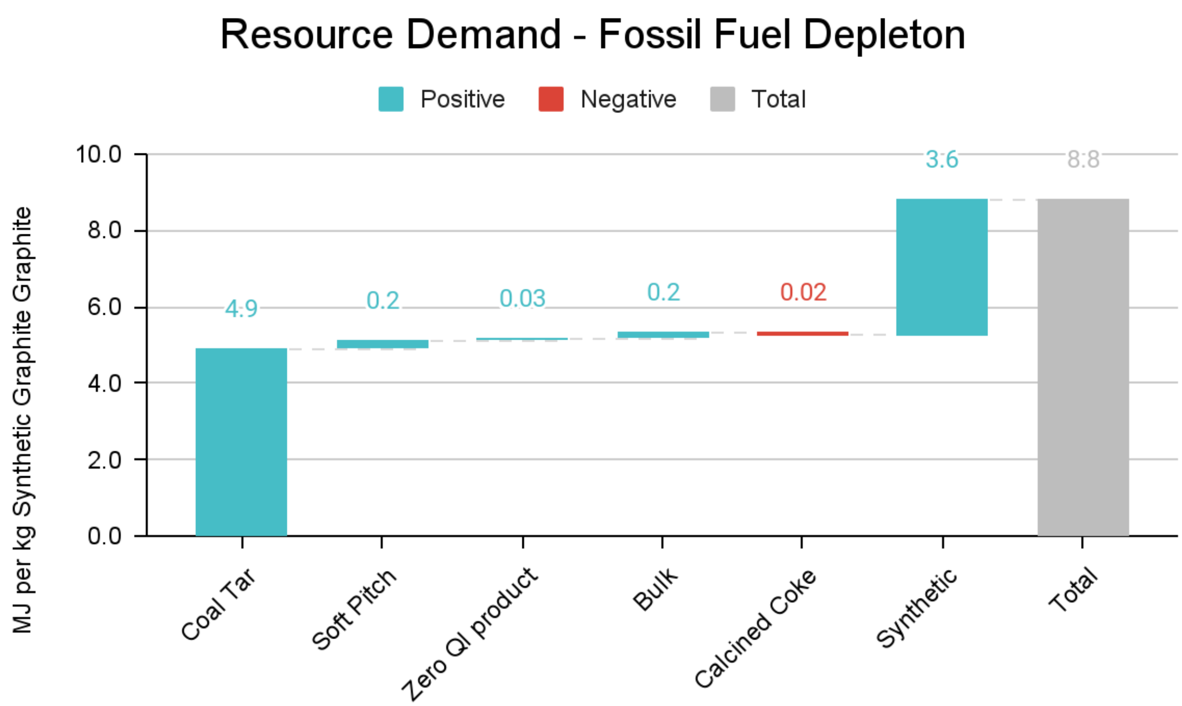

Figure 6. Total Fossil Fuel Depletion by Stage

3.2.2. Fossil Fuel Depletion - Contribution Analysis

Contribution analysis of fossil fuel depletion is presented in Figure 7. The top three most significant contributors to fossil fuel depletion in the production of Epsilon's synthetic graphite anode are:

- 3.0 MJ per kg synthetic graphite anode associated with electricity sourced from the grid for the graphitisation of the synthetic graphite to produce the final anode-grade product.
- 2.7 MJ per kg synthetic graphite anode associated with coking coal consumption required for coal tar precursor material production.
- 2.2 MJ per kg synthetic graphite anode associated with the consumption of compressed air utilised in coal tar production.

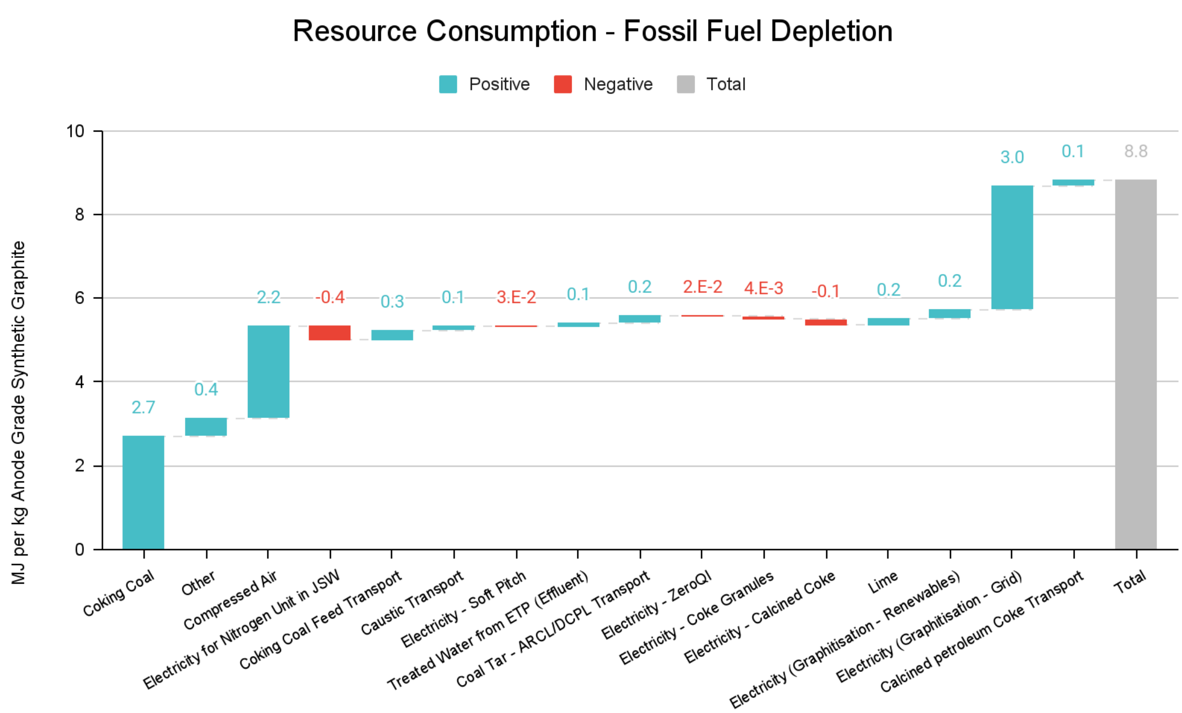

Figure 7. Fossil Fuel Depletion Contribution Analysis

3.3. Photochemical Ozone Formation

3.3.1. Photochemical Ozone Formation - Total

The total photochemical ozone formation for Epsilon's synthetic graphite anode is -0.32 kg NMVOC eq. per kg synthetic graphite anode, according to the LCA model produced by Minviro. The results are presented in Figure 8. The impact value is negative, meaning Epsilon's process reduces photochemical ozone formation, rather than increasing.

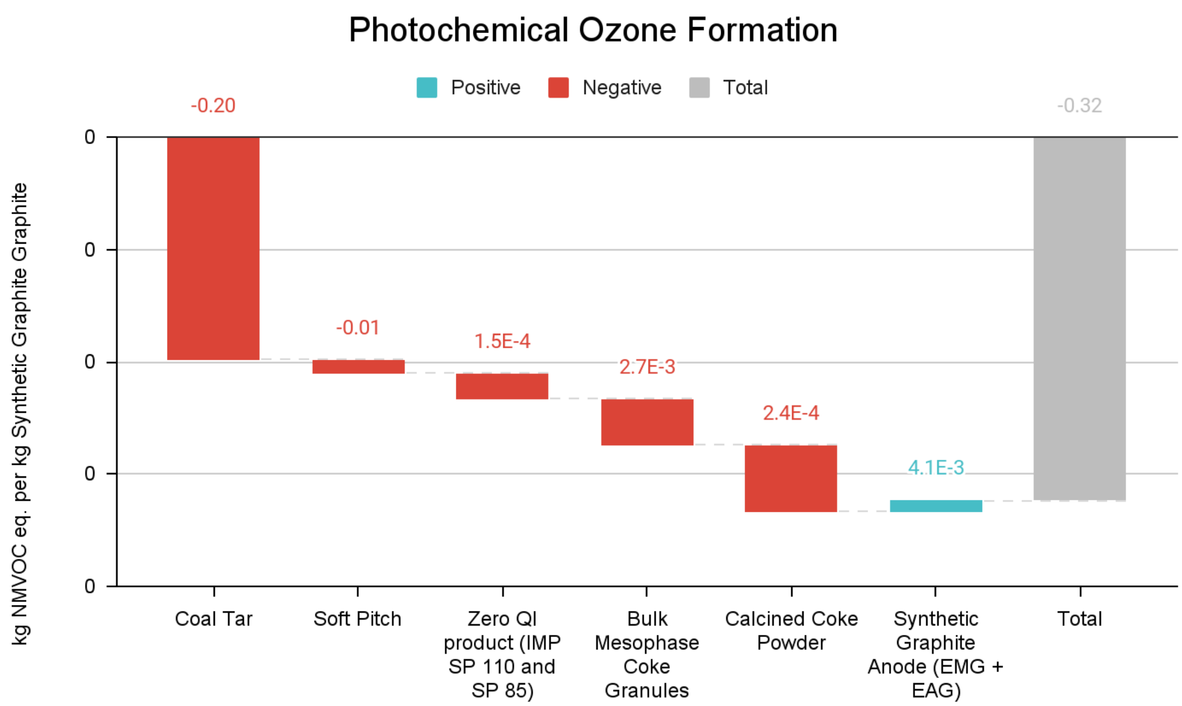

Figure 8. Total Photochemical Ozone Formation by Stage

3.3.2. Photochemical Ozone Formation - Total Contribution Analysis

The contribution analysis of photochemical ozone formation is presented in Figure 9. The top three most significant contributors to photochemical ozone formation impact value in the production of Epsilon's synthetic graphite anode are:

- -0.16 kg NMVOC eq. per kg synthetic graphite anode associated with the electricity required for the capture of waste nitrogen gas.

- -0.05 kg NMVOC eq. per kg synthetic graphite anode associated with the electricity required for bulk mesocoke powder production.
- -0.04 kg NMVOC eq. per kg synthetic graphite anode associated with the consumption of waste blast furnace gas and the electricity required for coke granules production.

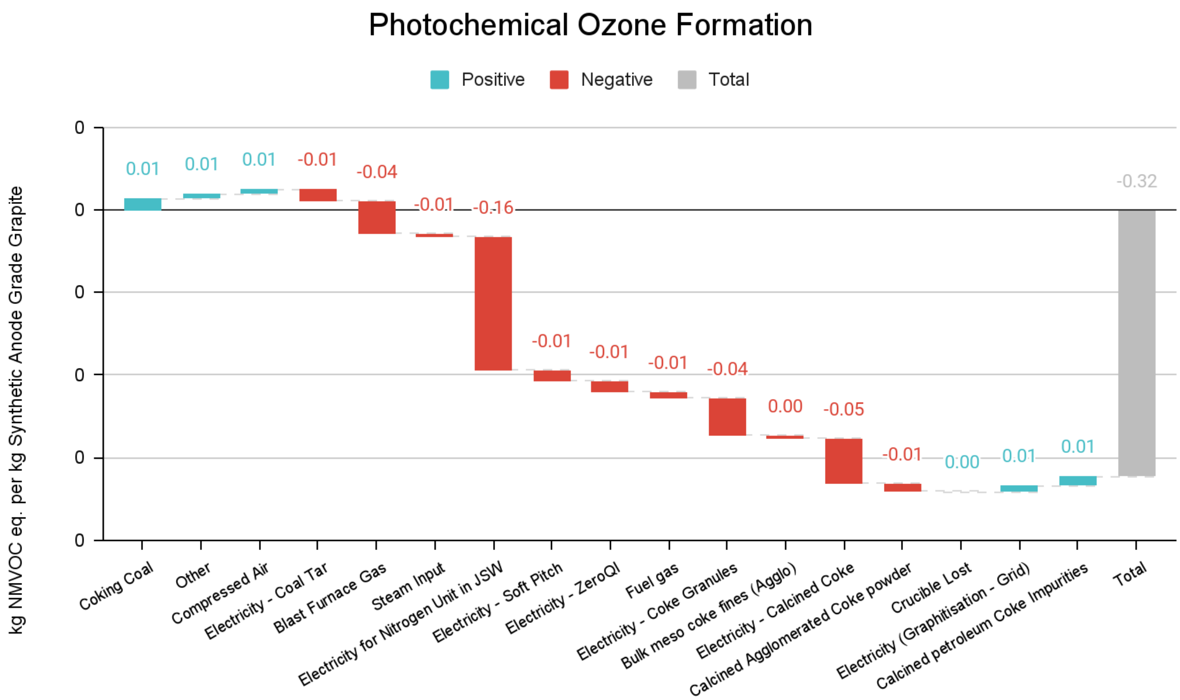

Figure 9. Total Photochemical Ozone Formation Contribution Analysis

3.4. Acidification Potential

3.4.1. Acidification Potential - Total

The total acidification potential for Epsilon's synthetic graphite anode is 7.9E-2 mol H^+ eq. per kg synthetic graphite anode according to the LCA model produced by Minviro. The total acidification potential is presented, broken down by area of the LCA, in Figure 10.

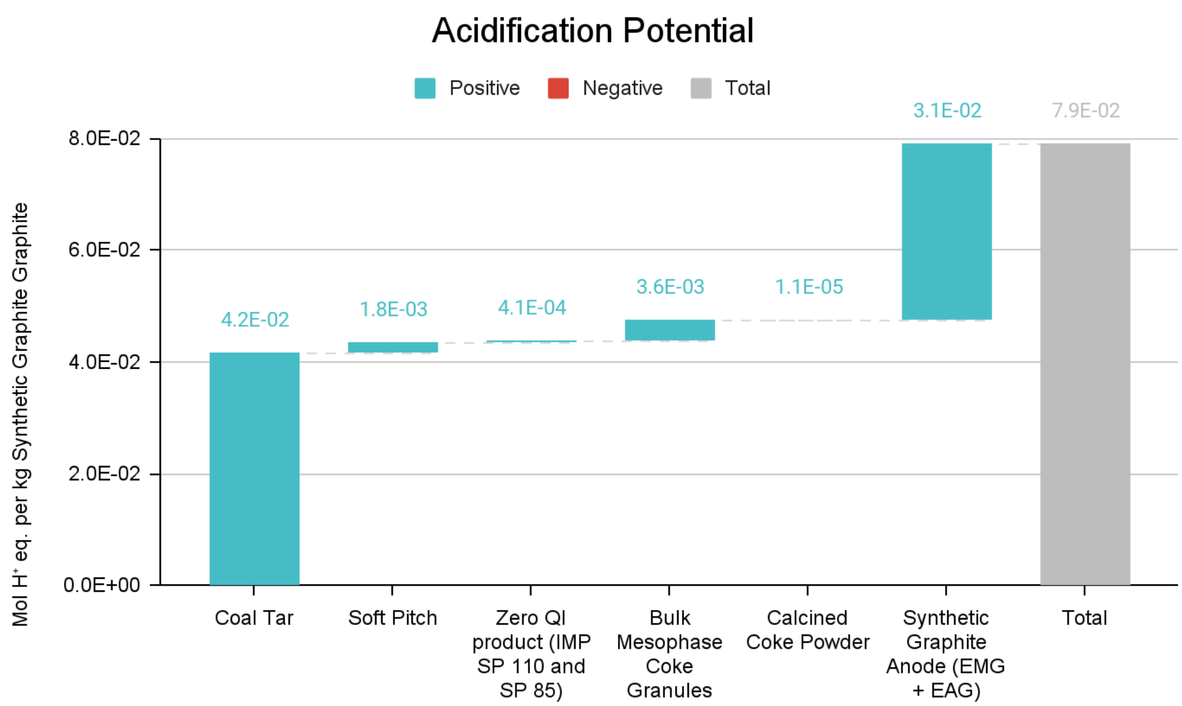

Figure 10. Total Acidification Potential

3.4.2. Acidification Potential - Contribution Analysis

Contribution analysis of the acidification potential is presented in Figure 11. The top three most significant contributors to acidification potential in the production of Epsilon's synthetic graphite anode are:

- 3.0E-2 mol H^+ eq. per kg synthetic graphite anode associated with the consumption of coking coal for coal tar production.
- 1.4E-2 mol H^+ eq. per kg synthetic graphite anode associated with electricity sourced from the grid for the graphitisation of synthetic graphite.
- 1.3E-2 mol H^+ eq. per kg synthetic graphite anode associated with the release of calcined coke impurities as a result of the combustion of calcined coke and petroleum coke within graphitisation.

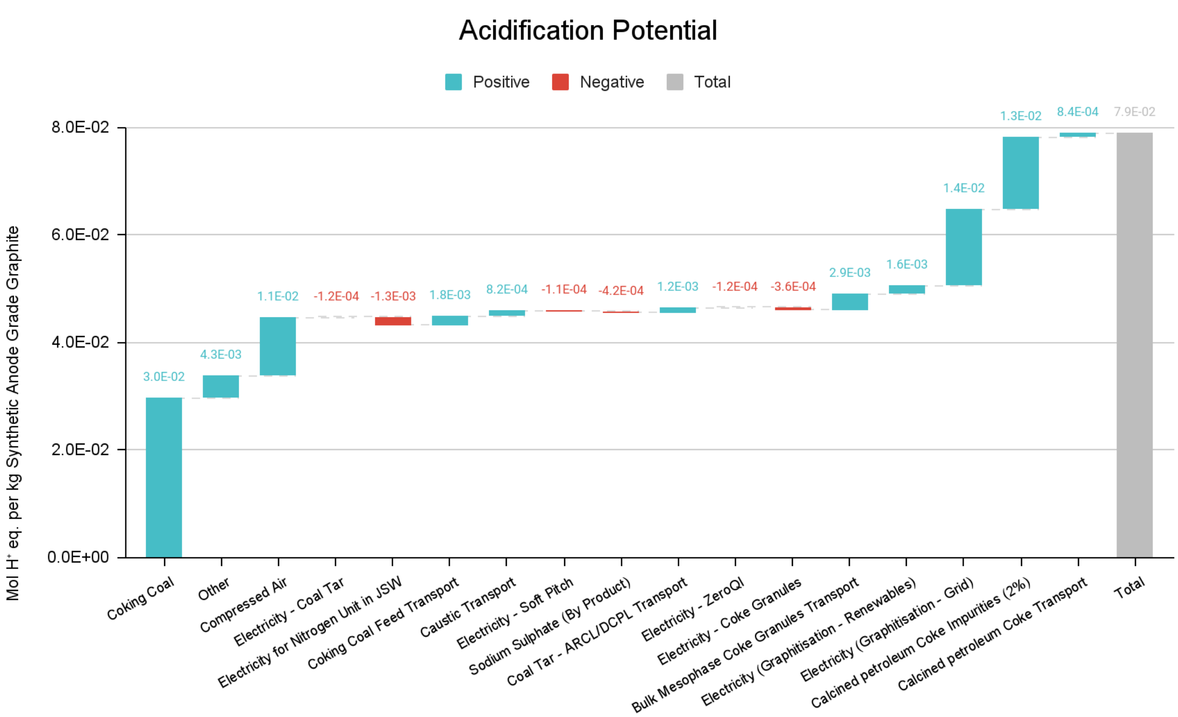

Figure 11. Acidification Potential Contribution Analysis

3.5. Freshwater Eutrophication Potential

3.5.1. Freshwater Eutrophication Potential - Total

The total freshwater eutrophication potential for Epsilon's synthetic graphite anode is 1.3E-2 kg P eq. per kg synthetic graphite anode according to the LCA model produced by Minviro. The total freshwater eutrophication potential is presented, broken down by area of the LCA, in Figure 12.

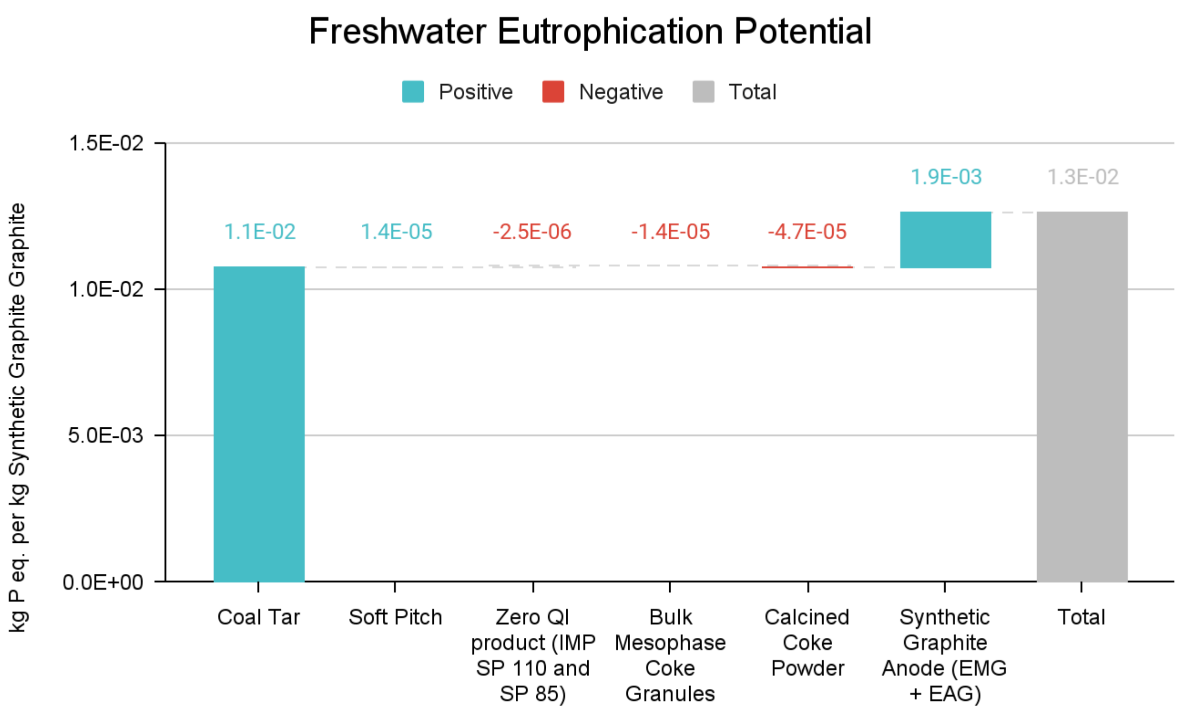

Figure 12. Total Freshwater Eutrophication Potential by Stage

3.5.2. Freshwater Eutrophication Potential - Contribution Analysis

Contribution analysis of the freshwater eutrophication potential is presented in Figure 13. The top three most significant contributors to freshwater eutrophication potential in the production of Epsilon's synthetic graphite anode are:

- 9.5E-3 kg P eq. per kg synthetic graphite anode associated with the consumption of coking coal for coal tar production.
- 1.8E-3 kg P eq. per kg synthetic graphite anode associated with the consumption of electricity sourced from the Keralan grid for the graphitisation stage.
- 1.3E-3 kg P eq. per kg synthetic graphite anode associated with the consumption of compressed air for clearing processes within the coal tar production stage.

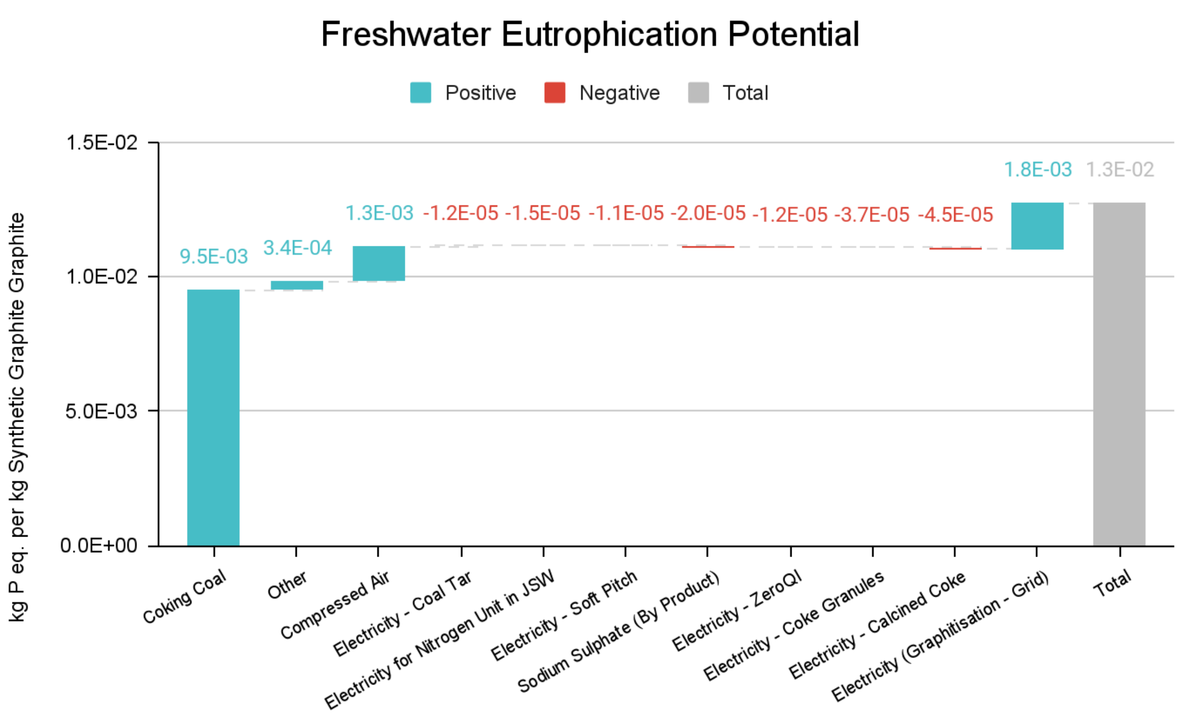

Figure 13. Freshwater Eutrophication Potential Contribution Analysis

4. Intermediate Products - Results

Table 11 presents the results for the environmental impact associated with the production of the two intermediate products produced within the Epsilon production process. The transportation of each product to its downstream processing facility and/or customer is included. The production process of each is described in section 2.4.

For the bulk mesocoke granules production, the global warming potential is 0.3 kg CO_2 eq. per kg bulk mesocoke granules. For the production of bulk mesocoke powder, the global warming potential 1.7 kg CO_2 eq. per kg bulk mesocoke powder.

Table 11. Results Summary of LCA Study - per kg Bulk Mescoke Granules, Bulk Mesocoke Powder, and Synthetic Graphite Anode

Impact Category	Bulkmesocoke Granules (per kg Bulkmesocoke Granules)	Bulkmesocoke Powder (per kg Bulkmesocoke Powder)	Synthetic Graphite Anode (per kg Synthetic Graphite Anode)	Unit
Global Warming Potential	0.3	1.7	5.2	per kg CO_2 eq.
Resource Demand - Fossil Fuel Depletion	3.6	6.3	8.8	MJ
Photochemical Ozone Formation	-0.19	-0.40	-0.32	kg NMVOC eq.
Freshwater Eutrophication Potential	7.3E-3	1.3E-2	1.3E-2	kg P eq.
Acidification Potential	3.2E-2	5.7E-2	7.9E-2	Mol H^+ eq.

5. Comparison Scenario Analysis

Minviro has developed generic process route data for making comparisons between existing graphite production pathways and new pathways in development. These comparison scenarios are presented in this chapter. They do not refer to specific operators and do not use the confidential information of other parties. This study does not intend to support comparative assertions.

The objective of this chapter is to compare the results of producing Epsilon's synthetic graphite anode with the production of natural and synthetic anode-grade graphite, namely:

1. Natural anode-grade graphite produced in Heilongjiang Province, China.
2. Anode-grade synthetic graphite produced in Inner Mongolia, China.

These options were chosen as comparison points, as China is the largest producer of these graphite products. Graphite products can have different environmental impacts depending on the natural resource they are produced from, and the process technology chosen in flowsheets. The LCI used for the comparison scenarios are Ecoinvent 3.8[3] and the Environmental Footprint 3.0 database.[17]

Efforts have been made to ensure the system boundaries for the comparison scenarios are the same as the system boundary assumed for Epsilon's synthetic graphite production.

For the comparison scenarios, the LCIs were collected internally from Ecoinvent 3.8, or from public databases. The system boundaries can be obtained from section 5.1 and 5.2 of this report. The studies were desk-based, meaning that all data was either collected from public sources or assembled from public and private databases. Foreground and background data were used from Ecoinvent 3.8.

5.1 Natural anode-grade Graphite - Heilongjiang Province, China

The aim of this comparison scenario analysis is to compare the results of producing Epsilon's synthetic graphite anode with the production of natural anode-grade graphite via other routes.

This comparison route models the production of natural anode-grade graphite, produced in Heilongjiang Province, China. This is a cradle-to-gate study, with the cradle defined as the point of resource extraction, and the end-gate defined as the final natural anode-grade graphite product. The transport of the product to market has not been included.

The functional unit for the process is 1 (one) kg of natural anode-grade graphite (99.95% C), produced in Heilongjiang Province, China.

The stages modelled include:

1. **Primary Extraction**: open-pit mining in China using diesel-powered hauling equipment and conventional ammonium nitrate fuel oil to liberate ore and waste, followed by traditional load and haulage. The ore contains 11% C and the deposit has an assumed strip ratio of 1.
2. **Concentrating**: metallurgical plant for concentration of graphite ore including crushing, grinding, and multistep flotation. Electricity is sourced from the Heilongjiang regional grid. Thermal energy is sourced from the combustion of hard coal. The upgrading has a graphite recovery of 94% from ore feed to graphite concentrate. The graphite concentrate has a grade of 95% C.
3. **Upgrading**: processing at a chemical plant involving spheronisation and purification of graphite concentrate to purified spherical graphite (PSG). The purification stage uses the hydrofluoric acid purification process, to remove the remaining impurities from the graphite concentrate to produce the final purified product. The PSG is coated to produce the final product. The final carbon content of the CLP >99.9% C. Electricity is sourced from the Heilongjiang regional grid.
4. **Transport**: graphite concentrate is transported from the mine to the processing plant via lorry.

System Boundary

The system boundary for this comparison route is shown in Figure 14. This comparison scenario was chosen as it is a well-defined process, and is representative of natural anode-grade graphite production from mining, concentrating and upgrading of natural anode-grade graphite in China.

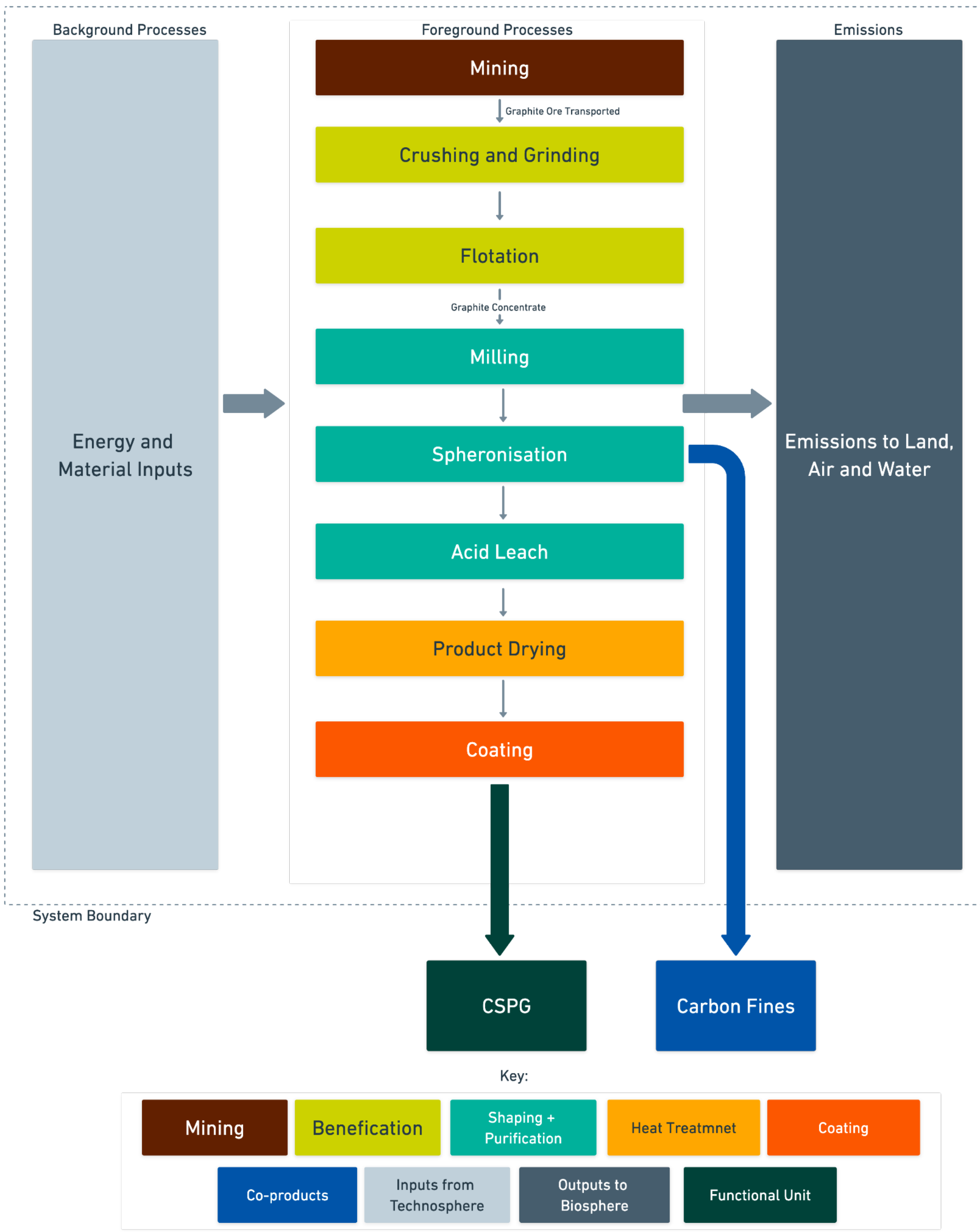

Figure 14. System Boundary of Natural Anode Grade Graphite, Heilongjiang Province, China

LCA Allocation Procedure

In this study, the foreground processes were calculated on a step-by-step basis. Each process stage has a single output, except for the spheronisation stage, where micronised graphite is produced as a co-product. Economic allocation was used to split the environmental impact of this stage to each of the products produced. The economic value of the fines accounts for 25% of the total process.[7] Allocation of the background data is according to the Ecoinvent 3.8 database.

Global Warming Potential

The total GWP for this scenario is 14.7 kg CO_2 eq. per kg natural anode-grade graphite, as seen broken down by contribution in Figure 15. This GWP value is the product of specific LCA data in Minviro's database. Similar operations with different inputs or outputs may have different GWP, depending on a variety of factors.

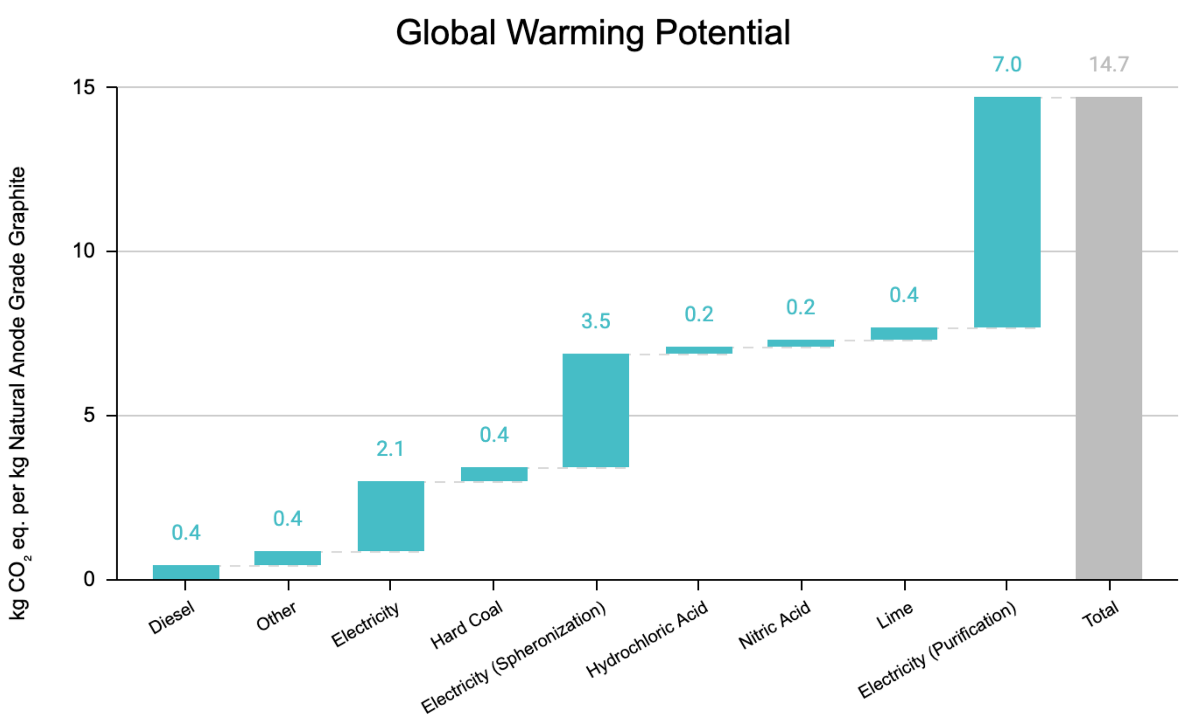

Figure 15. Global Warming Potential Breakdown for Natural Anode Grade Graphite, Heilongjiang Province, China

5.2 Synthetic anode-grade Graphite - Inner Mongolia, China

The aim of this comparison scenario analysis is to compare the results of producing Epsilon's synthetic graphite anode with the production of synthetic anode-grade graphite via other routes.

This comparison route models the production of synthetic anode-grade graphite produced in Inner Mongolia, China. This is a cradle-to-gate study, with the cradle defined as the point of precursor production of petroleum coke, and the end-gate defined as the final synthetic anode-grade graphite product. The transport of the product to market has not been included.

The functional unit for the process is 1 (one) kg of synthetic anode-grade graphite, produced in Inner Mongolia, China.

The stages modelled include:

1. **Precursor Production:** The production of petroleum coke precursor is a combination of calcined and green coke produced as a result of oil refining.
2. **Processing:** The petroleum coke precursor material undergoes calcination to produce needle coke. It is assumed that 1.6 kg of petroleum coke is required to produce 1 kg of synthetic anode-grade graphite. The needle coke goes through a series of crushing, grinding and sieving stages to produce spheroidised shape, then undergoes surface treatment where carbonisation occurs. Argon, liquid chlorine, quicklime and caustic soda are added within the carbonisation stage to mitigate oxidation of the petroleum coke. The feed is then transferred into an Acheson furnace, where graphitisation occurs at high temperatures to remove impurities. The output from the Acheson furnace is PSG. The synthetic graphite goes through a final coating and sieving stage to produce anode-grade synthetic graphite. Asphalt is added within the coating stage.

System Boundary

The system boundary for this comparison route is shown in Figure 16. This comparison scenario was chosen as it is a well-defined process, and is representative of synthetic anode-grade graphite production from precursor production and processing of synthetic anode-grade graphite in China.

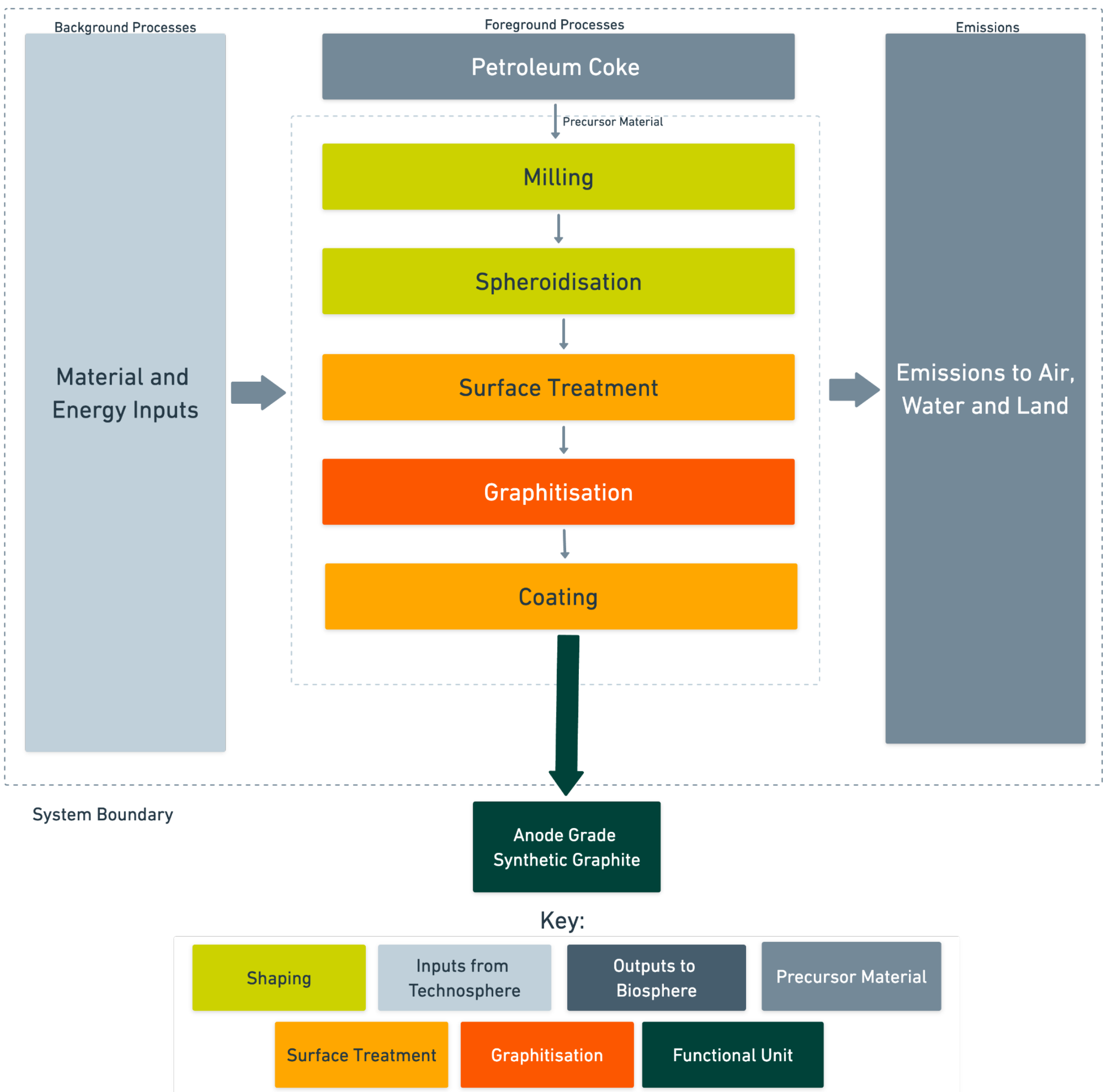

Figure 16. System Boundary of Synthetic Anode Grade Graphite, Inner Mongolia, China

LCA Allocation Procedure

100% allocation is given to the functional unit of 1 kilogram of synthetic anode-grade graphite. There are no co-products produced within the process modelled.

Global Warming Potential

The total GWP for this scenario is 23.1 kg CO_2 eq. per kg synthetic anode-grade graphite, as seen broken down by contribution in Figure 17. This GWP value is the product of specific LCA data in Minviro's database. Similar operations with different inputs or outputs may have different GWP, depending on a variety of factors.

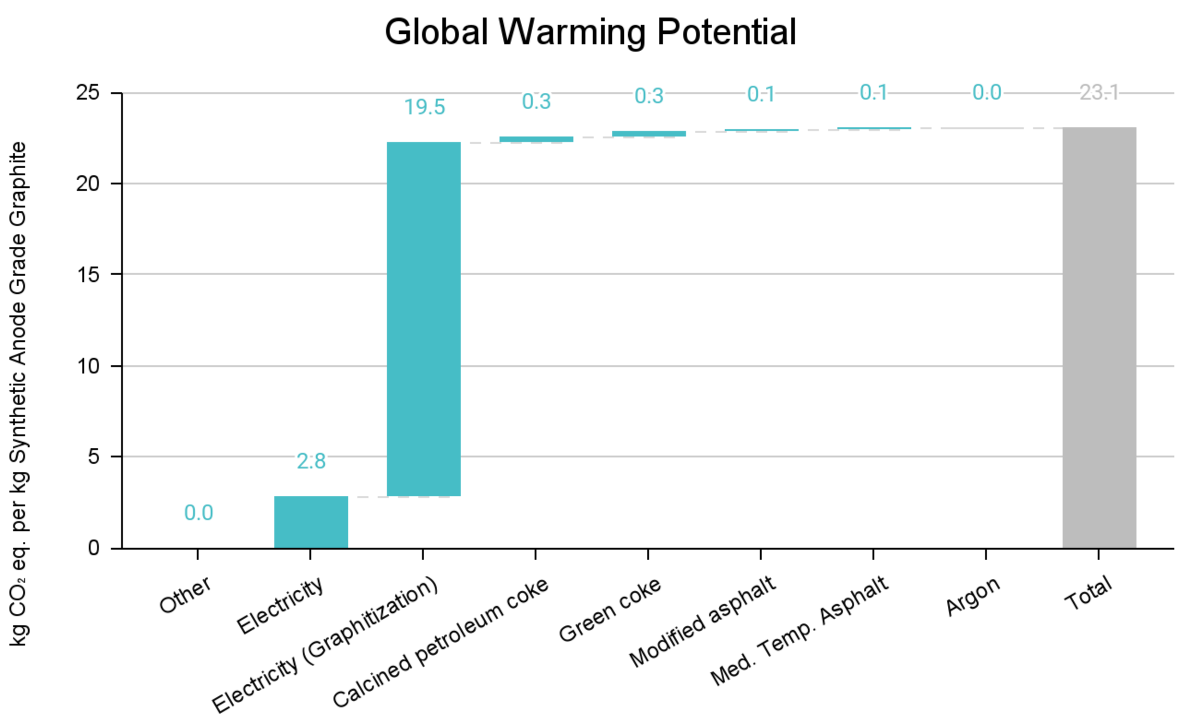

Figure 17. Global Warming Potential Breakdown for Synthetic Anode Grade Graphite, Inner Mongolia, China

5.3. Global Warming Potential Comparison

A comparison of the anode-grade natural and synthetic graphite production route's GWP can be seen in Figure 18 and Table 12. The GWP calculated for Epsilon's synthetic graphite anode production route is 5.2 kg CO_2 eq. per kg synthetic graphite anode. The natural anode-grade graphite production route, located in Heilongjiang Province, China, has a GWP of 14.7 kg CO_2 eq. per kg natural anode-grade graphite. The GWP calculated for the synthetic anode-grade graphite process route, located in Inner Mongolia, China, is highestat 23.1 kg CO_2 eq. per kg anode-grade synthetic graphite. The higher result for the Inner Mongolian anode-grade synthetic graphite route is mainly due to the embodied impact of the Inner Mongolian grid being sourced from coal based power stations.

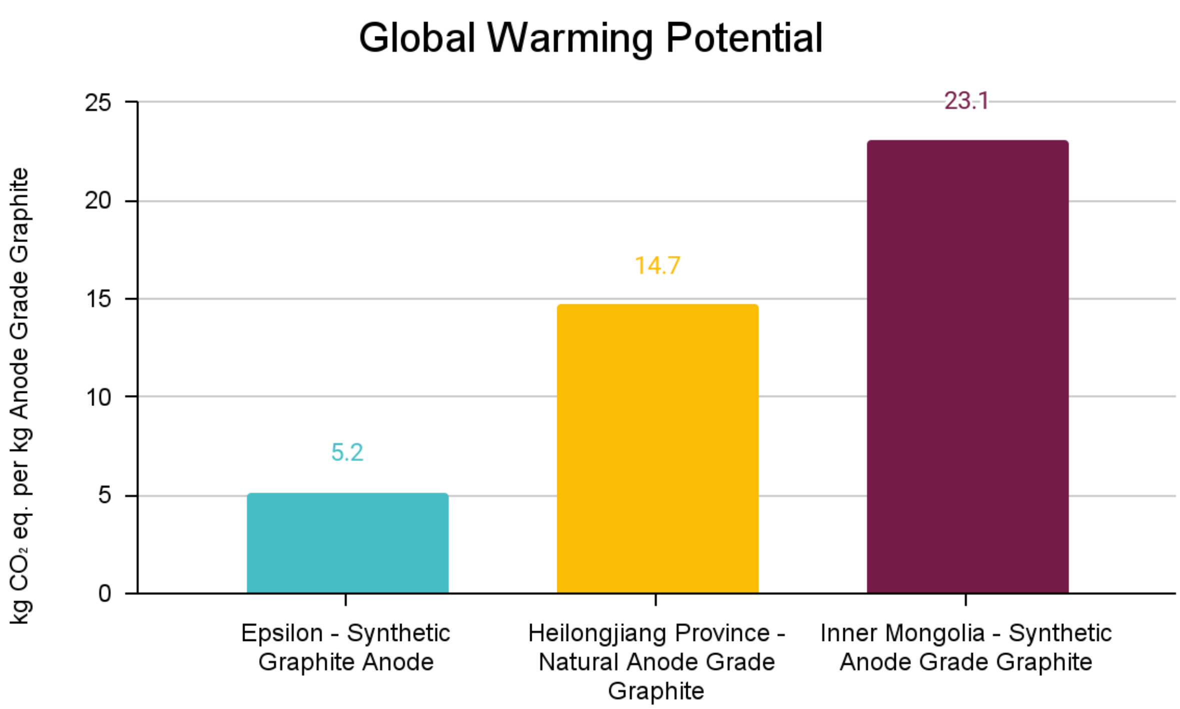

Figure 18. Comparison of Global Warming Potential Impact for Producing Anode Grade Graphite for Epsilon's Process and in China

Table 12. Results of Comparison Scenarios in Terms of Percentage Variation to the Epsilon Base Case Scenario

Comparison Scenario	Comparison Scenario Result (kg CO_2 per kg anode-grade Graphite)	Epsilon Project Result (kg CO_2 per kg Synthetic Graphite Anode)	Percentage Variation
Natural anode-grade Graphite - Heilongjiang Province	14.7	5.2	64.9%

Synthetic anode-grade Graphite - Inner Mongolia	23.1	5.2	77.6%

Percent Variation equation: $(Imapct_{China} - Impact_{Epsilon}) / Impact_{China}$

6. Data Quality Assessment

The foreground and background data of the LCI were judged on technological and time representativeness, geographical coverage, completeness, precision, and consistency. Foreground data used in this study was generated from data provided by Epsilon. The data is sourced from Epsilon's detailed engineering study, produced in 2021-2022. The data has an uncertainty of 15%. The comparison scenarios are based on published engineering studies and academic literature, which are functioning operations. The background data used in this LCA was from Ecoinvent 3.8.[3] The limitations to the study are discussed in section 2.8. The comparison scenario data was gathered from generic datasets developed by Minviro.

- Technological representativeness: Epsilon conducted detailed engineering studies in 2021 and 2022, which produced detailed energy and material balances for each stage of Epsilon's synthetic graphite anode production. These were used to determine the viability of the project, and the data used within this study. The energy and material input for JSW's CPP was unavailable, therefore, it was assumed JSW's CPP has the same environmental impact as Epsilon's CPP. All background data was sourced from Ecoinvent 3.8. A proxy characterisation factor was used for aluminium phosphate, due to missing the datapoint within Ecoinvent 3.8. **The technological representativeness is considered to be good - very good.** The comparison scenarios are based on technical reports and academic studies, which have been reviewed by an external expert. **The technological representativeness of the comparison scenarios is considered to be good.**
- Time representativeness: all foreground data was based on the engineering studies provided by Epsilon in 2021 and 2022. **The time representativeness is considered to be very good.** All background data was sourced from Ecoinvent 3.8, which was updated in 2021, however, it is possible that some background data points are based on outdated datasets. Some of the data collected for the comparison scenarios is collected from sources that could be more than 8 years old. **The time representativeness of the comparison scenarios' background data is considered to be good.**

- Geographical Coverage: regional-specific data was selected for the foreground and background processes where possible for JSW's and Epsilon's processes, based on Epsilon's project in India. All background data sources were sourced from Ecoinvent 3.8. **The geographical representativeness is considered to be very good. The geographical representativeness of the comparison scenarios is considered to be good.**
- Completeness: foreground processes were checked for the completeness of the mass and emission inventory. All background data points for Epsilon's project were sourced from Ecoinvent 3.8, of which the completeness is documented. **The completeness is considered to be good - very good.** The comparison scenarios are based on technical reports and academic literature detailing projects similar to those described. **The completeness of the comparison scenarios is considered to be fair.**
- Precision: the data for the production of the precursor and primary products is based on primary information sources provided by JSW, from their 2021 and 2022 detailed engineering studies. All background data sources were sourced from Ecoinvent 3.8. **The precision of the data was considered to be good.** For the comparison scenarios, the data was collected from technical reports or academic literature detailing projects similar to those described. All background data sources were sourced from Ecoinvent 3.8. **The precision of the comparison scenarios is considered to be fair - good.**
- Methodological appropriateness and consistency: all primary data was provided by Epsilon, with the same level of detail for all inputs and outputs. All background data sources were sourced from Ecoinvent 3.8. Multi-functionality is dealt with in Epsilon's process and the comparison scenarios when required, using economic allocation and system expansion. However, as the use-phase and end-of-life-phase of the products are not included, it only covers a part of the product life cycle. **The methodological appropriateness was considered to be fair. The methodological appropriateness of the comparison scenarios is considered to be fair.**

The data quality rating and data quality level for each area are presented in Table 13. A data quality rating (DQR) of less than or equal to 1.6 is considered a data quality level of "high quality". A data quality rating greater than 1.6 and less than or equal to 3.0 is considered a data quality level of "basic quality". A data quality rating of greater than 3.0 is considered a data quality level of "data estimate".

Table 13. Data Quality Assessment for the Project Life Cycle Inventory and Comparison Scenarios

Data Quality Indicator	Coal Tar	Soft Pitch	Zero Qi	Bulk Mesocoke Granules	Bulk Mesocoke Powder	Synthetic Graphite Anode	Comparison Scenarios
Technological Representativeness	1	1	1	1	1	1	1
Time Representativeness	1	1	1	1	1	1	1
Geographical Representatives	1	1	1	1	1	1	2
Completeness	2	1	1	1	1	1	3
Precision	1	2	2	2	2	2	2
Methodological Appropriateness and Consistency	3	3	3	3	3	3	3
Data Quality Rating	2.1	2.1	2.1	2.1	2.1	2.1	2.4
Data Quality Level	Basic Quality	Basic Quality	Basic Quality	Basic Quality	Basic Quality	Basic Quality	Basic Quality

7. Sensitivity Analysis

Sensitivity analysis was carried out to explore the effects that variations in reagent, material, and energy consumption may have on the final product life cycle impact assessment results. The investigated variations are of the different contributing factors individually.

This analysis studies the effect of variation of the top five main contributors to GWP in the LCA: coking coal, electricity (graphitisation - grid), compressed air, blast furnace gas, and electricity required for the nitrogen unit.

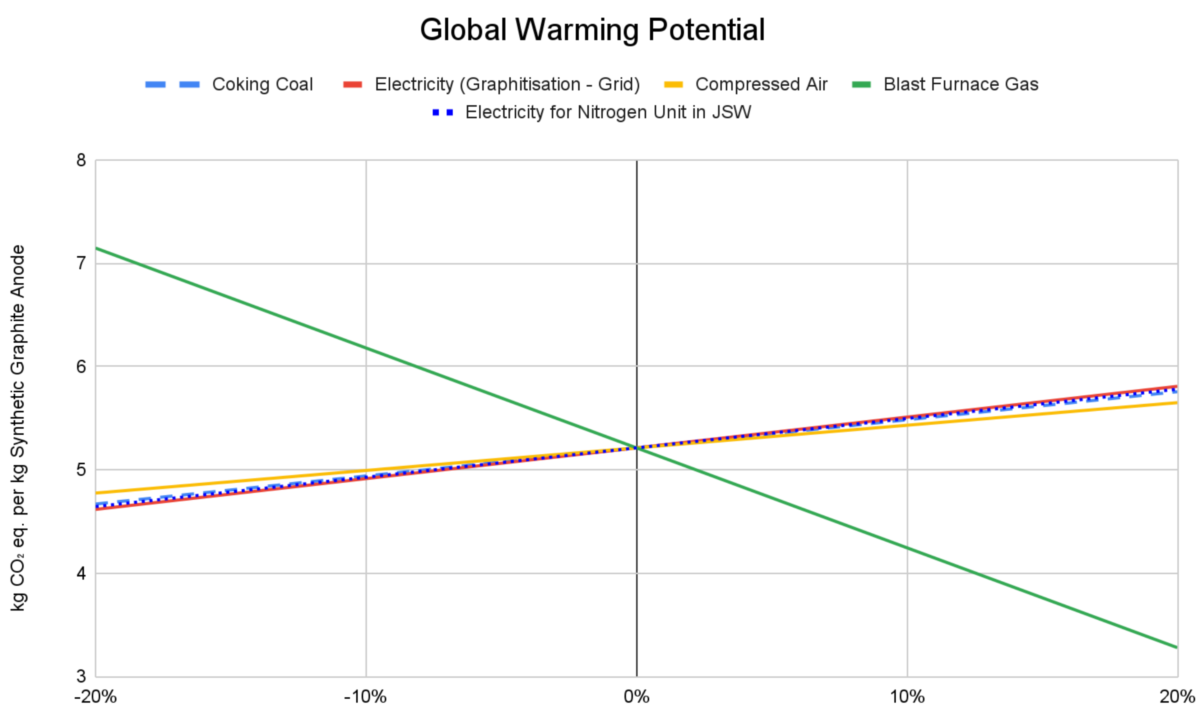

Figure 19. Sensitivity Analysis of Major Contributors to Global Warming Potential

This analysis shows that the LCA model for GWP is sensitive to the GWP contributions of blast furnace gas, sourced from captured waste gas, electricity for the graphitisation stage, and coking coal to the process because they are some of the largest contributors. Meanwhile, the model is less sensitive to minor inputs, such as the GWP contributions of compressed air and electricity for the nitrogen unit at JSW.

If the GWP contribution of blast furnace gas, the most significant contributor to GWP, increased or decreased by 20%, the total GWP would vary between 7.1 and 3.3 kg CO_2 eq. per kg synthetic graphite anode. Overall, the more blast furnace gas consumed, the larger the credit Epsilon receives. Nonetheless, this will also impact the amount of direct CO_2 emissions released. Meanwhile, if the GWP contribution of coking coal, or electricity required for the nitrogen unit, the least significant contributors, increased or decreased by 20%, the total GWP would vary between 4.6 and 5.8 kg CO_2 eq. per kg synthetic graphite anode. This is a clear demonstration of the high sensitivity of the LCA model to a few major inputs to the process of manufacturing Epsilon's synthetic graphite anode. These top contributors should be the main targets of environmental impact mitigation strategies.

8. Uncertainty Analysis

The uncertainty in the LCI and data quality has been explored in relation to the environmental impacts of the project using a Monte Carlo simulation, which assesses the range and likelihood of different impacts.

The Monte Carlo method, also a type of statistical simulation methods, is a precise method of numerical calculation guided by probability statistical theory. The method uses random numbers to solve practical problems, whereby random variables are generated with a certain probability distribution and the numerical characteristics of the model are estimated with statistical methods. The Monte Carlo method randomly samples the values of uncertain variables and combines with the predetermined impact assessment method to simulate statistically significant environmental impact evaluation results. This can reflect the influence of uncertain factors more accurately. The use of Monte Carlo simulation in LCA can effectively present the uncertainty associated with the LCA and its inputs. The results of the Monte Carlo simulation assist with understanding the impact of risk and uncertainty in the prediction and forecasting of models.

8.1 Epsilon's Synthetic Graphite Anode

In the Monte Carlo simulation conducted for the LCA, uncertainty was addressed by calculating a standard deviation of each item, assuming an uncertainty of 15% for all items in the LCI. Emissions cannot be modelled unless the materialistic reason for the emission increases as well (e.g. direct emissions associated with the combustion of diesel). The Monte Carlo simulation does not consider the uncertainty of the background data, as it is assumed that the 15% uncertainty associated with the detailed engineering stage of the project will include the uncertainty of the background data.[16] The Monte Carlo simulation was run through 1,000 iterations using a normal probability distribution. As the project moves from detailed engineering into operation, the uncertainty and therefore standard deviation will decrease. The results of the Monte Carlo simulation for the global warming potential are presented in Figure 20. Values generated in the simulation range from -2.0 to 12.1 kg CO_2 eq. per kg synthetic graphite anode. The mean value of the simulation is 5.2 kg CO_2 eq. per kg synthetic graphite anode, which is the same as the finding of the LCA.

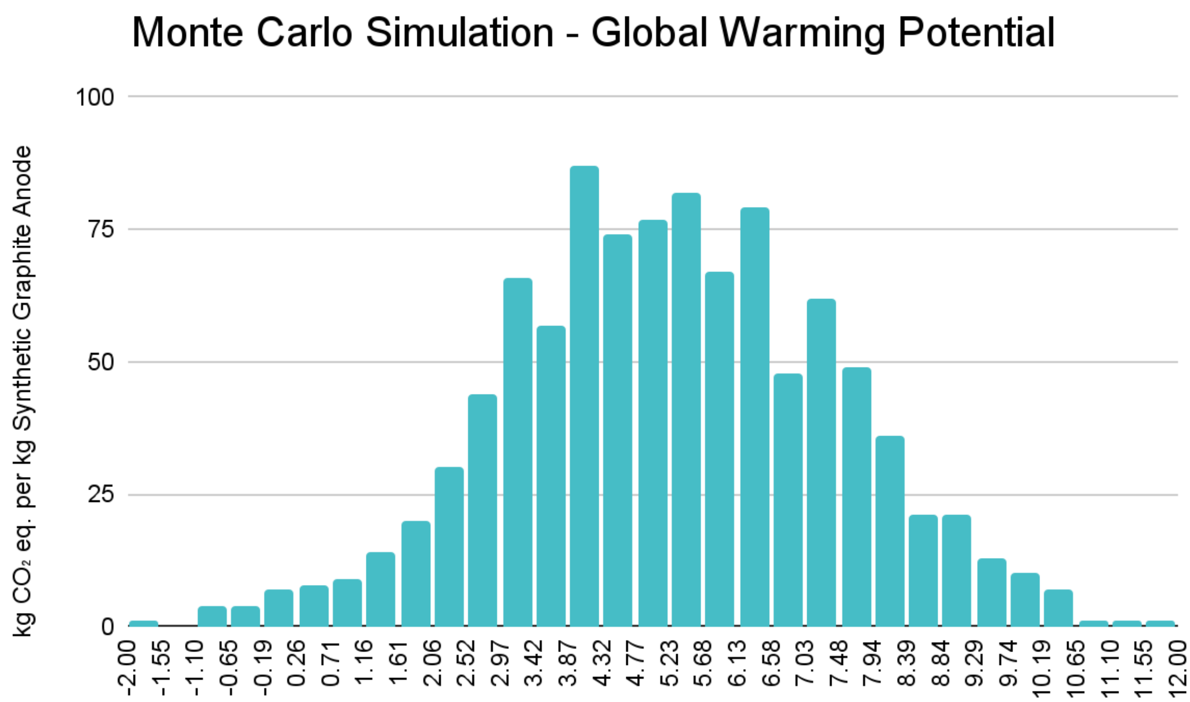

Figure 20. Monte Carlo Simulation for Global Warming Potential

Table 14. Statistics Describing Results of the Monte Carlo Simulation of Global Warming Potential

Parameter	**Global Warming Potential (kg CO_2 eq. per kg Synthetic Graphite Anode)**
LCA Study Result	5.2
Mean	5.2
Median	5.2
Minimum	-1.8
Maximum	11.9
20^{th} Percentile Value (P20)	3.4
80^{th} Percentile Value (P80)	7.2
Standard Deviation	2.1

9. Conclusions and Recommendations

9.1. Conclusions

Using Epsilon's data defined in the 2021-2022 detailed engineering studies, the expected environmental impacts of Epsilon's synthetic graphite anode, and intermediate products (bulk mesocoke granules and powder) have been quantified using LCA. The impact categories investigated in this LCA were global warming potential, fossil fuel depletion, photochemical ozone formation, freshwater eutrophication potential, and acidification potential.

It was found that the GWP of producing one kilogram of synthetic graphite anode is 5.2 kg CO_2 eq. per kg synthetic graphite anode. The main drivers of GWP impact are the consumption of electricity sourced from the Keralan grid for the graphitisation stage and the consumption of coking coal for the coal tar precursor production. Credits are given to the heat sources for each stage, due to being captured waste gas (mixture of blast furnace gas and mixed tail gas) which is consumed to generate heat.

The acidification potential, freshwater eutrophication potential and fossil fuel depletion follow the same trend in impact drivers as the global warming potential impact category. In comparison, the photochemical ozone formation impact category has a negative result, meaning photochemical ozone formation is reduced as a result of synthetic graphite anode being formed. This is due to the electricity and heat consumed being sourced from waste gases.

Comparison scenarios were conducted to quantify the environmental impact difference between Epsilon's synthetic graphite anode, and natural and synthetic anode grade graphite produced in Heilongjiang Province and Inner Mongolia, China, respectively. The global warming potential for Epsilon's graphite product is expected to be lower than the equivalent products produced in China.

We have greatly enjoyed working with Epsilon on this interesting and enjoyable project. We hope to continue our relationship with the goal of minimising the environmental impacts of manufacturing your critical product.

9.2. Recommendations

Minviro has several recommendations for Epsilon to improve the quality of this LCA and to improve the environmental performance of Epsilon's synthetic graphite anode product.

- This LCA was built using detailed engineering study data. When the project reaches the full operation stage, it is recommended to repeat the LCA to understand the LCa impacts, using data that has reached a higher level of definition. It will be critical to reproduce the LCA annually with actual production data so that Epsilon know the CO_2 equivalent of emissions that occur each year. To improve data quality, the LCA should be updated using higher quality data from mass and energy balances to provide a more accurate indication of the environmental impact results.
- The LCA was carried out using life of mine (LOM) average data, whilst it is expected that the consumption of consumables and production volume of graphite concentrate will vary year-on-year. It is recommended that this LCA is adapted to be a temporally explicit LOM LCA study when Epsilon commences construction.
- For the comparison scenario analysis, public data was collected, and proxy data from Minviro's internal database was used. It is recommended to repeat the comparison scenario analysis using data collected directly from operational facilities to minimise the uncertainty.
- The infrastructure and equipment used in this project have not been taken into account in this LCA. On average, over a LOM of 10 years, 0.05-0.5 kg CO_2 eq. per kg of product is consumed for the production and utilisation of the equipment. For future LCAs, this should be taken into account.
- Repeat the LCA and use the pairwise-method for the comparison of products.[18]
- At this stage, the study does not take into account the use of the synthetic graphite anode in LIB's or the end of life. It is recommended to include this in further LCA's to understand the full cradle-to-grave or cradle-to-cradle environmental impacts.
- A large contributor to the impact is as a result of 20% of the electricity required for graphitisation is sourced from the Keralan grid. It is recommended to source this electricity from fully renewable sources to further minimise the impact. Additionally, coking coal is the other major impact driver within this LCA. It is recommended to

explore different coking coal sources which have a more environmentally friendly process, to further mitigate the environmental impacts.

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Appendix A - Epsilon's Energy and Material Consumption and Transport Data

The full energy and material data and the associated emissions used in this study is presented in Table 15. The transport of consumables and products to and from Epsilon's facilty is shown in Table 16.

Table 15. Summary of the Project's Energy and Material Consumption Data and the Associated Emissions

Inventory Item	Ecoinvent 3.8	Input/Output	Value	Units	Reference Unit
Coking Coal	*hard coal// market for hard coal*	Input	15,738,833	t	per year
Sodium Hydroxide	*sodium hydroxide, without water, in 50% solution state// market for sodium hydroxide, without water, in 50% solution state*	Input	5,748	t	per year
Nitrogen Gas	-	Input	9,849	t	per year
Compressed Air	*Calculated*	Input	24,788,593	t	per year
Electricity	*Combined Power Plant*	Input	606,430	MWh	per year
Blast Furnace Gas	*Calculated*	Input	6,430,672,859	Nm3	per year
Coke oven gas	*Calculated*	Input	685,425,433	Nm3	per year
Steam Input	*Calculated - CPP*	Input	1,816,689	t	per year
Electricity for Nitrogen Unit in JSW	*Calculated*	Input	875	MW	per year
Soften Water	*tap water// market for tap water*	Input	2,616,574	m3	per year
ETP Water Regeneration	*Water Treatment Plant - Calcualted*	Output	293,058	m3	per year
CO_2 Emissions	*carbon dioxide (fossil) (air, unspecified (long-term))*	Emissions	259	kg	per t of Met Coke

Coke Oven Gas Emissions	*Calculated*	Output - 95% Recycled	4,938,392,045	Nm3	per year
Sulphur Output (By Product)	*sulfur// sulfur production, petroleum refinery operation*	Co-Product	340	t	per year
Coke Breeze Output	-	Co-Product	30,175	t	per year
Metallurgical Coke	-	Co-Product	10,247,026	t	per year
Coal Tar	-	Intermediate Product	446,951	t	per year
Soft Pitch Production					
Coal Tar feed- JSW	*Calculated*	Input	256,607	t	Year
Coal Tar feed- ARCL/Dovi	*Calculated*	Input	190,344	t	Year
Sulphuric Acid	*sulfuric acid// market for sulfuric acid*	Input	2,062	t	Year
Caustic Soda	*sodium hydroxide, without water, in 50% solution state// market for sodium hydroxide, without water, in 50% solution state*	Input	842	t	Year
DAP	*diammonium phosphate// market for diammonium phosphate*	Input	4,832	Kgs	Year
Urea	*inorganic nitrogen fertiliser, as N// nutrient supply from ammonia, anhydrous, liquid*	Input	4,832	Kgs	Year
Aluminium Phosphate	*aluminium sulfate, powder// market for aluminium sulfate, powder*	Input	12,719	Kgs	Year
Hypo	*sodium sulfate, anhydrite// market for sodium sulfate, anhydrite*	Input	1,367	Kgs	Year

Electricity	*Calculated*	Input	27,877	MWh	Year
Mixed Gas (Coke Oven / Blast Furnace)	*Calculated*	Input	90,602	GCal	Year
Total Water Process Input	*tap water// market for tap water*	Input	349,638	m3	Year
Process Water by dehydration	*sodium tripolyphosphate// market for sodium tripolyphosphate*	Input	11,943	t	Year
Treated Water from ETP (Effluent)	*Calculated*	Output	80,617	m3	Year
ETP Sludge Generation	*process-specific burdens, inert material landfill// market for process-specific burdens, inert material landfill*	Output	20,059	Kgs	Year
CO_2 Emissions	*carbon dioxide (fossil) (air, unspecified (long-term))*	Emissions	16,839	t	Year
Anthracene Oil	-	Co-Product	85,771	t	Year
Ind Naphthalene	-	Co-Product	21,862	t	Year
Refine Naphthalene	-	Co-Product	10,140	t	Year
Wash Oil	-	Co-Product	37,523	t	Year
Carbon Black Oil	-	Co-Product	6,790	t	Year
Light Oil	-	Co-Product	2,054	t	Year
Residual Oil	-	Co-Product	1,174	t	Year
Phenol Oil	-	Co-Product	8,120	t	Year
Zero Qi/Impregnated Pitch	-	Co-Product	2,666	t	Year

Phenol Oil from Na-Ph Process	-	Co-Product	3,576	t	Year
Sodium Sulphate (By Product)	*sodium sulfate, anhydrite// market for sodium sulfate, anhydrite*	Co-Product	3,260	t	Year
Reactor pitch by product	-	Co-Product	339	t	Year
Tricanter Sluldge	-	Co-Product	226	t	Year
Used Oil from Process	-	Co-Product	1,811	Litre	Year
Soft Pitch	-	Intermediate Product	250,946	t	Year
Zero Qi Production					
Soft Pitch	*Calculated*	Input	250,946	t	year
Anthracene oil (AO)	-	Input	5,507	t	year
Wash Oil (WO)	-	Input	578	t	year
Kerosene (KO)	*kerosene// market for kerosene*	Input	3,886	t	year
Electricity (CPP)	*Calculated*	Input	4	MW	Hour
Steam	*Calculated*	Input	3	t	hour
Fuel gas	*Calculated*	Input	7,730	m3	hour
Process Water	*tap water// market for tap water*	Input	337	m3	day
Boiler Feed Water	*Recycled*	Input	202	m3	day
Make up for Cooling Water	*tap water// market for tap water*	Input	1,754	m3	day
Blow down (Hot water + seal water)	*Recycled*	Input	249	KL	Day

Treated Water from ETP (Effluent)	*Calculated*	Output	40	m3	Day
Condensate Recovery	*Recycled*	Recycling	62	m3	Day
CO_2 Emissions	*carbon dioxide (fossil) (air, unspecified (long-term))*	Emissions	2	t	hour
ETP Sludge Generation	*process-specific burdens, inert material landfill// market for process-specific burdens, inert material landfill*	Output	15,094	Kgs	year
HQP SP 105	-	Co-Product	92,789	t	Year
RAO - Recovered Solvent	*Recycled*	Co-Product	136,315	t	year
RAO - Recovered Solvent	*Sold*	Co-Product	14,629	t	year
Reactor pitch by product	-	Co-Product	769	t	year
Used Oil from Process	-	Co-Product	1,500	t	year
Zero QI product (IMP SP 110 and SP 85)	-	Intermediate Product	140,539	t	Year
Bulk Mescoke Granules					
Zero QI Pitch	*Calculated*	Input	134,545	t	Year
Wash Oil	-	Input	300	t	Year
Nitrogen	*Burden Free*	Input	345,600	Nm3	Year
PP Bags	-	Input	74,000	Nos	Year
Electricity from CPP	*Calculated*	Input	1	MWh	per MT product
Diesel (Haulage)	*diesel, burned in building machine// diesel, burned in building machine*	Input	5	Litre	Day

Steam	*Calculated*	Input	1	t	Hour
Process Water-Cooling/manufacturing Process	*tap water// market for tap water*	Input	733,211	KL	Year
Others -Domestic/Gardening./fire Hydrant	*Recycled*	Input	264,771	KL	Year
Blow down water from Cooling tower	*Recycled*	Input	14,664	KL	Year
Water Treated from ETP	*Calculated*	Output	12,464	KL	Year
Flushed Wash Oil	-	Recycled	300	t	Year
Pitch Oil	-	Co-Product	60,545	t	Year
Bulk Mesophase Coke Granules	-	Intermediate Product	74,000	t	Year
Bulk Mesocoke Powder					
Bulk Mesocoke Feed	*Calculated*	Input	74,000	t	Year
Zero QI Pitch for coating	*Calculated*	Input	5,994	t	Year
Bulk meso coke fines (Agglo)	*Calculated*	Input	13,189	t	Year
Zero QI pitch (Hight Softening Point -HSP)	*Calculated*	Input	2,638	t	Year
Zero QI Pitch (Low Softening Point- LSP)	*Calculated*	Input	1,319	t	Year
Electricity from CPP	*Calculated*	Input	2	MWh	Per t of Product
Cooling Water	*Recycled*	Input	15	m3	Day

Process & Handling Loss (5% of input) (A)	*Recovered and Sold*	Output	857	t	Year
Calcined Agglomerated Coke powder (Agglo)	*Calculated*	Co-Product	14,498	t	Year
Total Fines Generared form process	-	Co-Product	25,164	t	Year
Pitch Oil	-	Co-Product	4,743	t	Year
Bag Filter Fines - Total	-	Co-Product	8,876	t	Year
Pitch Oil from Agglo	-	Co-Product	1,187	t	Year
Calcined Coke Powder	-	Intermediate Product	41,814	t	Year
Synthetic Graphite Anode					
Calcined Bulk Meso Phase Coke powder	-	Input	41,814	t	Year
Calcined Agglomerated Coke powder	-	Input	14,498	t	Year
Crucibles	*silicon carbide// market for silicon carbide*	Input	13,875	t	Year
Calcined Petroleum Coke	*petroleum coke// market for petroleum coke*	Input	208	t	Year
Carbon Black	*carbon black// market for carbon black*	Input	99,162	t	Year
Lime	*quicklime, in pieces, loose// market for quicklime, in pieces, loose*	Input	4,961	t	year
Silica (Sand)	*silica sand// market for silica sand*	Input	2,645	t	year

Electricity (Graphitisation - Renewables)	*Calculated*	Input	11	MWh	t Product
Electricity (Graphitisation - Grid)	*electricity, high voltage// electricity production, natural gas, conventional power plant*	Input	3	MWh	t Product
Cooling Water	*Recycled*	Input	80	m3	per day
Process Water	*tap water// market for tap water*	Input	1,443	m3	year
Atmospheric Air	-	Input	15,000	t	year
Calcined Petroleum Coke Impurities (2%)	*Calculated*	Output	5,000	t	Year
Calcined Petroleum Coke Sulphur content (3%)	*sulfur Dioxide//sulfur dioxide direct emissions*	Output	7,500	t	Year
Cooling tower blowdown	*Recycled*	Input	15	m3	per day
Recoverable Fines Material Loss	-	Recycled	2,640	t	Year
Loss (Graphitisation process)	-	Output	3,519	t	year
Used Crucibles	-	Co-Product	13,667	t	Year
Used Calcined petroleum Coke	-	Co-Product	94,201	t	Year
Gypsum	-	Co-Product	15,872	t	year
Carbon Black	-	Co-Product	2,635	t	year
Synthetic Graphite Anode (EMG + EAG)	-	Product	50,153	t	Year

Table 16. Summary of the Project's Transport of Consumables and Products

Inventory Item	Locations	Transport Type	Value	Units
Coking Coal Feed	*Abroad to Chennai / Vizag / Ratnagiri Port - Shipping*	Ship		
Coking Coal Feed Transport	*Port to JSW Vijayangar - Rail*	Rail	800	km
Caustic Transport	*Aditya Birla (RD Chem), Karwar Mysore, Karnataka - Tanker*	Tanker	370	km
Coal Tar Output Transport	*M/s ECPL, Vijayanagar, Karnataka - Tanker*	Tanker	10	km
Coke Oven Product Coke Transport	*M/s Jindal Steel Works, Vijayanagar, Karnataka - Converyer*	Conveyor	2	km
Sulphur Dispatch Transport	*Mother Earth Environment Pvt Ltd, Kdduchur, Katnatka - Truck*	Truck	230	km
Coal Tar -JSW Transport	*M/s Jindal Steel Works, Vijayanagar, Karnataka - Tanker (Normal tanker of 30 Tons capcity)*	Tanker	10	km
Coal Tar - ARCL/DCPL Transport	*M/s. JSW Dolvi, Maharastra - Tanker (Normal tanker of 30 Tons capcity)*	Tanker	830	km
Causic Soda Transport	*Karwar, Mysore, Karnataka - Tanker*	Tanker	370	km
Hypo Transport	*Hospate, Karnataka - Truck*	Truck	80	km
DAP Transport	*Hospate, Karnataka - Truck*	Truck	80	km
Urea Transport	*Hospate, Karnataka - Truck*	Truck	80	km
Sulphuric Acid Transport	*Balabhadrapuram, AP - Tanker (Sodium Phelonate Treatment)*	Tanker	970	km
Aluminium Phosphate Transport	*Hospate, Karnataka - Tranker*	Tanker	80	km
ETP Sludge Generation Transport	*M/s Ramki Environmental Engineer, Karnataka - Tractor*	Tractor	500	km
ETP water Transport	*M/s ECPL, Vijayanagar, Karnataka - Pipeline. Recycled back into process*	Recycled	0	km
Used Oil from Process Transport	*M/s Shantadurga Petrochemical, Gulbarga, Karnataka - Truck (Reprocessing to make it useable)*	Truck	250	km
Tricanter Sluldge Transport	*Recycle to Cock Over Plant, M/s JSW -Truck (Recycling in Coke Oven Plant)*	Truck	10	km
Reactor Waste Material Transport	*M/s ECPL, Sambhalpur Plant - Truck*	Truck	1,350	km
Kerosene (KO) Transport	*M/S IOCL Depot, Mysuru*	Truck	370	km
ETP Sludge Generation - Transport	*M/s Ramki Environmental Engineer, Karnataka - Authorised Hazardous waste disposal*	Tractor	500	km
ETP water Transport	*M/s ECPL, Vijayanagar, Karnataka - use for process water after treatment*	Pipeline		
Reactor Waste Material/Tricanter Transport	*M/s ECPL, Sambhalpur Plant - Seling to customer*	Truck	1,350	km

Used Oil from Process Transport	*M/s Shantadurga Petrochemical, Gulbarga, Karnataka - Reprocessing and reused for equipment*	Truck	250	km
Wash oil Transport	*M/s ECPL, Vijayangar, Bellary*	Tanker	6	km
PP Bags Transport	*M/s.Marudhar Ploy sacks,Banglore.*	Truck / Lorry	400	km
Bulk Mesophase Coke Granules Transport	*Chennai Port, India*	Container / Truck	600	km
Bulk Mesophase Coke Granules Transport	*Xingang Port, China*	Container	8,300	km
Bulk Mesophase Coke Granules Transport	*End Customer*	Container / Truck	650	km
Pitch Oil Transport	*M/s.Epsilon Carbon Private Limited (CT-Division), Bellary, Karnataka*	Truck / Tanker	6	km
Zero QI pitch (Hight Softening Point -HSP) Transport	*M/s ECPL, Vijayanagar, Karnataka*	Pipeline	3	km
Zero QI Pitch (Low Softening Point- LSP) Transport	*M/s ECPL, Vijayanagar, Karnataka*	Pipeline	3	km
Milled / Shaped Powder Transport	*M/s EGPL, Vijayanagar, Karnataka*	Truck	10	km
Pitch Oil Transport	*M/s ECPL, Vijayanagar, Karnataka*	Pipeline	3	km
Bulk Meso coke (BMC) Transport	*M/s EGPL, Vijayanagar, Karnataka*	Truck	20	km
Agglomerated Coke powder Transport	*M/s EGPL, Vijayanagar, Karnataka*	Truck	20	km
PP Bags Transport	*M/s.Marudhar Ploy sacks,Banglore.*	Truck	400	km
Carbon Black Transport	*M/s ECPL, Vijayanagar, Karnataka*	Truck	20	km
Lime Transport	*Balakot, Karantaka*	Truck	185	km
Calcined petroleum Coke Transport	*Coke Vendor (RCII, Sunvira etc)*	Truck	800	km
Graphite Powder Transport	*Chennai Port, India*	Container / Truck	600	km
Lime Transport	*Water Treatment Chemical*	Truck	50	km
poly Transport	*Water Treatment Chemical*	Truck	50	km
antiscalent Transport	*Water Treatment Chemical*	Truck	340	km
antioxdiant Transport	*Water Treatment Chemical*	Truck	340	km
Hcl Transport	*Water Treatment Chemical*	Tanker	50	km
O2 scanvenger Transport	*Water Treatment Chemical*	Truck	340	km
corrosion inhpitor Transport	*Water Treatment Chemical*	Truck	340	km
Effluent Treatment Chemicals Transport				
sodium hypochlorite Transport	*Effluent Treatment Chemicals*	Truck	50	km
ferric cheloride Transport	*Effluent Treatment Chemicals*	Truck	50	km
sulphuric acid Transport	*Effluent Treatment Chemicals*	Tanker	970	km
Caustic Lye Transport	*Effluent Treatment Chemicals*	Tanker	370	km
bioside Transport	*Effluent Treatment Chemicals*	Truck	50	km
ETP Sludge Generation Transport	*Waste treatement purpose*	Truck	500	km

ETP water Transport	*Recycle to Process*	Pipeline	0	km