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Life cycle assessment and carbon footprint analysis of power supply.

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Abstract

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Emissions of the anthropogenic greenhouse gases (GHG) that drive climate change and its impacts around the world are growing. According to climate scientists, global carbon dioxide emissions must be cut by as much as 85 percent below 2000 levels by 2050 to limit global mean temperature increase to 2 degrees Celsius above pre-industrial levels [1]. Accordingly, this research is aimed to calculate and minimize adverse impacts of our power supply equipment on the environment, setting the target to halve our absolute GHG emissions by 2030, later by 2050 achieving the target of a carbon neutral. Life Cycle Assessment (LCA) studies on power supplies are analyzed to detect the sources of variation across their results, considering the impact on global warming potential (GWP100). The research question is, what is the total carbon footprint of our power supply and how to optimize the power supply with respect to total GHG emission for green future. The manufacturing and use phases are undoubtedly the life cycle phases contributing most strongly. From the manufacturing phase, Aluminum from the metal's parts play a key role, and the estimation of their impact should be thoroughly scrutinized. The results highlight that the use phase and losses of the power supply is crucial as electricity production types and markets accounts for a significant part of the GWP. Recommendations of increasing efficiency up to 98% will decrease losses and decrease aluminum in the cooling parts. Using different electricity production clean sources such as solar and wind energy will decrease manufacturing electricity emissions. The research methodology consists of qualitative and quantitative approaches. Both OpenLCA software with environmental footprint database EF and manual calculation is conducted. The study further provides new insight into the (LCA)-based on different database sources and a description. The LCA approach used in the research is consistent with the ISO standards [ISO 14040:2006, ISO 14044:2006, ISO/TR 14047:2003, ISO/TS 14048:2002] and PAS 2050.

Keywords: GHG emission; carbon footprint; emission factor EF; life cycle assessment; LCA; kilogram of carbon dioxide (KgCO2eq); Global warming potential (GWP).

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Ilmastonmuutosta ja sen vaikutuksia aiheuttavien ihmisen aiheuttamien kasvihuonekaasujen päästöt kasvavat kaikkialla maailmassa. Ilmastotutkijoiden mukaan maailmanlaajuisia hiilidioksidipäästöjä on vähennettävä jopa 85 prosenttia vuoden 2000 tasosta vuoteen 2050 mennessä, jotta maapallon keskilämpötilan nousu voidaan rajoittaa kahteen celsiusasteeseen esiteolliseen aikaan verrattuna [28]. Tämän tutkimuksen tavoitteena on näin ollen laskea ja minimoida virtalähde haitalliset vaikutukset ympäristöön asettamalla tavoitteeksi puolittaa absoluuttiset kasvihuonekaasupäästömme vuoteen 2030 mennessä ja myöhemmin vuoteen 2050 mennessä saavuttaa hiilineutraali tavoite teholähteitä koskevia elinkaariarviointitutkimuksia analysoidaan, jotta voidaan havaita niiden tulosten vaihtelun lähteet, kun otetaan huomioon vaikutus ilmaston lämpenemispotentiaaliin (GWP100). Tutkimuskysymyksenä on, mikä on virtalähteidemme kokonaishiilijalanjälki ja miten virtalähteitä voidaan optimoida kasvihuonekaasupäästöjen kokonaismäärän osalta vihreän tulevaisuuden varmistamiseksi. Valmistusvaiheessa metalliosista peräisin olevalla alumiinilla on suuri merkitys, ja niiden vaikutusten arviointia olisi tarkasteltava perusteellisesti. Tulokset korostavat, että käyttövaihe ja sähkönsyötön häviöt ovat ratkaisevan tärkeitä, sillä sähköntuotantotyypit ja -markkinat muodostavat merkittävän osan GWP:stä. Suositukset hyötysuhteen nostamisesta 98 prosenttiin vähentävät häviöitä ja jäähdytysosien alumiinin vähentämistä. Erilaisten sähköntuotantolähteiden, kuten aurinko- ja tuulienergian, käyttö vähentää valmistussähkön päästöjä. Tutkimusmenetelmä koostuu kvalitatiivisesta ja kvantitatiivisesta lähestymistavasta. Sekä OpenLCA -ohjelmisto, jossa on ympäristöjalanjälki-tietokanta EF, että manuaalinen laskenta suoritetaan. Tutkimus tarjoaa lisäksi uutta tietoa (LCA)-ohjelmistosta, joka perustuu erilaisiin tietolähteisiin ja kuvaukseen. Tutkimuksessa käytetty LCA-lähestymistapa on yhdenmukainen ISO-standardien [ISO 14040:2006, ISO 14044:2006, ISO/TR 14047:2003, ISO/TS 14048:2002] ja PAS 2050 kanssa.

Asiasanat: kasvihuonekaasupäästöt; hiilijalanjälki; päästökerroin EF; elinkaariarviointi; LCA; hiilidioksidikilo (KgCO2eq); ilmaston lämpenemispotentiaali (GWP).

Contents

List of figures

List of tabulations

List of Abbreviations

BSI	British Standards Institution
COP	Conference of the Parties.
CO2e	Carbon dioxide equivalent
CH 4	Methan
EPD	Environmental product declaration
EEIO	Environmentally extended input-output
EF	Environmental footprint
EJ	Exa joules
HFCs	Hydrofluorocarbons
HB	Half -bridge
GHG	Greenhouse gases.
GW	Global warming
GWP	Global warming potential
ICE DB	Inventory carbon and energy database.
IEA	International energy agency
INDC	Intended Nationally Determined Contribution
IO LCI	Input output life cycle inventory
KgCo2eq	Killo gram of carbon dioxide equivalent
KWH	Killo watt hour
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
NDC	Nationally determined contribution.
N 2O	Nitrous oxide
OEFSRs	Organization environmental footprint sector rules
PSU	Power supply unit
PEFCR	Power environmental footprint category rules
PFC	Power factor correction
PFCs	Perfluorocarbons
PM	Particulate matter
PWB	Printed wiring board.

SF 6	Sulphur hexafluoride
UN	The United Nations
UNFCCC	The United Nations Framework Convention on Climate Change.
ZVS	Zero voltage switching.

1 Introduction

Governmental, private, and nonprofit organizations, local movements, and individuals understand that climate change is one of the most pressing sustainability problems of our generation. Extraordinary climate conditions and the economic, social, and ecological weight added to governments are related to environmental change. So, there is a huge thrust to develop technologies that will advance greener options.

Different organizations have been tracking their greenhouse gas GHG emissions and have begun taking steps toward adapting to a world that is marked with energy and climate crises. These iterate the importance and need to accurately measure and reduce GHG emissions.

Climate change requires comprehensive actions to reduce greenhouse emissions and limit the rise in global temperature to 1.5°C. EU has set targets on reducing greenhouse gas emissions to at least 55% below 1990 levels by 2030, and to achieve climate neutrality by 2050.[2]

At the Paris climate conference (Conference of the Parties, COP 21) in December 2015, 195 countries adopted the first global climate agreement under which all Parties participate in climate change mitigation through nationally determined contributions (NDC) and committed themselves to reducing their emissions by 40% by 2030, to limit the global temperature increase to 2 °C [2, Page 3]

Article 2 of the Paris agreement sets the ambitious mitigation target of holding global mean temperature increase well below 2°C and pursuing efforts to limit the increase to 1.5°C. To make these targets operational, Articles 3 and 4 of the Paris Agreement contain provisions that require all Parties to undertake and communicate progressively more ambitious efforts to mitigate climate change. [3, Page 5]

The transition net emissions from the trend around 2030 to 2100 (Fig. 1). The possibility for a negative level of global net emissions is excluded from the analysis due to the uncertainty in large-scale deployment of negative emission technologies. [3, Page 16]

Four pathways are specified with assorted colour (Fig. 1) and (Fig. 2).as follows: [3, Page 16]

1. Emissions will return to an increasing path, and equal to the higher estimate of INDC targets in 2030 (unconditional targets).
2. Emissions will return to an increasing path, and equal to the lower estimate of INDC targets in 2030 (conditional targets).
3. Emissions will stabilize at 2015 levels until 2030, after which they start to decline.
4. Emissions peaked in 2015 and start to decline gradually starting from the current year.

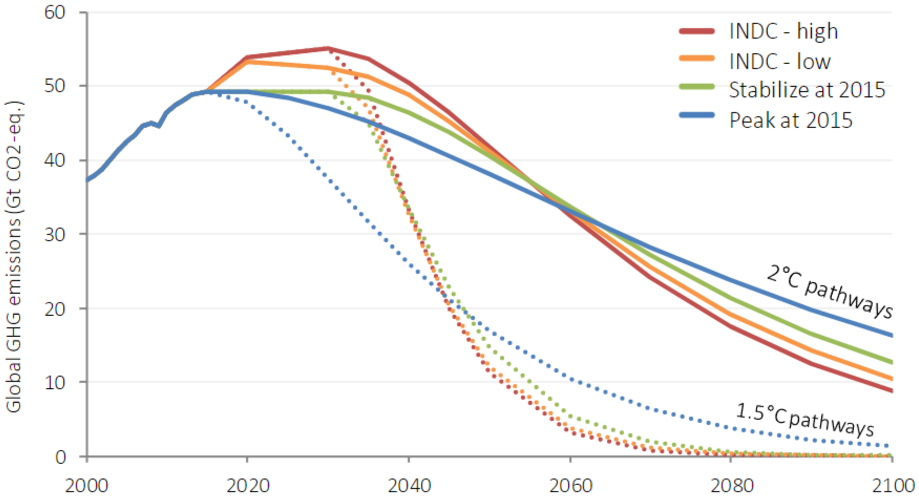


Figure 1:Emission pathways with four assumptions for the emission development between 2015 and 2030 and global GHG emissions. [3. page 17].

While allowing emissions to peak above the temperature limit and decline to the target by 2100 while keeping global mean temperature increase at either 1.5°C or 2°C, with four assumptions for the emission development between 2015 and 2030 shown in (Fig. 2). [3. page17]

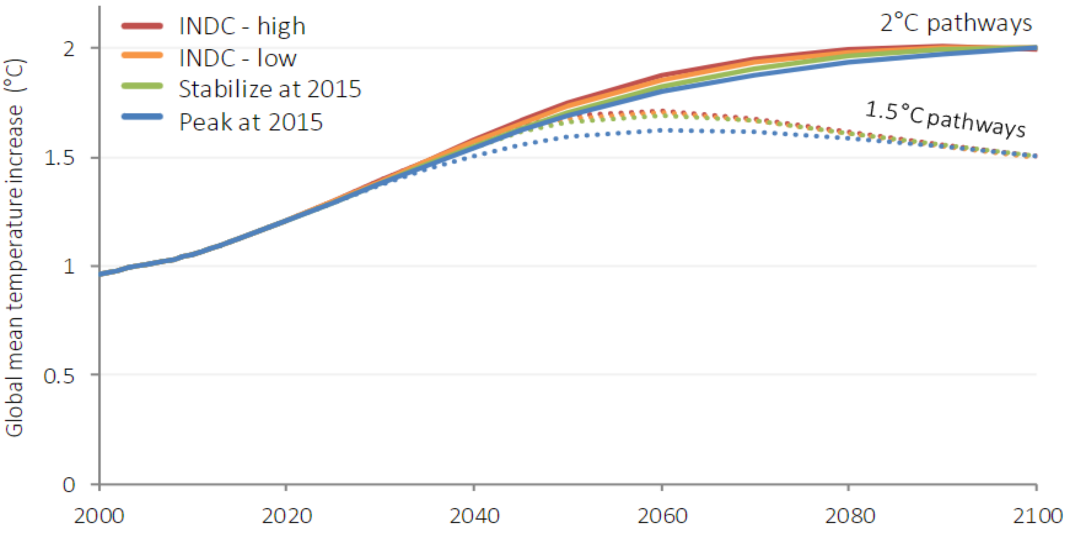


Figure 2: Emission pathways with four assumptions for the emission development between 2015 and 2030 and increases in 2100 at either 1.5°C or 2°C in global mean temperature. [3. page 17].

As shown in (Fig. 1) and (Fig. 2), it can be said that both considered temperature targets are not physically impossible to reach even if emissions in 2030 correspond to the current set of INDC targets.

Meeting the 1.5°C target would require an annual reduction rate in global emissions far above 10%. Such a reduction would imply a near-zero emission level already in 2070 and at least 45% reduction in emissions by 2030. For the 2°C target, a much more lenient rate –around 2% to 3% per year –would be sufficient. [3. page 18].

While these pathways do not necessarily conform to the currently prevailing view of feasible emission reduction rates, they are here used to represent the needed action to meet the stringent temperature targets.

Results over the 21st century show that there is driver of emissions reductions in Finland (Fig. 3). Applying to both a 2 °C (66% probability to stay below 2 °C) and a Paris Agreement 1.5 °C compatible pathway (50% probability to be below

1.5 °C 2100) for Finland until 2100.[4]

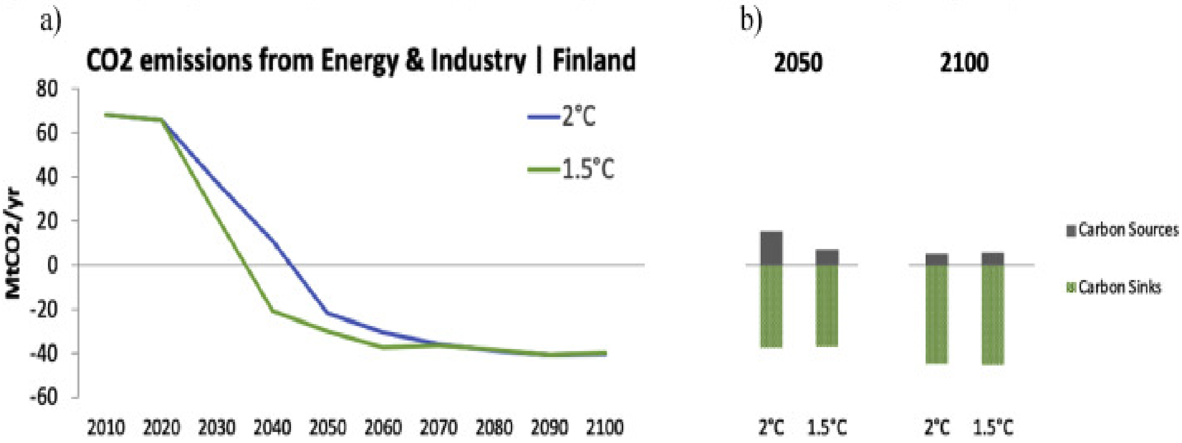


Figure 3 Total CO2 emissions from energy and industry in Finland across scenarios (a) under 2 °C and 1.5 °C pathways (b) and carbon emissions sources and sinks in 2050 and 2100.[4]

As figure 3 shows, from 2020 there is declining in the yearly emissions to transition the trend around 2030 with exponentially declining emissions to 2100 and the possibility for a negative level of net emissions yearly.[4]

Past and current actions, including the release of carbon dioxide (CO 2) and other greenhouse gases through human activities such as the burning of fossil fuels, emissions from chemical processes, and other sources will influence future global climate. It is the production of energy that is responsible for 87% of global greenhouse gas emissions [2. page 17].

The GHG emissions associated with goods and services reflect the impact of processes, materials and decisions occurring throughout the life cycle of the goods and services. Studies have presented a range of 2030 global emissions from 50 to 55 $GtCO_2$-eq, there is industry desire for a consistent method for assessing the life cycle GHG emissions of goods and services.

Carbon dioxide is considered as the most harmful of greenhouse gases, in earth's atmosphere, carbon dioxide is a trace gas that plays an integral part in the greenhouse effect, carbon cycle, photosynthesis and oceanic carbon cycle. It is one of greenhouse gases in the atmosphere of Earth. The current global average concentration of carbon dioxide (CO2) in the atmosphere is 421 ppm as of May 2022 (0.04%). This is an increase of 50% since the start of the Industrial Revolution, up from 280 ppm during the 10,000 years prior to the mid-18th century.[5]

Carbon footprint is the volume of greenhouse gas emissions resulting from a product or activity (the lower, the better). While the carbon footprint is a good indicator of the impact of a company’s greenhouse gas emissions, it does not capture the entire environmental impact.

Carbon footprint Analysis: Concepts, Methods, Implementation, and case studies provides up-to-date technical information and practical guidance on measuring and reducing energy and GHG emissions.

Carbon handprint is the beneficial impact of a product or service on reducing carbon dioxide emissions (the higher, the better).

On the one hand, power supply products have a carbon footprint, which can be minimized by design, production, and coordination. On the other hand, power supply products can maximize the handprint of the application where they are used, with high power efficiency, developing product and advanced energy management.

Actions such as improving energy efficiency, reducing the use of materials, reducing the production electricity, making climate-friendly choices of raw material, developing product recyclability, reducing the amount of waste material, lengthening product lifespans and improving product usability can have an impact on a product's carbon footprint.

Common solutions of energy savings will create a positive climate impact. Reducing the energy consumption and carbon footprint of power supplies include the use of renewable energy sources, improving the efficiency of the power converter, and optimization of the overall volume to minimize energy losses in these power supplies.

The life cycle assessment (LCA) is an internationally recognized environmental analysis technique with a set of standards to evaluate the possible burdens on the environment and resource consumption in every step of a product or process [6]. This way, the overall impact of a product or service on the environment is assessed.

Facing the requirement of green economy, energy conservation, emissions reduction, and sustainable development, optimizing the power supply emissions will be forthcoming, calculating the total greenhouse emission GHG of the power supply production is one of the most effective ways.

1.1 Objectives and definition of the research area

The growing demand of electricity and power generation contribute significantly to greenhouse gases emissions and global climate change. This detrimental role is becoming more pronounced as the economic and industrial advancements are accelerating throughout the world. To this end, there has been a tendency for emissions detection during the life cycle of these power supplies.

Global carbon dioxide (CO2) emissions from energy combustion and industrial processes grew 0.9% or 321 Mt in 2022 to a new all-time high of 36.8 Gt. This estimate is based on the International Energy Agency IEA’s detailed region-by-region and fuel-by-fuel analysis.[7]

The introduction of a carbon market in the electricity market is greatly beneficial since it can optimize the power generation structure, increase the proportion of renewable energy generation, promote the reduction of electricity prices, and facilitate the achievement of the goal of “carbon peaking and carbon neutrality”.

The power supplies bear a heavy burden in a time when consumers expect an uninterrupted reliable power supply with less loses and a reduction in carbon emissions. As expectations increase, it becomes the task of power supplies researcher and designer to develop new structures to meet these demands.

Results for GHG emissions vary considerably across studies for devices that seem to be quite similar. These variations can in principle have two sources: (a) variations in the materials, energy sources and processes used and (b) variations in the LCI data used to assess their environmental impact (primary or secondary data and their quality).

This study analysis the environmental impact of a power supply system based on context 6000W - PSU in terms of global warming potential over 100 years (GWP100).

The target of this research is to present the total GHG emission of this power supply product as one product of Efore Telecom Finland Oy.

Based on this research platform, the strategy targets in the future: to meet the Paris agreement goal -which aligned with Efore Telecom Finland Oy sustainability public target -, which committed ¨ to setting a public target to halve our absolute GHG emissions by 2030, using 2019 figures as baseline, aligned with the 1.5°C target set by The Paris Agreement. Later by 2050 achieving the target of a carbon neutral.

This can be used as a metric for comparative analysis for different power supplies, with a developed market.

The main goals are to find a methodology that quantify the CO2 equivalent emission for each of cradle to gate, transport and use phase of the lifetime for this power supply and determining the life cycle phases that are contributing most strongly.

By selecting better power supply´s option and to target selection of materials and systems based on the reported values. Later analysis at different efficiency value that help to achieve the goals of high efficiency power supply by market transmission, further affect the whole electricity market.

First step in analysing life cycle assessment and carbon content of this case's study power supply.

1.2 Challenges

1. How could Efore Telecom Finland Oy help realize Paris agreement goal in the future?
2. Identifying the large contributor of higher greenhouse gas GHG emissions and result recommendations for the impact reduction.
3. The shortage in the emission factor database used in LCA method. These shortcomings relate, among other things, to the data eligibility, the varying quality of data, access to databases and the ease of use of data in various software.
4. Lack of a reference book on carbon management and methodologies related to power supply.
5. Calculation assumption for analysis purpose.

1.3 Questions to answer

Based on this study objectives, the question that arose are:

1. How to analyse the life cycle assessment and the total GHG emission (KgCO2e) of this power supply at each stage either by using Open LCA software and by manual calculations?
2. What is the highest and the least emission amount kg Co2e of this power supply? What state reflect high emission value at each stage from Cradle -to -gate, transportation and use stage?
3. What is the related emission factor Ef for each stage used in manual calculation?
4. How could efficiency, and carbon emission minimization are to be met?
5. What observations of each phase and Improvements can be made to reduce the footprint emissions?
6. What are different scenarios, strategies suggested for this study and the resulted total footprint range? Future recommendations?

1.4 Significance of the thesis

This study will help to understand the concept of greenhouse gas emission of the power supply during the main stages of the product from cradle -to -gate, transportation and finally losses in using stage.

The study will represent the theoretical overview of the life cycle assessment and carbon footprint emission of the product and make a reduction in the total emission either by raw material manufacturing electricity reduction or by increasing efficiency that consumes less energy and decrease losses and consequently produces less CO2.

With the aid of openLCA software tools and other reference database in manual calculations, such as ecoinvent database V3 and Inventory of Carbon and Energy -ICE DB and others, the power supply Life Cycle and emissions will be assessed and monitored.

Hence, the results will align with Efore Telecom Finland Oy sustainability public target, which aligned with the 1.5°C target set by The Paris Agreement.

Aside from decreasing devastating environmental effects, executing LCA has business advantages. It can be used to assess the need for a systematic analytical tool for the environmental assessment of a product throughout its entire life cycle and deep analysing of the power supply with lack of data base resources and references.

1.5 References of framework / Research methods

The research methodology is a mixed method including qualitative and quantitative methods. The qualitative research method explores power supplies and energy efficiency methods through a comprehensive literature review and study of earlier research. In addition to literature review of related references of databases uses in the methodology and different standards used in LCA methods of analysing.

The quantitative research method focuses on evaluating the collected data from the Efore Telecom Finland proprietary- information for EPD (environmental product declaration) for section of product’s footprint emissions and the information provided by the suppliers.

To be able to study the power supply based on uniform life cycle inventory LCI data, we performed simplified LCA on this device for which enough information were available. We used a process-based methodology for the LCI method, and the characterization model was the IPCC2007-100 years (characterization factor: GWP100).

The impact category chosen is climate change. The scope of the analysis included the power supply without any accessories. The functional unit was the use of the device for a period of 10 years at different two efficiencies 96% and up to 98%.

Our analyses do not pretend to be exhaustive, and the results may thus underestimate the impact. The focus lies on the manufacturing (cradle-to-gate), use phase, and the transportation for the GWP indicator, as we identified these phases as the ones causing the largest contributions.

The applicability of research objectives and research questions will be evaluated in this stage and discussing the result of the evaluation from environmental views. Finally, research contributions and benefits will be presented and generalize the findings.

1.6 Theses contents

This thesis is organized into six chapters. The first chapter described the thesis background, problem, objectives, questions, limitations, and the significance of the thesis and methodology.

Chapter two explains information about the power supply designing, losses, and power factor correction, and about the efficiency of the power supply and how can be used to reduce the CO2 cost sustainability. Finally brief introduction to the electricity and power sources emissions.

The next chapter explain the greenhouse gas GHG protocol with detailed about GHG protocol scopes and emissions, GHG protocol publications and tools by highlighting the scopes related to this case study. Chapter four about various sources of data bases used and datasets in addition to OpenLCA software for calculations and methodology results.

The concept of carbon footprint analysis and Life Cycle Assessment (LCA) in the base of theoretical literature are highlighted there in chapter 5, in addition to product-based standard used. Finally, chapter six is our case study using LCA starting from goals and scopes, LCI, LCIA, and conclusion, underlines accentuate on findings, the contributing of the thesis, and further recommendations (Fig. 4).

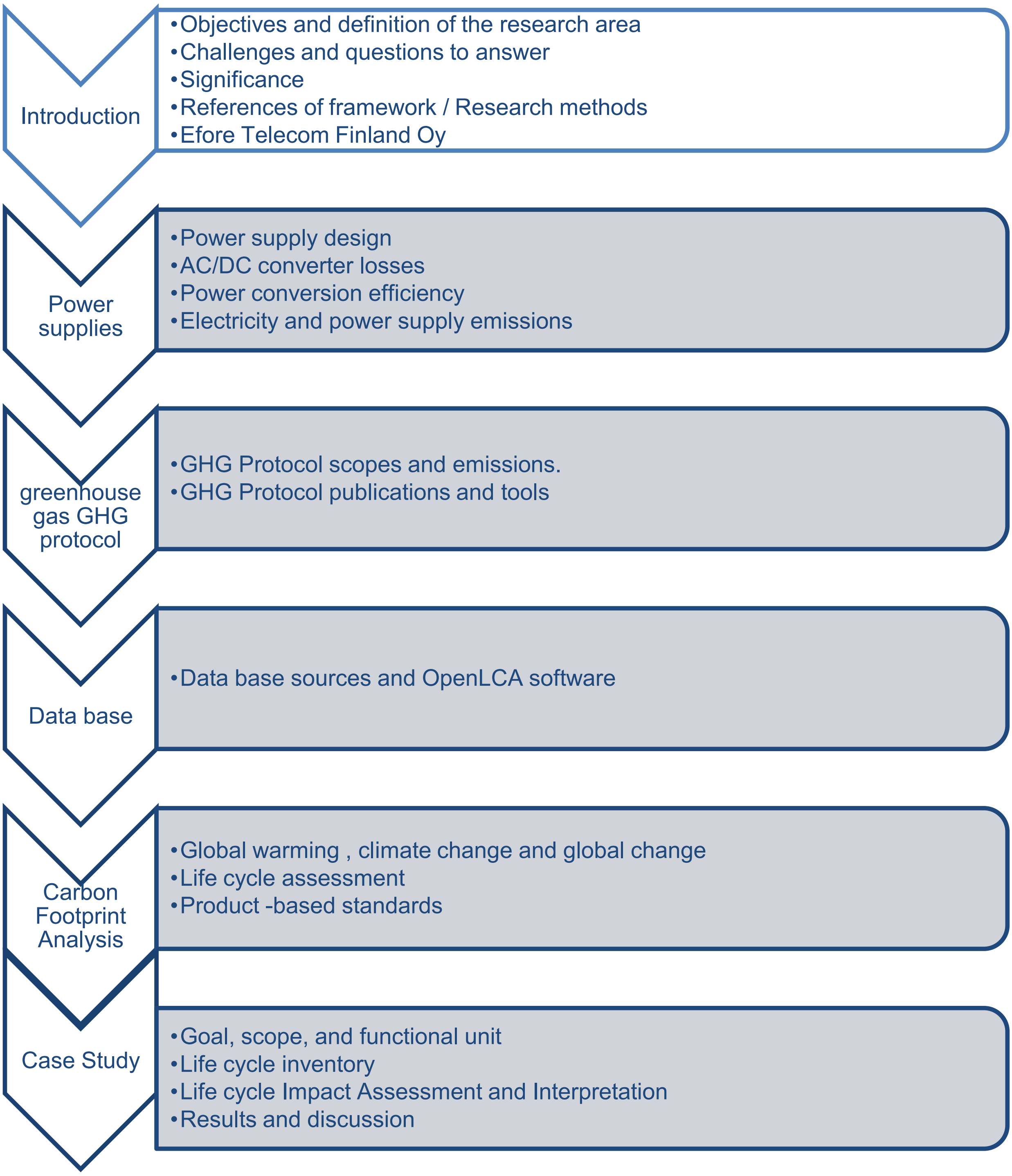


Figure 4 Thesis contents summary.

1.7 Efore Telecom Finland Oy

Efore is an international company which designs and manufactures custom and standard power products and systems for wide-ranging use in demanding telecom and energy storage applications.

Efore develops and manufactures power supplies, systems, cabinets, and battery energy storage solutions. Efore is headquartered in Finland and has facilities in Sweden, China, and Thailand.

Efore practices and develops their business in a manner that improves the profitability and competitiveness of operations, takes environmental aspects into account, and meets the needs of customers.

2 Power supplies

The considerable variation in the properties of power supplies is due to the advances in semiconductor technology, electronics design, manufacturing techniques, and whether the power supply is used in energy applications.

Power supplies convert AC voltage provided by the mains into the DC voltage required by systems and machines. During this process, a certain amount of energy is always lost in the form of heat. These losses are a form of wasted energy and cannot be avoided entirely. But they can be reduced to a minimum. [8]

Successful protection of our environment starts small. In the industrial environment, modern power supplies can increase efficiency and avoid wasting energy.

2.1 Power supply design

The more you know about the system in which your power supply is going to be operating, the better you can make design choices up front. And making proper choices at the beginning is vastly less costly and time-consuming than trying to make fixes later.

Power supply products process and distribute power from an energy source, such as AC mains or DC energy storage, to an energy consumer, such as telecommunications infrastructure or industrial equipment. Such products include switching converters, power distribution units, lithium batteries. They include electronic components, such as semiconductors, resistors, capacitors, as well as materials such as copper, aluminium, rubber, plastics, and more.

Recently, as information technology (IT) devices, such as computer, server, and telecom, have rapidly grown, the importance of power supply units (PSUs) has been increased. In general, PSUs need two requirements:

1. High efficiency for environmental conservation and energy saving.
2. High-power quality to meet the harmonics regulations.

For these reasons, PSUs typically adopt a two-stage structure that consists of a boost power factor correction (PFC) stage and dc/dc stage, as shown in Fig. 5. The input voltage for the power supply system is 230 V AC, through the boost - PFC stage, step up voltage stage resulted 400V DC, by passing Dc-Dc stage of isolated transformer result output -48 V Dc at the output capacitor result.

For the dc/dc stage, a half-bridge (HB) LLC converter is one of the most popular topologies due to its wide zero-voltage-switching (ZVS) range, low-voltage stress on the primary and secondary devices, and no offset current in the transformer.[9]

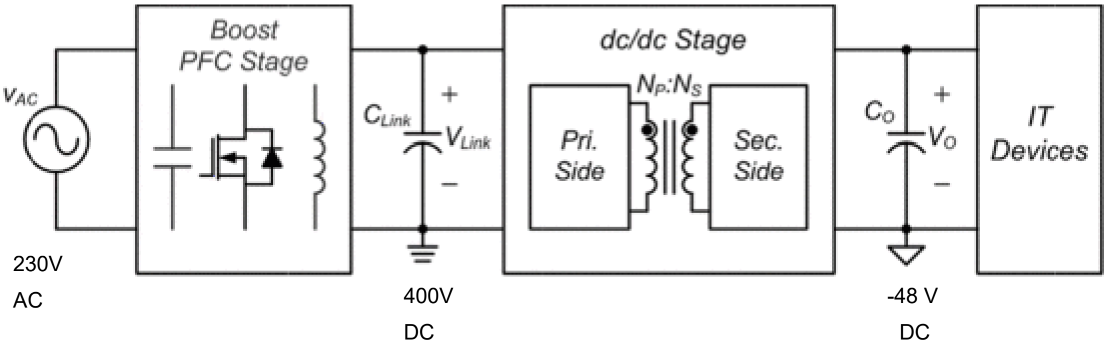


Figure 5 General PSU, two- stage structure [10]

For convenience, practical design of power supply book following steps summarizes the various choices of converter topology selection checklist.[10]

Topology Selection Checklist:[10]

1.Step-up or step-down. Is the input voltage always higher or always lower than the output? If not, you cannot use a buck or non-isolated flyback.

2. Duty cycle. Is the output voltage different by more than a factor of 5 from the input voltage? If so, you will need a transformer. Calculate duty cycle to ensure that it does not have to get too small or too large. (definition: duty cycle =on time/switching period of a switch).

3. What output voltages are required? If more than one, a transformer may be required, unless you can post regulate. Large numbers of outputs suggest more than one converter may be an excellent choice.

4. Is isolation required? What is voltage amount? Isolation necessitates a transformer.

5. What are the EMI requirements? Tight requirements suggest staying away from topologies with discontinuous input current and choosing continuous mode operation.

6.The power semiconductors technology is selected based on cost, efficiency, and power requirements: Si or SiC MOSFETs, IGBTs, or GaN devices.

7. Is the supply required to operate with no load? If so, choose discontinuous mode-unless the answer to question 8 is Yes.

8. Can synchronous rectification be afforded? This makes the converter continuous regardless of load.

9. Is the output current extremely high? Then it might be good to use voltage mode rather than current mode.

2.2 AC/DC converter losses

Different topologies of AC/DC converter have been improved such as Quasi-resonant flyback converter, Half-Bridge resonant mode converter, Full-bridge resonant mode converters, Single –ended forward converter and two transistor topologies.

Resonant converters (soft switching) have better efficiency than traditional hard switching converters, switching semiconductor devices have improved over the years.

Soft-switching techniques such as ZVS (Zero Voltage Switching) will substantially reduce the switch-on losses. In addition to this technique the switch-off losses are dependent on the rate of change of V DS (dV DS /dt), which in turn is affected by the primary leakage inductance of the transformer.

Varity properties affect the switch on losses, the FET switching losses increase linearly with switching frequency. Reduction of the switch-off losses on the primary side can be covered by a fast recovery diode on the output side.[11]

2.3 Power Factor Correction

Because of needed high working frequency and low loss. A Power Factor Correction PFC circuit is used as first stage to shape the input current to follow the shape of the sinusoidal input voltage.

An AC-DC converter with high power factor by the method of single stage power factor correction improved the power factor from about 90-92% to 94% then 96% to state of art up to 98% peak, and the output DC voltage has high stability compared to normal PFC with 96% efficiency.[12]

The Power Factor Correction (PFC) circuits also allow higher output powers without exceeding the maximum input current limit of the mains supply as shown in equation 1.1:

$$\mathrm{Pout} = \eta * \mathrm{PF} * \mathrm{Vin} * \mathrm{Iin} \qquad \mathrm{Eq.\,1.1}$$

$\text{where PF} = \text{power factor and } \eta = \text{efficiency}$

For an 85% efficient AC/DC converter operating from a fixed 230VAC supply fitted with a 10A over-current protection: PF = 0.70 allows a maximum output power of 0.70 x 0.85 x 230V x 10A ≈ 1370W

PF = 0.95 allows a maximum output power of 0.95 x 0.85 x 230V x 10A ≈ 1860W.

There are four main operating modes used for active power factor correction: discontinuous, continuous, critical-conduction and mixed-mode.[11]

2.4 Power conversion efficiency

Efficiency is defined as output power Po divided by input power Pin. Power loss P loss in a power delivery path determines the overall efficiency η, as illustrated [12]

$$\eta = \frac{Po}{Pin} = \frac{Pin - Ploss}{Pin} \qquad \mathrm{Eq.\,1.2}$$

For a power supply with 6000 W output power with efficiency 96 %, the power losses between input and output would be 250 W. These 250 W are emitted in the form of heat with P waste = (Pout/η) – Pout.

It is a fact that every percentage point is decisive when it comes to efficiency. If we increase the efficiency in our example to 98 % it becomes clear, 2 % more does not sound like too much, but the resulting losses would decrease to less than half to 122.4 W, which means about saving 127.6 W from heat losses.

If you transfer this example to the total number of power supplies in an application and consider the additional cooling required in the system, this has a significant impact on the CO2 balance.[8]

2.4.1 Efficiency can reduce CO2 costs sustainably.

The German Umweltbundesamt calculates the real CO2 damage costs on a yearly basis. Based on 2021, one ton of CO2 causes environmental damage of € 201.[8]

Let us continue the calculation example from above. Suppose 100 power supply with 70% average load supplies with an efficiency of 96 % run 24 hours a day and 365 days a year. This operation takes place over 10 years. It results in wasted energy of 1533000 kWh = 1533 MWh.

Now the CO2 emission factor must be considered. This factor describes the ratio of the mass of an emitted substance to the unit of energy produced.

For the year 2020, the Federal Environment Agency calculated as part of a study that the generation of one kilowatt hour of electricity causes 366 grams of carbon dioxide.

The wasted energy of the 100 power supplies with 96 % efficiency - from our example - result in 561 t CO2. If we multiply that with the emission factor, we end up with CO2 costs of € 112777. For the sake of simplicity, we assume that the CO2 damage costs will remain stable over the 10 years - realistically speaking, they will rather continue to rise.

If we calculate the same example with the tested increased efficiency power supplies, whose efficiency is 2 % higher (98 %), the CO2 emissions are already reduced to 275-ton CO2. The costs therefore drop to € 55275 (saving about € 57502), Fig 6.

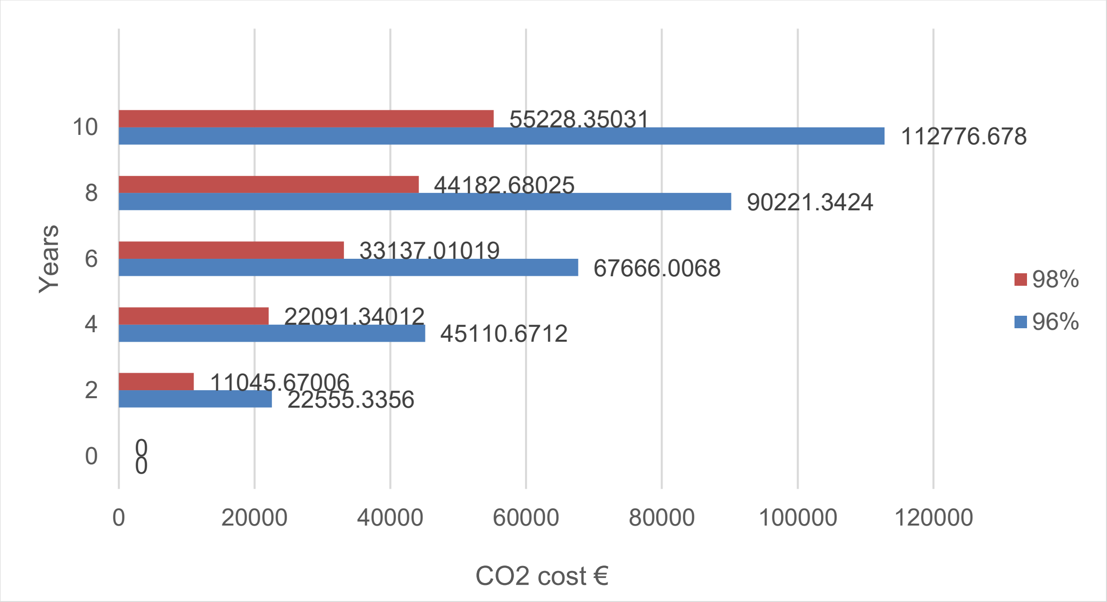


Figure 6 : Calculation example of 100 power supplies | operation: 24 h per day, 365 days per year | CO2 emission factor = 366 g per kwh | CO2 damage costs per t = 201 €.

In summary as shown in Fig 6, the higher the efficiency and the longer the service lifetime, the lower the CO2 costs and lower CO2 emissions. Ecological and sustainable thinking therefore also pays off financially for companies.

2.5 Electricity and power supply emissions

Electricity directly or indirectly has been linked to every action. Gas-to-coal switching pushed up global CO2 emissions from electricity generation by well over 100 million tonnes, notably in the United States and Europe where competition between gas and coal power plants is tightest.

The rebound of global CO2 emissions above pre-pandemic levels has largely been driven by China, where they increased by 750 million tonnes between 2019 and 2021.[13]

The EIA released that by 2050, global energy consumption is forecast to rise by almost 50% to over 960 Exa Joules (EJ) (or 911 Peta-btu (Pbtu)). Of that over 450 EJ (429 Pbtu) - 47% - will be used in the generation of electricity. [14]

Electrification is due to play a major part in the world's transition to #NetZero. However, over the next 30 years, the losses associated with the conversion of primary energy (conventional fuels and renewables) into electricity are the largest contribution.[14]

Electricity losses are an important problem worldwide that should be mitigated since they generate an impact on CO2 emissions and drive a possible rate increase. However, to generate reductions, it is imperative to measure the carbon footprint of that energy losses. Losses may vary from system to system. They can be <6% in very efficient systems, and more than 15% in very inefficient systems [15.]

The power sector is a significant contributor to global carbon emissions and has received widespread attention from scholars; however, the path to achieving carbon reductions from power sources and supply still is unclear.

There is an increasing concern about controlling and reducing carbon emissions in power systems. In this regard, researchers have focused on managing emissions on the production and manufacturing side, transportation and use side.

However, achieving the goals of detection the total carbon footprint and greenhouse gas GHG emission of a power supply, further affect the whole electricity market; is a worth study need to develop.

3 Literature review of greenhouse gas GHG protocol

Companies should select calculation methods that ensure that the inventory appropriately reflects the GHG emissions of the activities and serves the decision-making needs of users, both internal and external to the company.

These different scopes of GHG protocol, offer guidance on how to decide which categories require a more precise, and often more labor-intensive, method of data collection, and which might be adequately served by a less precise method.

In most cases, the categories that generate the largest number of emissions should receive the most precise data collection treatment, however, smaller categories that are important to customers or employees may receive help from more precise treatment as well. Categories most relevant to the company’s business goals may also receive more attention. [1]

3.1 GHG Protocol scopes and emissions

Figure 7 shows the 15 distinct reporting categories in scope 3 and shows how scope 3 relates to scope 1 (direct emissions from owned or controlled sources) and scope 2 (indirect emissions from the generation of purchased electricity, steam, heating, and cooling consumed by the reporting company).

Scope 3 includes all other indirect emissions that occur in a company’s value chain. The 15 categories in scope 3 are intended to provide companies with a systematic framework to measure, manage, and reduce emissions across a corporate value chain. The categories are designed to be mutually exclusive to avoid a company double counting emissions among categories.[1]

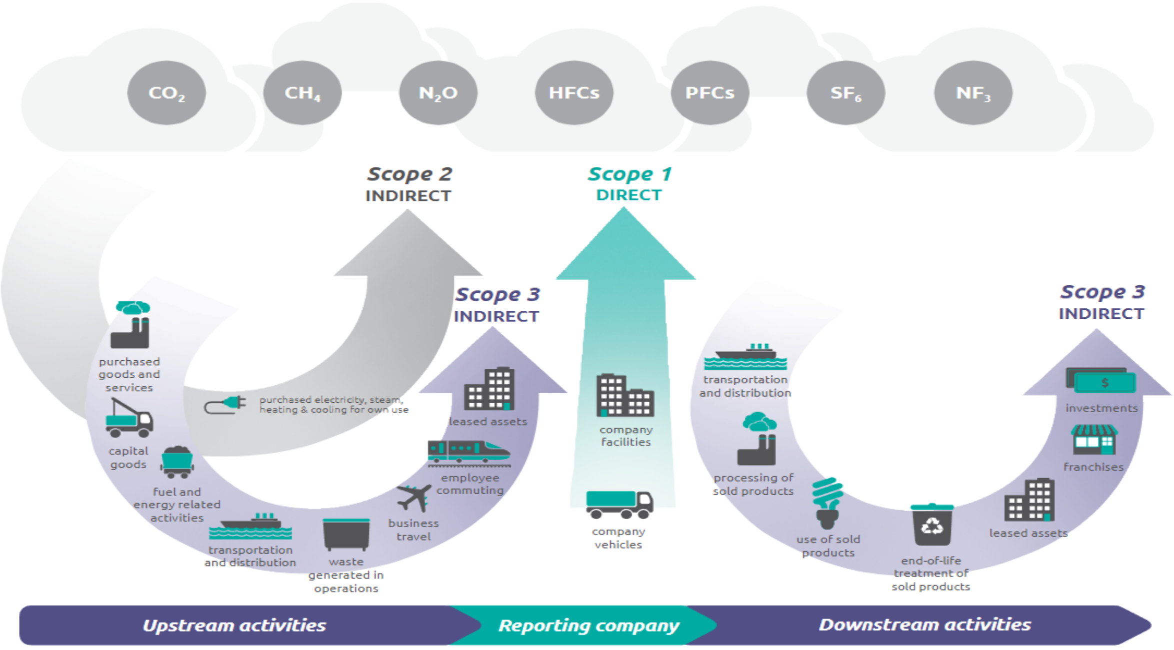


Figure 7 Overview of GHG Protocol scopes and emissions across the value chain.[1]

As shown in Figure 7 for most scope 3 categories, and the relations between scope 3 and scope 1&2 including the up-steam activities and downstream activities.

Companies should select calculation methods within a category based on the following criteria: [1]

a) The relative size of the emissions from the scope 3 activity.
b) The company’s business goals.
c) Data availability.
d) Data quality.
e) The cost and effort needed to apply each method.
f) Other criteria shown by the company.

3.1.1 Overview of data types

Calculating emissions requires the use of two types of data:

1. Activity data.
2. Emission factors.

“Activity data” is a quantitative measure of a level of activity that results in GHG emissions (for example kilograms of material purchased).

An “emission factor” is a factor that converts activity data into GHG emissions data (for example kg CO_2 emitted per kilograms of material produced). [28]

3.1.2 Applicable greenhouse gases and global warming potential values

For each of the categories, companies needed to calculate emissions of all the GHGs required by the United Nations Framework Convention on Climate Change (UNFCCC)/Kyoto Protocol at the time the inventory.

Originally, the requirements of the UNFCCC/Kyoto Protocol, and therefore of the GHG Protocol, were limited to a set of six individual GHGs or classes of GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6). However, changes to international accounting and reporting rules under the UNFCCC/Kyoto Protocol now also require the reporting of another GHG, nitrogen trifluoride (NF_3). [1]

In this study, carbon dioxide equivalent (CO_2e) emissions stand for emissions of all greenhouse gases, aggregated, and converted to units of CO_2e using global warming potential (GWP) values.

Global warming potential GWP values describe the radiative forcing impact (or degree of harm to the atmosphere) of one unit of a given GHG compared to one unit of carbon dioxide. GWP values convert GHG emissions data for non-CO_2 gases into units of CO_2e. [1]

3.2 GHG Protocol publications and tools

GHG publications and calculation tools offer help in calculating emissions from various scope 3 categories.

3.2.1 Category 1: Purchased Goods and Services

This category includes all upstream (i.e., cradle-to-gate) emissions from the production of products purchased or gotten by the reporting company in the reporting year. Products include both goods (tangible products) and services (intangible products).

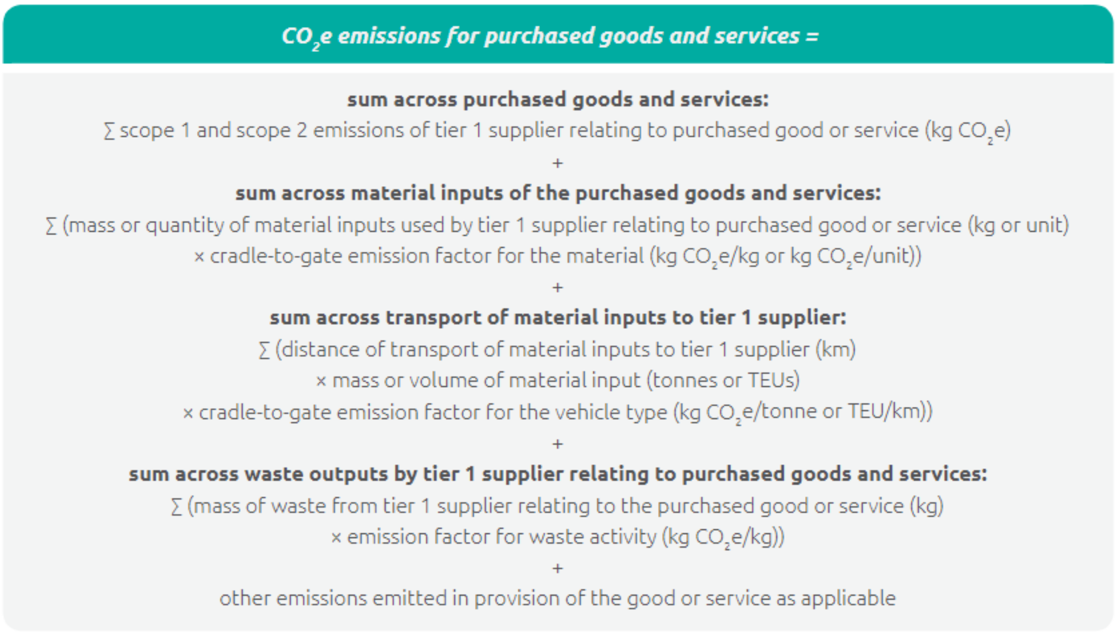
Companies may find it useful to differentiate between purchases of production-related products (e.g., materials, components, and parts) and non-production-related products (e.g., office furniture, office supplies, and IT support). This distinction may be aligned with procurement practices and therefore may be a useful way to organize and collect data more efficiently. [1]

There are four methods used for calculating emissions from goods and services. [1]

1. Supplier-specific method – collects product-level cradle-to-gate GHG inventory data from goods or services suppliers.
2. Hybrid method – uses a combination of supplier-specific activity data (where available) and secondary data to fill the gaps. Which will be used in this study.
3. Average-data method – estimates emissions for goods and services by collecting data on the mass of goods or services purchased.
4. Spend-based method – estimates emissions for goods and services by collecting data on the economic value of goods and services purchased.

Hybrid methods

The activity data needed are in the three main group, first from given scope 1 and scope 2 data. Second mass or volume of material inputs (e.g., bill of materials), and distance from the origin of the raw material inputs to the supplier and finally quantities of waste output other emissions with detailed calculation as shown in figure 8.[1]



CO_2e emissions for purchased goods and services =

sum across purchased goods and services:
∑ scope 1 and scope 2 emissions of tier 1 supplier relating to purchased good or service (kg CO_2e)
+
sum across material inputs of the purchased goods and services:
∑ (mass or quantity of material inputs used by tier 1 supplier relating to purchased good or service (kg or unit)
× cradle-to-gate emission factor for the material (kg CO_2e/kg or kg CO_2e/unit))
+
sum across transport of material inputs to tier 1 supplier:
∑ (distance of transport of material inputs to tier 1 supplier (km)
× mass or volume of material input (tonnes or TEUs)
× cradle-to-gate emission factor for the vehicle type (kg CO_2e/tonne or TEU/km))
+
sum across waste outputs by tier 1 supplier relating to purchased goods and services:
∑ (mass of waste from tier 1 supplier relating to the purchased good or service (kg)
× emission factor for waste activity (kg CO_2e/kg))
+
other emissions emitted in provision of the good or service as applicable

Figure 8 Hybrid method (where supplier-specific activity data is available for all activities associated with producing the purchased goods). [1]

As shown in figure 8, The next step in the calculation is emission factors needed for each input data amounts. Depending what activity data has been collected from the supplier, companies may need to collect emission factors.

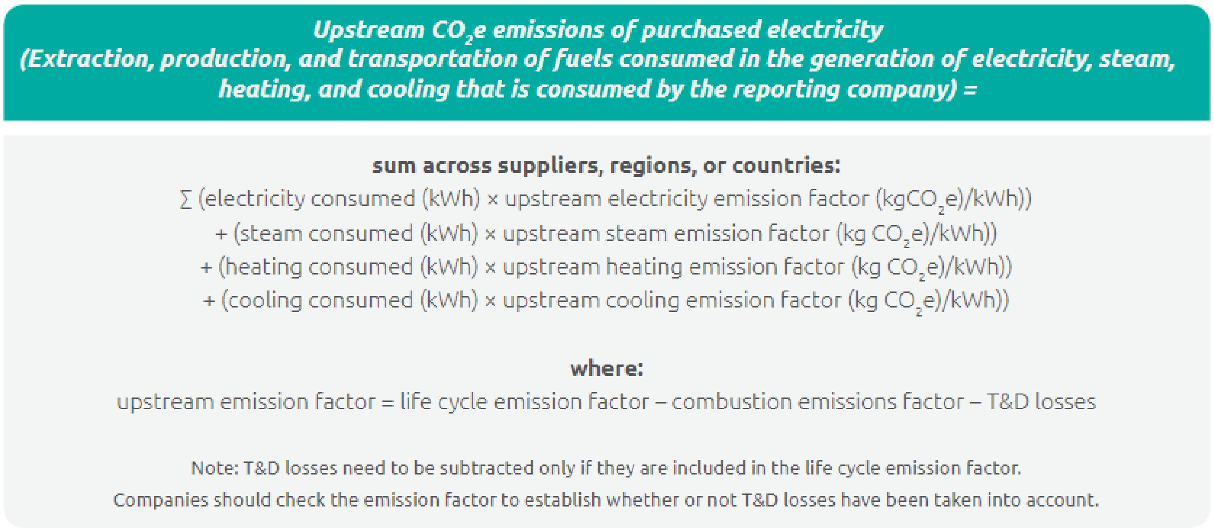
3.2.2 Fuel- and Energy-Related Activities

This category includes emissions related to the production of fuels and energy purchased and consumed by the reporting company in the reporting year that are not included in scope 1 or scope 2.

This activity includes the extraction, production, and transportation of fuels consumed in the generation of electricity, steam, heating, and cooling that is consumed by the reporting company in the manufacturing steps.

According to the activity data needed, companies should collect data on total quantities of electricity, steam, heating, and cooling purchased and consumed per unit of consumption (e.g., MWh), broken down by supplier, grid region, or country as shown in Figure 9.

To calculate emissions from this activity, companies should use life cycle emission factors that exclude emissions from combustion, since emissions from combustion are accounted for in scope 2 (in the case of electricity).[1]



Upstream CO_2e emissions of purchased electricity
(Extraction, production, and transportation of fuels consumed in the generation of electricity, steam, heating, and cooling that is consumed by the reporting company) =

sum across suppliers, regions, or countries:
∑ (electricity consumed (kWh) × upstream electricity emission factor (kgCO_2e)/kWh))
+ (steam consumed (kWh) × upstream steam emission factor (kg CO_2e)/kWh))
+ (heating consumed (kWh) × upstream heating emission factor (kg CO_2e)/kWh))
+ (cooling consumed (kWh) × upstream cooling emission factor (kg CO_2e)/kWh))

where:
upstream emission factor = life cycle emission factor – combustion emissions factor – T&D losses

Note: T&D losses need to be subtracted only if they are included in the life cycle emission factor.
Companies should check the emission factor to establish whether or not T&D losses have been taken into account.

Figure 9 Calculation formula for Upstream emissions of purchased electricity. [1]

As detailed shown in figure 9, the calculation formula for Upstream emissions of purchased electricity, steam, heating, and cooling consumed in kilo watt hour kWh. Companies should select an emission factor using supplier-specific method. If data for the above is not available or applicable, companies should use average-data method. [1]

3.2.3 Upstream Transportation and Distribution

This category includes emissions from transportation and distribution of products purchased in the reporting year, between a company's tier one suppliers and its own operations in vehicles not owned or used by the reporting company (including multi-modal shipping where multiple carriers take part in the delivery of a product but excluding fuel and energy products).

Emissions may arise from the following transportation and distribution activities throughout the value chain:[1]

   a. Air transport.
   b. Rail transport.
   c. Road transport.
   d. Marine transport.

Companies may use the following methods to calculate scope three emissions from transportation: [1]

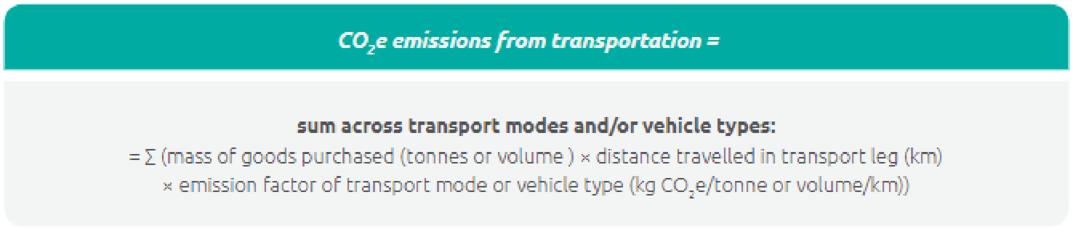
1. Fuel-based method, which involves figuring out the amount of fuel consumed and applying the right emission factor for that fuel.
2. Distance-based method, which involves figuring out the mass, distance, and mode of each shipment, then applying the right mass-distance emission factor for the vehicle used. Which selected in this study.
3. Spend-based method, which involves figuring out the amount of money spent on each mode of business travel transport and applying secondary (EEIO) emission factors.

Distance-based method (transportation)

Companies should collect data on the distance travelled by transportation suppliers. This data may be obtained by:

1. Mass or volume of the products sold.
2. Actual distances provided by transportation supplier.
3. Online maps or calculators.
4. Published port-to-port travel distances.

Figure 10 details the calculation formula of distanced based method which multiply the mass of the goods by distance travelled in Km by the related emission factors in KgCO2/tonne/Km. [1]



CO_2e emissions from transportation =

sum across transport modes and/or vehicle types:

= Σ (mass of goods purchased (tonnes or volume) × distance travelled in transport leg (km) × emission factor of transport mode or vehicle type (kg CO_2e/tonne or volume/km))

Figure 10 Calculation formula of Distance-based method (transportation).[1]

As shown from figure 10, in addition to the total mass of goods in tonnes or kg, the related emission factor needed. Common forms of emission factors are kg CO 2e/ton/km for road transport or kg CO 2e/TEU/km for sea transport. See appendix1, table 2.

Category 5 (waste generated in operations), Category 6 (business travel), Category 7 (Employee Commuting), Category 8 (upstream leased assets), Category 9 (Downstream Transportation and Distribution). Category 10 (Processing of Sold Products) will skip in this study.

3.2.4 Use of Sold Products

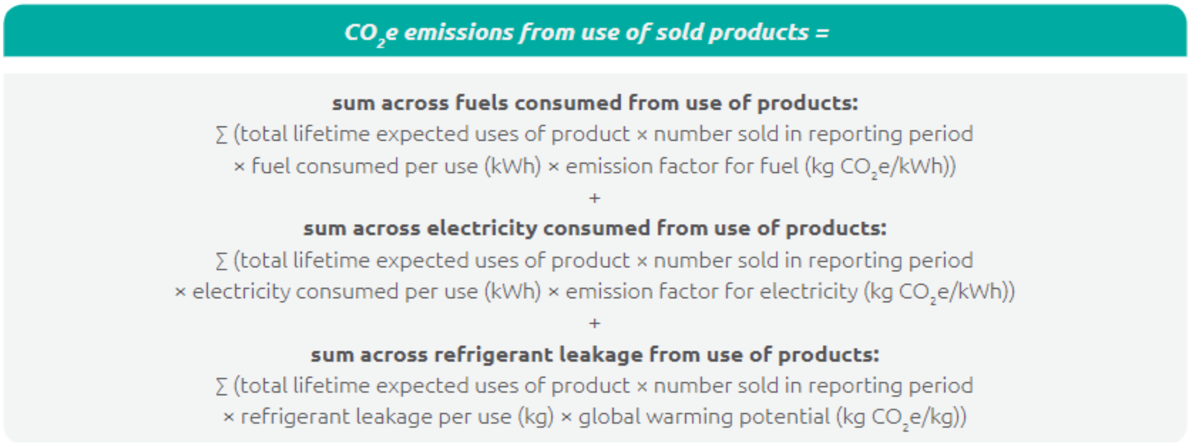
This category includes emissions from the use of goods and services sold by the reporting company in the reporting year, include the scope one and scope two emissions of end users. End users include both consumers and business customers that use final products.

The Scope 3 standard divides emissions from the use of sold products into two types:

1. Direct use-phase emissions.
2. Indirect use-phase emissions.

Companies has needed to report a description of the methodologies and assumptions used to calculate emissions.

The Calculation method detailed in figure 11 for direct use-phase emissions from products that directly consume energy (fuels or electricity) during use. In this method, the company multiplies the lifetime number of uses of each product by the amount sold and an emission factor per use. Companies should then aggregate use-phase emissions of all products. [1]



CO_2e emissions from use of sold products =

sum across fuels consumed from use of products:
∑ (total lifetime expected uses of product × number sold in reporting period
× fuel consumed per use (kWh) × emission factor for fuel (kg CO_2e/kWh))
+
sum across electricity consumed from use of products:
∑ (total lifetime expected uses of product × number sold in reporting period
× electricity consumed per use (kWh) × emission factor for electricity (kg CO_2e/kWh))
+
sum across refrigerant leakage from use of products:
∑ (total lifetime expected uses of product × number sold in reporting period
× refrigerant leakage per use (kg) × global warming potential (kg CO_2e/kg))

Figure 11 Calculation formula of direct use-phase emissions. [28]

Category 12 (End-of-Life Treatment of Sold Products), Category 13 (Downstream Leased Assets), Category 14 (Franchises), Category 15 (Investments), will also skip in this study and method calculation. [1]

For more detailed description and minimum boundaries of scope 3 with 15 categories see table 1, appendix1.

4 Data base sources and OpenLCA software

Generally, data sources for activity data may include: [1]

1. National statistics published by government agencies.
2. Government agency energy management departments.
3. Company suppliers.
4. Internal data systems (e.g., financial accounting systems).
5. Bills and invoices.

Data sources for emission factors include: [1]

1. The data sources on the GHG Protocol website.
2. Company- or supplier-developed emission factors (e.g., if the supplier has conducted a reliable cradle-to-gate product GHG inventory or internal LCA report).
3. Life cycle databases.

4. Industry association.
5. Government agencies (e.g., Defra provides emission factors for the United Kingdom).
6. Environmentally extended input-output (EEIO) databases. A list of EEIO databases is provided on the GHG Protocol website.

In this study, the databases used in Open LCA software version 9.1.0.53 Green Delta, is from Environmental Footprint secondary data. References emission factor databases in each process used in manual calculation summarized in Table1.

Table 1 References databases for key processes along the life cycle of a power supply

Process	Life Cycle Inventory dataset	References
Raw material extraction and processing	Metallic, Aluminum & alloys, China market, Cragle to gate	From aluminium world org.
	Metallic, Aluminum General, Eur consumption - Includes Eur production and imports - At world average recycled	Inventory of Carbon and Energy -ICE DB
	Metallic, Aluminum, China market, Cradle to gate	Inventory of Carbon and Energy -ICE DB
Electricity for product manufacturing	Electricity production, Average China Market per KWh	Energy Institute - Statistical Review of World Energy (2023)
	Electricity, China market, of hard coal power plants	From THE ECOINVENT DATABASE V3
	Electricity, China market, natural gas power plants without CHP	From THE ECOINVENT DATABASE V3

	Metallic, 30% of stainless-steel scrap collected for recycling at the end-of-life, ‘Cradle to Gate’ emissions	From https://www.worldstainless.org/
	Metallic, 50% of stainless-steel scrap collected for recycling at the end-of-life, ‘Cradle to Gate’ emissions	
	Metallic, 75% of stainless-steel scrap collected for recycling at the end-of-life, ‘Cradle to Gate’ emissions	
	Metallic, 85% of stainless-steel scrap collected for recycling at the end-of-life, ‘Cradle to Gate’ emissions	
	Metallic, 85% of stainless-steel scrap collected for recycling at the end-of-life, ‘Cradle to Gate’ emissions	Inventory of Carbon and Energy -ICE DB
	Metallic, Copper & alloys, Primary copper production within the pyrometallurgical route, of Copper Concentrate (28% Cu)	From International Copper Association
	Metallic, Copper & alloys, Primary copper production within the hydrometallurgical route, is refined copper cathode	
	Metallic, Copper, EU production data. 37 % recycled content.	from Kupfer Institut LCI data - ICE DB
	Metallic, Copper, Virgin	from Kupfer Institut LCI data - ICE DB
	Metallic, Copper, Recycled	from Kupfer Institut LCI data - ICE DB

	Metallic, Zinc	From EFDB emission factor database
	Metallic, General Zinc	Inventory of Carbon and Energy -ICE DB
	Metallic, Zinc, Recycled content of general Zinc 30%	Inventory of Carbon and Energy -ICE DB
	Metallic, Magnesium	From EFDB emission factor database
	PWB Bare & Passives	From OPEN LCA software - Environmental footprint EF database
	Polymeric (Nylon), (Polyamide) 6 Polymer, 38.6 MJ/kg Feedstock Energy (Included). Doesn't include final fabrication.	Inventory of Carbon and Energy -ICE DB
	Polymeric (Nylon), (Polyamide) 6.6 Polymer, 50.7 MJ/kg Feedstock Energy (Included). Doesn't include final fabrication.	
Transport By Clean Cargo	Transport, Freight and shipping emissions, Trade Lane: Asia to-from North Europe, DRY relevant Ef, number of TEU containers,	From Clean Cargo/ 2020
	ship distance in km	
Electricity for product using	Electrcity, Average Europe Market per KWh	European Environment Agency -2023
	Electricity, Average electricity production in Finland per KWh	Energy Authority, Finland ,2019

	Electricity, globally production, natural gas, combined cycle power plant /CO2	From THE ECOINVENT DATABASE V3
	Electricity, globally production, lignite power plants (brown coal)	From THE ECOINVENT DATABASE V3

This table 1 summarized life cycle inventory datasets and references databases used in variety hand calculation from cradle to grave life cycle of power supply.

4.1 OpenLCA software

OpenLCA software, is easy installation and use, features for professional modelling and for collaboration in team, the largest set of data available for LCA, and not the least full transparency, openLCA is a desirable choice for use in industry.

The following are the other features of OpenLCA:[16]

1. Life cycle costing.
2. Regionalized and parameterized impact assessment.
3. Data quality results reporting.
4. Dynamics allocation approaches.
5. Export to Excel.
6. Supports import/export for number file formats.
7. Multiple languages.

The one of the data bases used in the Open LCA software in this study is Environmental Footprints database. The Environmental Footprint (EF) database has provided under the guidance of the European Commission and its Joint Research Centre in its newest version 3.1 (as of June 2023). The available EF data for the representative products is in line with the current product environmental footprint category rules (PEFCR) as well as the organization environmental footprint sector rules (OEFSRs).

The EF database is based on the EF 3.1 reference package and holds secondary life cycle inventory datasets adhering to EF standards from various providers. It built on available data from the EF reference package including the EF method package and EF compliant datasets from the respective EF nodes.[16]

There are four processes in the open LCA calculated project. The process is cradle to gate (raw material), transport, use at 96% efficiency and use at 98% efficiency. these raw materials added in the Flow screen to add the input data sets. There is need to find the provider for each item (A limited options for the Flows from Category and limited Provider character), later create the product system as figure 12 and then do direct calculation.

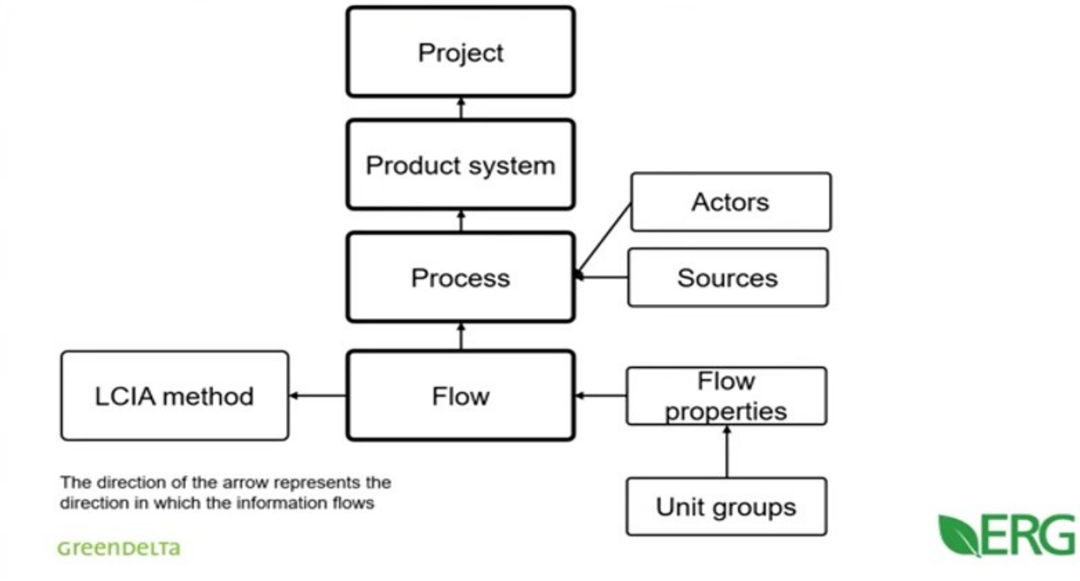


Figure 12 Element structure in openLCA software. [16]

As shown in figure 12, after added input data sets with flow properties for each unit groups, doing the processing, create the product system and then do direct calculation, selecting the calculation properties and LCIA impact assessment method here Environmental Footprint. Then from the result selected impact category Climate Change KgCO2eq for the output result.

5 Carbon Footprint Analysis

Carbon footprint analysis is the measurement of greenhouse gas GHG-emitting, processes their origins, and their composition and amounts. The GHG sinks and removal rates should also include in a carbon footprint analysis to figure out the “net” emission rates.

The phrase “carbon footprint analysis” is synonymous with the phrase “greenhouse gas inventory.” To have one unit for reporting results, emissions from these other gases normalized to the mass of CO2, and the carbon footprint results reported as mass of CO2 equivalent (CO2e) (e.g., kg of CO2e or metric tons of CO2e). [17, page 7]

Global warming changes Earth’s climate, which then adversely affects Earth physical (e.g., freshwater availability, sea level), chemical (e.g., ocean pH), and biological (species adaptation) systems.

GHGs cause global warming, and global warming causes climate change, which then causes global change.

5.1 Life cycle assessment and embedded carbon

Life Cycle Assessment LCA is the most comprehensive method for evaluating the environmental impact of the product in all its life- cycle stages. The LCA is a compilation and evaluation of material and energy inputs and outputs, and potential environmental impacts of a product during its lifetime.

LCA is a bottom-up process-based analysis method, which considers the greenhouse gas emissions from cradle to grave in the whole lifecycle process of the product or service obtained from raw material extraction through materials processing, production, distribution, utilization, repair and maintenance, and disposal or recycling as shown in figure 13.[9]

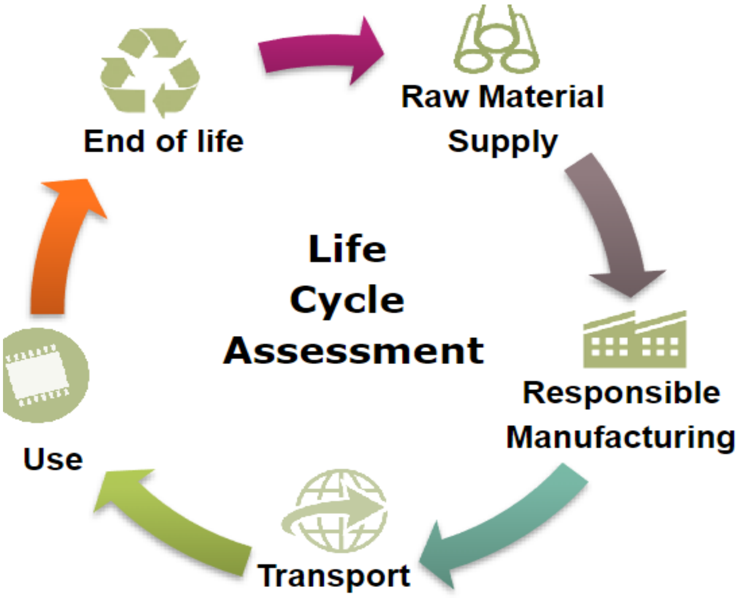


Figure 13 Life cycle assessment LCA. [18]

As shown in figure 13, Life cycle assessment of the product cover the whole life of the product from raw material inputs to the end of life.

With the concept of carbon footprint, LCA has become the most important carbon footprint accounting method at the micro level, especially at product or process level.

GHG LCA can provide information during which stage of the life-cycle significant emissions occur and therefore aid policymakers and stakeholders in focussing efforts where they are most effective in reducing GHG emissions.

When deciding between two or more alternatives, LCA can help decision-makers to compare the total cumulative emissions originating from a choice of technologies per unit of the product. [19]

5.2 Product -based standards

The ISO has two standards for LCA that form the foundation for most if not all LCA studies: [17]

1. ISO 14040:2006 Environmental management— Life cycle assessment— Principles and framework.
2. ISO 14044:2006 Environmental management— Life cycle assessment— Requirements and guidelines.

In addition, two other standards are available for life cycle impact assessment and for data documentation:

1. ISO/TR 14047:2003 Environmental management— Life cycle impact assessment— Examples of application of ISO 14042.
2. ISO/TS 14048:2002 Environmental management— Life cycle assessment— Data documentation format.

These four ISO standards are for any kind of LCA study; they are not specific to evaluating carbon footprint of products. Currently the most established product carbon footprint standard is PAS 2050, which is an international standard for the carbon foot printing of goods and services across the full life cycle (British Standards Institution [BSI] 2011). [17, page40]

PAS 2050 was prepared and published by the BSI in 2008 and later updated in 2011. PAS 2050 builds on existing LCA methods proved through ISO 14040 and ISO 14044 by giving requirements specifically for the assessment of GHG emissions within the life cycle of goods and services. These requirements further clarify the implementation of these standards in relation to the carbon footprint analysis of goods and services. [17, page40]

PAS 2050 is the standard that is currently using in carbon labelling of products. For example, the Carbon Trust, a not- for- profit company, uses PAS 2050 when it collaborates with companies to develop their Carbon Reduction Label. The Carbon Reduction Label places on the product and shows that a company is working to reduce its carbon footprint. In addition, it reports the GHG emissions per unit use of the product. [17, page40]

In 2011 the Greenhouse Gas Protocol Initiative published another standard for carbon footprint analysis of products: the Product Life Cycle Accounting and Reporting Standard (GHG Protocol Initiative 2011). This document builds on the framework and requirements proved in the ISO 14040, ISO 14044 LCA, and PAS 2050 standards with the intent of providing more specifications and guidance to ease the consistent quantification and public reporting of product life cycle GHG inventories. [17, page41]

The standards developed by the GHG Protocol Initiative, BSI, and ISO will play a key role in helping companies adopt these labels and accurately display the carbon footprint of their products.

6 Case study

The Life cycle assessment LCA is comprised of four indispensable stages: the definition of the goal and scope, the Life cycle inventory LCI analysis which is the construction of the product’s life-cycle model where all relevant mass and energy flows are quantified, Life cycle impact assessment (LCIA) which is the evaluation of the environmental relevance of these flows, and finally the interpretation of results as summary in figure 14.[20]

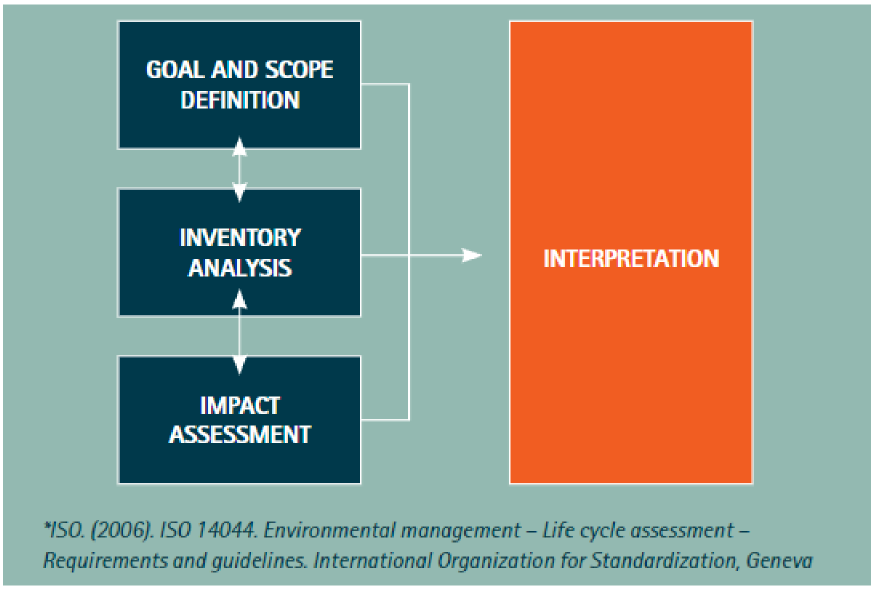


Figure 14 Life cycle assessment framework. [21]

As shown in figure 14, LCA tool requires a detailed input data gathering, time, and monetary resource-intensive process. Data gathering becomes even more problematic for power supplies, as there is not data availability for the components and needed electricity in manufacturing.

6.1 Goal, scope, and functional unit

The goal and scope define the exact questions that the analysis will try to answer and set its spatial, temporal, and technological boundaries.

The goal of this study is to figure out environmental impacts of the micro power supply 6000W - UPS. With aiming to recognize the stages in the life cycle of this power supply posing a burden on the environment and induce specific improvements.

After collecting data from relevant vendors, publicly available sources, and providers, in addition to Efore Telecom Finland Oy and its manufacturing factory in China we normalized results from LCAs as follows:

1.Comparison of the relative share of life cycle phases in overall GHG emissions (GWP100 indicator).

2.Identification of the largest sources of GHG emissions and their variation for each life cycle phase, which includes in particular:

   a) A detailed analysis of the impact of the raw materials manufacturing and subcomponents.
   b) An analysing of the use phase across different efficiencies, sources of electricity production and electricity mix (depending on the geographic location and production type).
   C) Introducing the recycling amount in the input raw materials.

3. Conducting simplified LCAs of selected power supply and removing sources of variation.

For this study, the scope covers the following life cycle stages:

1. Raw material manufacturing.
2. Power supply manufacturing.
3. Transportation.
4. Using the product (losses).

The type of analysis covering raw materials manufacturing, electricity requirements for manufacture and assembly of power supply parts, the system’s transport from manufacturing site in China to operation site in Europe markets, and its operation for 10 years. Not enough data was available modelling the system’s end-of-life phase (recycling, disposal).

A simplified layout of power supply entire life cycle shown in Fig. 15. Cradle-to-gate is a term used to denote the processes of raw material acquisition up to product assembly, right before transporting them to the product's user. Meanwhile, cradle-to-grave includes the product's use and end-of-life phases, so it is a complete overview of its whole life cycle (ISO, 2006).

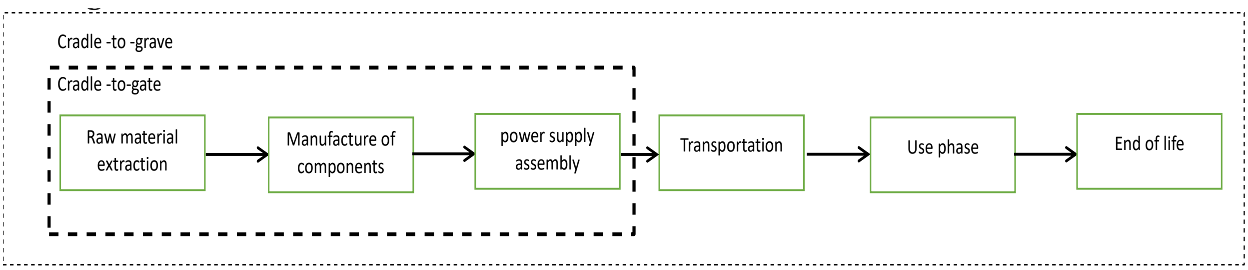


Figure 15 Schematic layout of power supply life cycle model.

From figure 15, the three main phases in this study are cradle to gate, transportation and use phase losses, represented with the relations.

The relationship between the raw materials extraction process, part manufacturing, power supply manufacturing and their transport and later product using stage, modelled in the system using different reference database figure 16. The electricity needed for the manufacturing and in the use, and process added in the system. The recycling processes discussed separately for the raw material components.

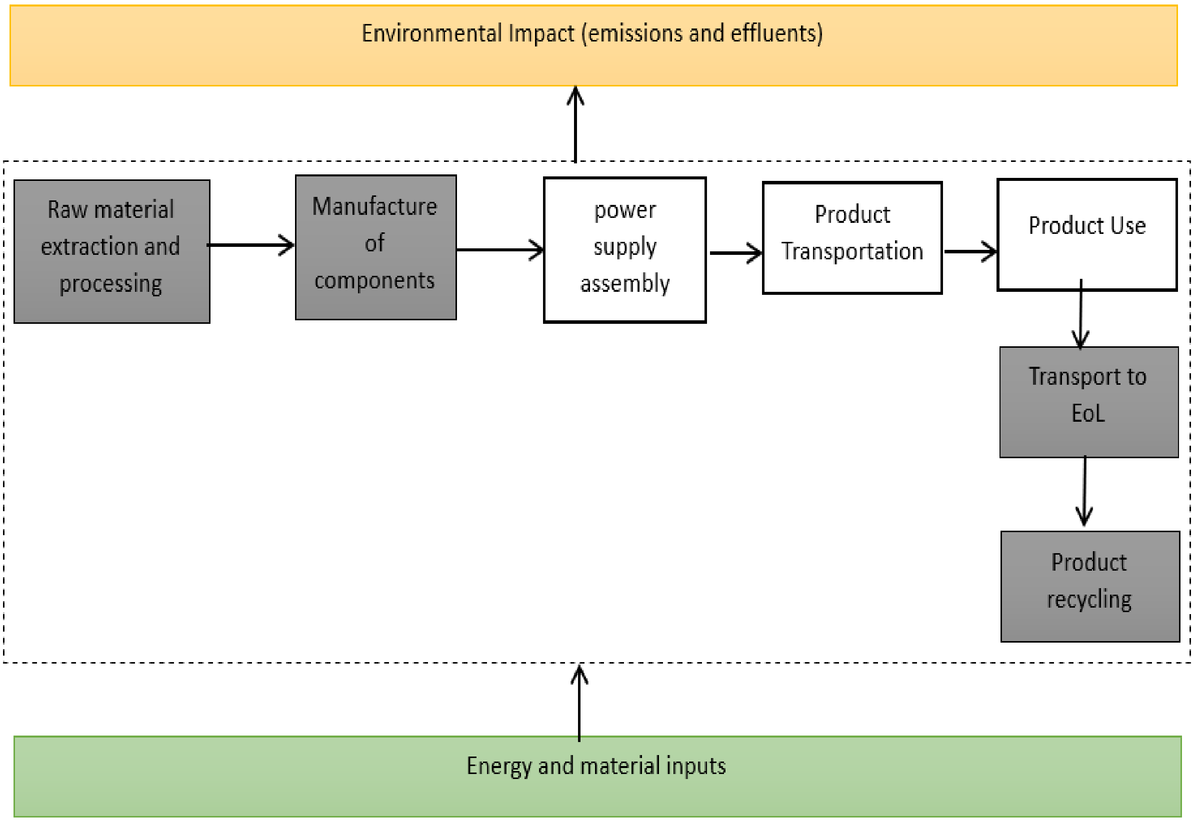


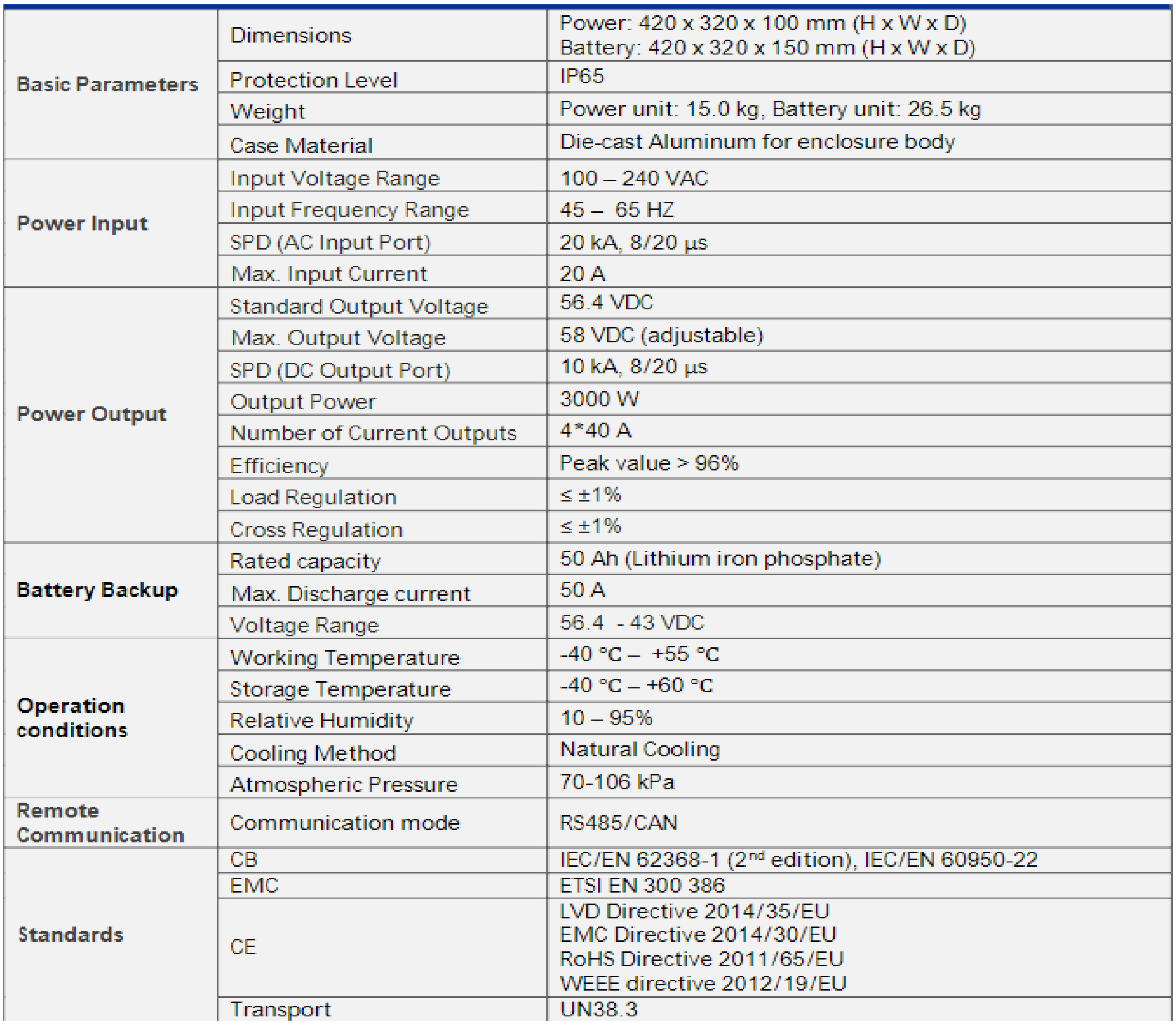
Figure 16 Detailed schematic layout of power supply.

As shown in figure 16, a detailed schematics layout with input energy as electricity in kWh and input material in Kg and their environmental impact output either emission to the air and effluents to the water.

However, such a system consists of materials which recycled and used as material inputs in another product’s manufacturing phase (Aluminium & alloys, steel, stainless steel, copper & alloys, and other materials). Equipment maintenance (all resulting material use and human labour), industry infrastructure manufacture and maintenance and land use skipped in this study.

The key physical properties of the micro power supply 6000W - PSU, which used for the analysis, summarized in Figure 17. The considerable variation in the properties is due to the advances in chemistry, manufacturing techniques, and whether the power supply used in energy applications.

In case of lack of detailed information about material composition and manufacturing techniques for the latest power supply technologies, aggregated knowledge about the energy and material flows assumed.



Basic Parameters	Dimensions	Power: 420 x 320 x 100 mm (H x W x D) Battery: 420 x 320 x 150 mm (H x W x D)
	Protection Level	IP65
	Weight	Power unit: 15.0 kg, Battery unit: 26.5 kg
	Case Material	Die-cast Aluminum for enclosure body
Power Input	Input Voltage Range	100 – 240 VAC
	Input Frequency Range	45 – 65 HZ
	SPD (AC Input Port)	20 kA, 8/20 µs
	Max. Input Current	20 A
Power Output	Standard Output Voltage	56.4 VDC
	Max. Output Voltage	58 VDC (adjustable)
	SPD (DC Output Port)	10 kA, 8/20 µs
	Output Power	3000 W
	Number of Current Outputs	4*40 A
	Efficiency	Peak value > 96%
	Load Regulation	≤ ±1%
	Cross Regulation	≤ ±1%
Battery Backup	Rated capacity	50 Ah (Lithium iron phosphate)
	Max. Discharge current	50 A
	Voltage Range	56.4 - 43 VDC
Operation conditions	Working Temperature	-40 °C – +55 °C
	Storage Temperature	-40 °C – +60 °C
	Relative Humidity	10 – 95%
	Cooling Method	Natural Cooling
	Atmospheric Pressure	70-106 kPa
Remote Communication	Communication mode	RS485/CAN
Standards	CB	IEC/EN 62368-1 (2nd edition), IEC/EN 60950-22
	EMC	ETSI EN 300 386
	CE	LVD Directive 2014/35/EU EMC Directive 2014/30/EU RoHS Directive 2011/65/EU WEEE directive 2012/19/EU
	Transport	UN38.3

Figure 17 Micro Power 3000W – PSU technical Specification.

Note: The datasheet shown in Figure 18 is for a 3000W version of the PSU with companion Lithium battery, and it given here for exemplification purpose only. The PSU analysed in the thesis is a 6000W- PSU, remarkably like the one described in the datasheet.

6.2 Life cycle inventory

Life cycle inventory (LCI) is the crucial phase of Life cycle assessment (LCA) which deals with the quantification and accumulation of a system inputs and outputs data. It involves the collection of the data necessary to meet the goals of the defined study.

6.2.1 LCI methods

There are three principal methods of LCI, with different modifications are elaborated. The three mains currently available LCI methods are: Process based modelling, Input output (IO) LCI and Hybrid method.

Each method requires different data, assumptions, and different calculations to perform. These methods help the practitioners to choose, use and further develop from different enormous number of LCA software available on the market. Moreover, this may aid scientific validation of future extension and modification in LCI methodology.

Choosing an appropriate method can increase reliability of the result and reduce error, time requirement and complexity. [22]

6.2.1.1 Process based modeling.

Process based modeling is the straightforward approach of inventory compilation via process analysis. There are two methods in this category, the first is process flow diagram, which using plain algebra, the number of commodities for fulfilling a certain functional unit obtained, and by multiplying the number of environmental interventions generated to produce them, the LCI of the product system calculated.

For a simple product system, process flow diagram method works fine. But industrial processes have multiple input streams or generate multiple output streams. Usually only one of the outputs is of interest for LCA study conducted. So, allocation problem comes into consideration. [22]

The very time consuming and other limitations of this method accentuate the necessity of a method where the whole product system with vast range of linear equations and solves them simultaneously. It can be applicable for product system with multiple input/output, internal looping, and recycling. This introduce the second method of process modelling which is the matrix method for process-based modeling.

Process oriented modelling needs lot of primary and axillary process data. It makes this method complicated and time consuming. On the other hand, cut off method is also criticized for underestimating inventory data of higher-order upstream stages. Therefore, input output IO LCI is adopted by practitioners which deliver the simple and faster solution with more expanded system boundary.[22]

6.2.1.2 Input output (IO) LCI

IO LCI method takes data from input output databases. This method considers far upstream stages into LCI calculation, so provide better result than process-oriented modeling.

In practical situation, a large input–output table representing the overall economy is too detailed to understand, and too extensive to use in making further numerical computation.

One disadvantage of IO, aggregated IO data is blind to individual processes. Consequently, it cannot use to guide technological or consumer choices at a product level.

Another problem of IO is it captures the upstream environmental burdens associated with raw materials acquisition and manufacturing stages, but not those associated with product use and end-of-life options.[22]

6.2.1.3 Hybrid method

Coming over the disadvantages of past tow methods and linking process based and IO based analysis, combining the strengths of both are called Hybrid method. There are three types of hybrid methods which are widely used in different LCA computations:

1. Tiered hybrid or process-based hybrid.
2. IO based hybrid.
3. Integrated hybrid.

In tiered hybrid, process data from main process modules are calculated by process-oriented modeling and then added to the far upstream data which are calculated by IO analysis.

However, in tiered hybrid method, there is no significant rule for determining the boundary between process and IO based modeling. Furthermore, due to overlapping between process and IO based data, double counting of inventory may also occur. These two problems are solved by practitioners via introducing IO based hybrid for LCI calculation.

In IO based hybrid method, the direct inputs to a specific product or process being studied are calculated using process analysis. Generally, the IO based hybrid approach is conducted by disaggregating specific sector in IO.

However, in this method, the process specific data is also collected via input output table which may increase the probability of data uncertainty. To remove this limitation, Integrated hybrid method is evolved.

Integrated hybrid is the matrix inversion method of hybrid analysis. The technology matrix consists of a typical process-based technology matrix, upstream and downstream cut-off matrices, and adjusted direct requirements matrix derived from the make and use tables in which economic flows corresponding to process modules have been subtracted.

Based on the above discussion, a comparative analysis can be done among all LCI methods. Matrix method is superior to the process flow diagram method particularly for the most simplified systems. Pure IO LCI can be most suitable for faster result. However, when process-based modeling and IO LCI is compared with tired hybrid analysis, the latter provides more reliable result with system completeness.

Uncertainty is lowest for inventory results found from process flow diagram and matrix method as it is seen that both methods directly consider the process data. On the contrary, IO LCI consists of highest level of uncertainty as it takes all data from IO table. Percentage of uncertainty for hybrid methods depends on the amount of data taken from IO table.

However, the calculation method of LCI still remains complex and time consuming. Process flow diagram, matrix inversion and disaggregation of input–output table require special expertise. Software development for Matrix method, updated input output table with latest data and newer technology information can make LCI more reliable and robust tool for sustainability assessment.

The dynamic LCI method also need more detailed study and standardized approach to provide more precise inventory results.

Regionalized databases, new impact assessment methods, improved methods for uncertainty analysis and different interpretation of LCI result i.e., aggregated LCI or weighted LCI and time distributed LCI method can be more substantial future development scope in this area.[22]

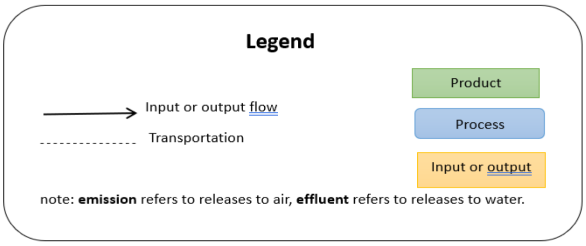
6.2.2 The inventory analysis of the research case study

First step in analysing life cycle and carbon content of a system is life cycle inventory (LCI) preparation. In the inventory analysis, all relevant flows, major resources, and energy consumption throughout the power supply lifecycle were considered.

We gathered LCI data from transparent sources with the best accuracy possible. The inventory data produced from the provider company Efore Telecom Finland - information for EPD (environmental product declaration) for section of product’s embodied emissions, and the information provided by the suppliers, in addition to project documentation.

For the system's modelling initially, an open-source software tool OpenLCA by Green Delta was selected, Environmental Footprint secondary data 2022-2023 database was used for inventory analysis. However, due to the lack of dataset available in OpenLCA, the approach was not adopted only from there, manual calculations were done later for the impact calculations.

Life cycle energy and environmental analysis boundary of the power supply in general is shown in Fig. 18.



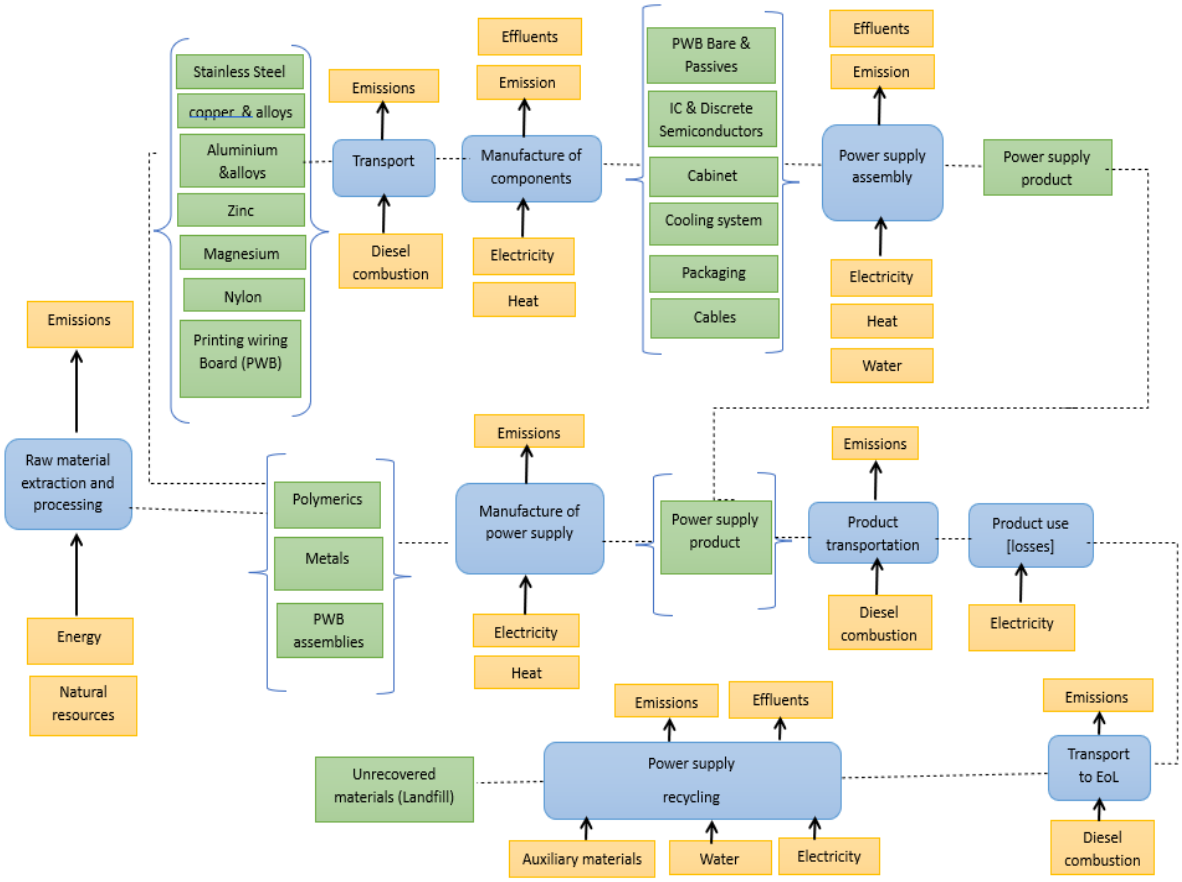


Figure 18 A detailed LCI and environmental analysis boundary of the power supply.

As shown in Figure 18, detailed life cycle inventory of the power supply at each stage and all related input energy, electricity, heat, and water and resulted emissions refers to air and effluent refers to water at each stage from cradle to grave. The arrow shows all input and output flows while dots show the transportation.

Variations can see in power supply LCA either by using OpenLCA software or by manual calculation. We will first give more information on each parts explanation before investigating the elements that affect the life cycle phases in detail.

6.2.2.1 Raw materials manufacturing

As seen from the system boundary flow chart figure 19, it is defined for the component manufacturing. including quantity of raw materials in Kg and sources of electricity, where the electricity was consumed.

Components that are not available in the datasets are modelled using the material composition. These components are listed as follows:

1. The integrated circuit IC and discrete semiconductors.
2. Printed wiring board PWB.
3. The cables.
4. The cooling systems.
5. The cabinets.
6. The packaging unit.

The assumption for the modelling raw materials used in Open LCA software modelling as follow:

1. For metallic all from material production - Aluminium is presented as ' Aluminium ingot (secondary) ‘, Copper is presented as `Copper (99.999%; electrolyte copper) `, Magnesium is presented as ´Magnesium ingot´, stainless steel is presented as ´Stainless steel (cold rolled) ´ and zinc is presented as ´Zinc redistilled zinc´, from the database.
2. Printed circuit boards- PCBs are modelled as Populated Printed wiring board (PWB) 2-layer and Populated Printed wiring board (PWB) 8-layer ´ from the database.
3. For polymerics nylon is presented as ´ Nylon 6 granulate (PA 6) ´ material production /plastics from the database.
4. All other units as the cables, cooling systems, cabinets and the packaging units are presented in the metallic and polymerics process and materials fractions.

Table 2 Modelling components used in raw material manufacturing in Software source OpenLCA.

	Amount	Unit
Aluminium ingot (secondary)	10.749	kg
Copper (99.999 %; electrolyte copper)	0.333	kg
Magnesium ingot	0.001	kg
Stainless steel (cold rolled)	0.227	kg
Zinc redistilled zinc	0.001	kg
Nylon 6 granulate (PA 6)	1.398	kg
Populated Printed wiring board (PWB) 2-layer	0.00764	m2
Populated Printed wiring board (PWB) 8-layer	0.14620	m2
Electricity -CH	40	kWh

As shown in table 2, all the input data sets for raw materials in kg, printed wiring board 2 layers and 4 layers with total area in m2 and total manufacturing electricity in kWh used in the flow process - openLCA software.

In the manual calculation the raw material composition list of the components of the power supply summarized in the three main groups metallic, polymerics and printed wiring board, in addition to the manufacturing electricity summarized in table 3.

Table 3 The raw materials list of power supply used in manual calculations.

Product main material fractions	Weight (g)	% of total weight	Comments
Metals:	11309	62.60 %	
Aluminum & alloys	10749	59.50 %	
Steel	0	0.00 %	
Stainless Steel	227	1.30 %	
Copper & alloys	333	1.80 %	Copper, Brass
Other metals	1	0.00 %	Zinc, Magnesium
Polymerics:	1398	7.70 %	
ABC / Polycarbonate	0	0.00 %	X% recycled content
SAN	0	0.00 %	
Polyethylene (HD)	0	0.00 %	
Other polymerics	1398	7.70 %	Nylon
PWB assemblies*:	5354	29.60 %	
Total product weight:	**18062**	**100 %**	

As shown in table 3, the total raw material input in the cradle to gate stage is 18.1 kg in addition to 40 kWh of manufacturing electricity from hard coal, production mix in the China market.

In the manual calculation detailed life cycle inventory data set of the process starting from raw material manufacturing to the power supply manufacturing electricity during the Cradle to gate stage and related GHG emission factors in (KgCO2eq/process unit) from different references and data base sources are summarized in table 4.

Table 4 Life cycle inventory dataset, GHG emission factor with references used in calculation.

Process	Life Cycle Inventory dataset	GHG emission factor (Kg CO2, eq./process unit)	References
Raw material extraction and processing	Metallic, Aluminum & alloys, China market, Cragle to gate	15.1	From aluminium world org.
	Metallic, Aluminum General, Eur consumption - Includes Eur production and imports - At world average recycled	6.67	Inventory of Carbon and Energy -ICE DB
	Metallic, Aluminum, China market, Cradle to gate	14.6	Inventory of Carbon and Energy -ICE DB
Electricity for product manufacturing	Electricity production, Average China Market per KWh	0.534	Energy Institute - Statistical Review of World Energy (2023)
	Electricity, China market, of hard coal power plants	0.96	From THE ECOINVENT DATABASE V3
	Electricity, China market, natural gas power plants without CHP	0.65	From THE ECOINVENT DATABASE V3

	Metallic, 30% of stainless-steel scrap collected for recycling at the end-of-life, ‘Cradle to Gate’ emissions	6.82	From https://www.worldstainless.org/
	Metallic, 50% of stainless-steel scrap collected for recycling at the end-of-life, ‘Cradle to Gate’ emissions	3.28	
	Metallic, 75% of stainless-steel scrap collected for recycling at the end-of-life, ‘Cradle to Gate’ emissions	2.42	
	Metallic, 85% of stainless-steel scrap collected for recycling at the end-of-life, ‘Cradle to Gate’ emissions	2.08	
	Metallic, 85% of stainless-steel scrap collected for recycling at the end-of-life, ‘Cradle to Gate’ emissions	4.39	Inventory of Carbon and Energy -ICE DB
	Metallic, Copper & alloys, primary copper production within the pyrometallurgical route, of Copper Concentrate (28% Cu)	1.1	From International Copper Association

	Metallic, Copper & alloys, Primary copper production within the hydrometallurgical route, is refined copper cathode	4.1	
	Metallic, Copper, EU production data. 37 % recycled content.	2.71	from Kupfer Institut LCI data -ICE DB
	Metallic, Copper, Virgin	3.81	from Kupfer Institut LCI data -ICE DB
	Metallic, Copper, Recycled	0.84	from Kupfer Institut LCI data -ICE DB
	Metallic, Zinc	3.66	From EFDB emission factor database
	Metallic, General Zinc	3.09	Inventory of Carbon and Energy -ICE DB
	Metallic, Zinc, Recycled content of general Zinc 30%	0.52	Inventory of Carbon and Energy -ICE DB
	Metallic, Magnesium	5.13	From EFDB emission factor database
	PWB Bare & Passives	------------	From OPEN LCA software
	Polymeric (Nylon), (Polyamide) 6 Polymer, 38.6 MJ/kg Feedstock Energy (Included). Doesn’t include final fabrication.	9.14	Inventory of Carbon and Energy -ICE DB

	Polymeric (Nylon), (Polyamide) 6.6 Polymer, 50.7 MJ/kg Feedstock Energy (Included). Doesn’t include final fabrication.	7.92	

As resulted from table 4, summarizing this table was crucial phase, finding the GHG emission factor for each LCI dataset of each part in its variety of description and feature.

Noticed here added recycled contents affect decreasing in the GHG emission factor, for example with stainless steel at 30% scrap, the Ef is 6.82 and with higher number of recycled contents and 80% of stainless-steel scrap the Ef decreased to 2.08 kgCo2eq/kg stainless steel.

Also noticed different electricity market with different electricity production type used in the manufacturing process of the product has different GHG Ef while China market chosen here, as the Efore factory found in China.

6.2.2.2 Power supply manufacturing

From the Efore factory in China, the total electricity used for the manufacturing process was 40 Wh. Total 40kWh for the power supply manufacturing consisting of: 2kWh for assembly and test and 38kWh for burn-in. Burn-in is the process where the finished product powered and provides load power for 8h. This done to screen-out units that fail early due to weak components or assembly errors.

By hand calculation the reference emission factor for manufacturing phase is 0.96 kgCo2e/kWh from the ecoinvent database V3, dataset electricity -China market, of hard coal power plants, is chosen in this case study.

6.2.2.3 Transportation

The information related to the location of the suppliers was available from the Efore Telecom Finland Proprietary and the Clean Cargo /2020 dataset.

The distance between the supplier and use place obtained from literature review, is 20000 km from China to Finland. Types of transportation obtained from the Clean Cargo/ 2020. For transportation Freight and shipping Transportation, Trade Lane: Asia to-from North Europe, DRY relevant emission factor Ef, number of TEU containers from the supplies is 1 TEU = 20foot ,20ft container has 288pcs and 40ft container has 576pcs.

The corresponding carbon emission factors is 0.044 (in Kg/TEU km). See appendix 2 - table 1 for details and references EF choice.

6.2.2.4 Use stage.

The use phase considers the amount of energy losses in the power supply throughout its operating lifetime. This explained either by different definitions of the use phase (e.g. here represent the losses energy) or different assumptions of user habits.

Energy efficiency is one of the most significant trends in power supply technology. High-efficiency power supplies help reduce energy consumption and operating costs while reducing heat generation and energy losses, making them ideal for applications demanding energy efficiency and eco-friendly designs.

The main parameter of the use phase would be the total energy losses (kWh) throughout the lifetime of the power supply. The choice of the functional unit (i.e. kWh) made as it relates to the environmental impacts on the use phase.

There are parameters for figuring out the kWh, and they change according to the power supply operating mode. The impact of the use phase varies with the assumptions that chosen operating lifetime, electricity mix (depending on the geographic location and sources of production), power supply efficiency and losses.

Using the characteristics of the power supply based on the following assumptions:

1. Operating lifetime: 10 years.
2. Duration working time: 24 h/day for 365 days /year.

In this study, the power uses at two different efficiencies first assessed at 96% and then raised up to 98%. Table 5 highlights the parameters used in this stage with input power rating 6kW. The system assumed to be operational for 10 years, forming the power supplies´ complete life cycle.

Table 5 Summary of the parameters required to determine the use phase.

Use phase condition	power rating (kW)	Power input	losses	duration (hours.)	Lifetime (years)	Total energy losses (kWh)
Efficiency 96%	6kW*0.5=3	3/0.96=3.125	0.125	24	10	10950
Efficiency 98%	6kW*0.5=3	3/0.98=3.061	0.061	24	10	5343.6

The calculations are done based on assumptions stated below:

1. The embodied carbon for electricity in Europe market for using phase losses is 0.265 kgCO2e per kwh from European Environment Agency - 2023.
2. All components of power supply are assumed to be manufactured in China.
3. Average power from power supply: a good approximation is 70% of the maximum power. So, 0.7*0.7 = 0.49 = approx. 0.5 or 50% of 6000W. In this case 0.5*6000=3000W average power.

4. Another reasoning is that efficiencies of 96% or 98% are peak efficiencies, which occur at 50% load, so dimensioning of power supply is done usually to operate it at the peak efficiency.
5. Other emission factor for different scenario of life inventory dataset for electricity type in the using phase are summarized in table 6.

Table 6 Embodied carbon for electricity in the using stage.

Process	Life Cycle Inventory dataset	GHG emission factor (Kg CO2, eq./KWh)	References
Electricity for product using	Electricity, Average Europe Market per KWh	0.265	European Environment Agency -2023
	Electricity, Average electricity production in Finland per KWh	0.234	Energy Authority, Finland ,2019
	Electricity, globally production, natural gas, combined cycle power plant /CO2	0.363	From THE ECOINVENT DATABASE V3
	Electricity, globally production, lignite power plants	1.26	From THE ECOINVENT DATABASE V3

As shown in table 6, different GHG emission factor for electricity production type while overestimated up to 1.26 kqCO2eq/kWh from globally production of electricity, lignite power plants.

For more detailed explaining of choosing each emission factor from difference references and related dataset of GHG emissions at each stage in the LCA of the power supply see appendix 2.

6.3 Life cycle Impact Assessment and Interpretation

In the LCIA step, all input and output flows are translated into contribution to the chosen environmental impact categories (e.g. global warming GW).

The purpose of LCIA is to provide additional information to help assess a product system’s LCI results to better understand their environmental significance.[21]

The environmental impact categories are climate change, acidification potential, resource use (fossils, minerals, and metals), and particulate matter (PM). This study's only the impact category chosen is climate change (kg CO2 equivalent). It is the heat absorbed by any greenhouse gas than that by the same mass of carbon dioxide.

GHG emissions measured by mass and shall convert into CO 2e emissions using the latest IPCC 100-year global warming potential (GWP) coefficients. [23] For example, methane has a GWP coefficient of twenty-five, means 1 kg of methane is equivalent to 25 kg CO 2e in terms of its GWP.

6.3.1 LCIA by a software tool OpenLCA, Green Delta

For this study, the life-cycle numerical model was created first by an open-source software tool OpenLCA by Green Delta, the method chosen for the calculation of the impact assessment results is Environmental Footprint (Mid-point indicator), normalization and weight set are PEF standard weight and normalization factors, calculation type Lazy/On-demand.

The results for the impact category shown below. In Figure 19, the contribution of each life cycle stage shown for the impact category.

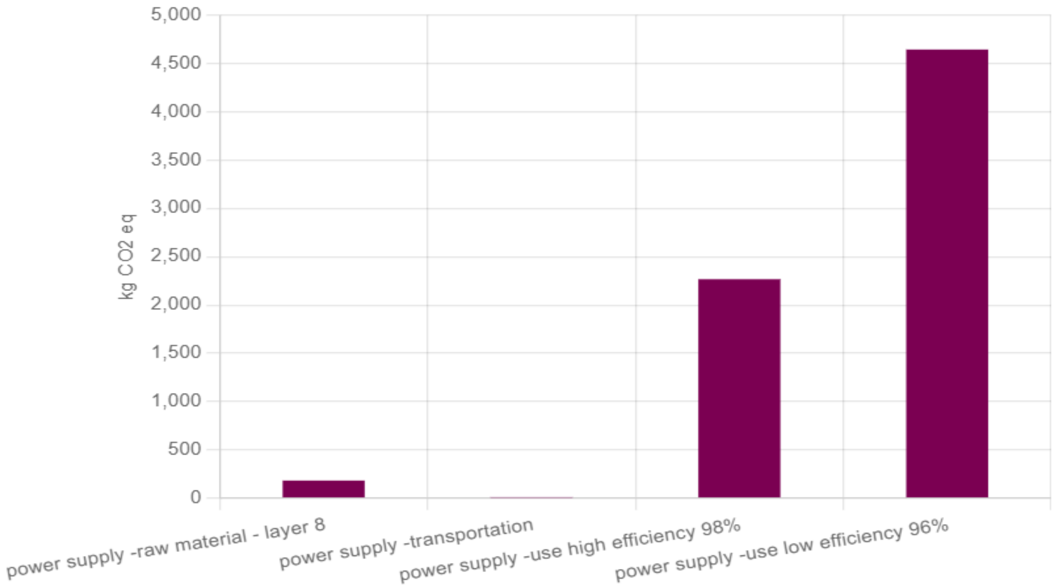


Figure 19 Absolute GHG emissions from openLCA software source.

As seen in figure 19, the losses in the use phases have the highest contribution to GWP with about 4644.4 of kgCO2eq at efficiency 96% and decreased to 2266.5 kgCo2eq at higher efficiency 98%. This followed by the raw material manufacturing in the cradle to gate phase with range of 181.8 kgCO2eq for cradle to gate phase and the least is transportation phases of GHG emissions is 3.1 kgCO2eq.

The relative GHG emission by phase in percentage % shown in figure 20, two observations from that figure:

1. The use phase losses contribute up to 92% of the total GWP impact at different efficiency.

1. The cradle to gate phase and the transportation phase collectively contributes about 8 % of the total impact.

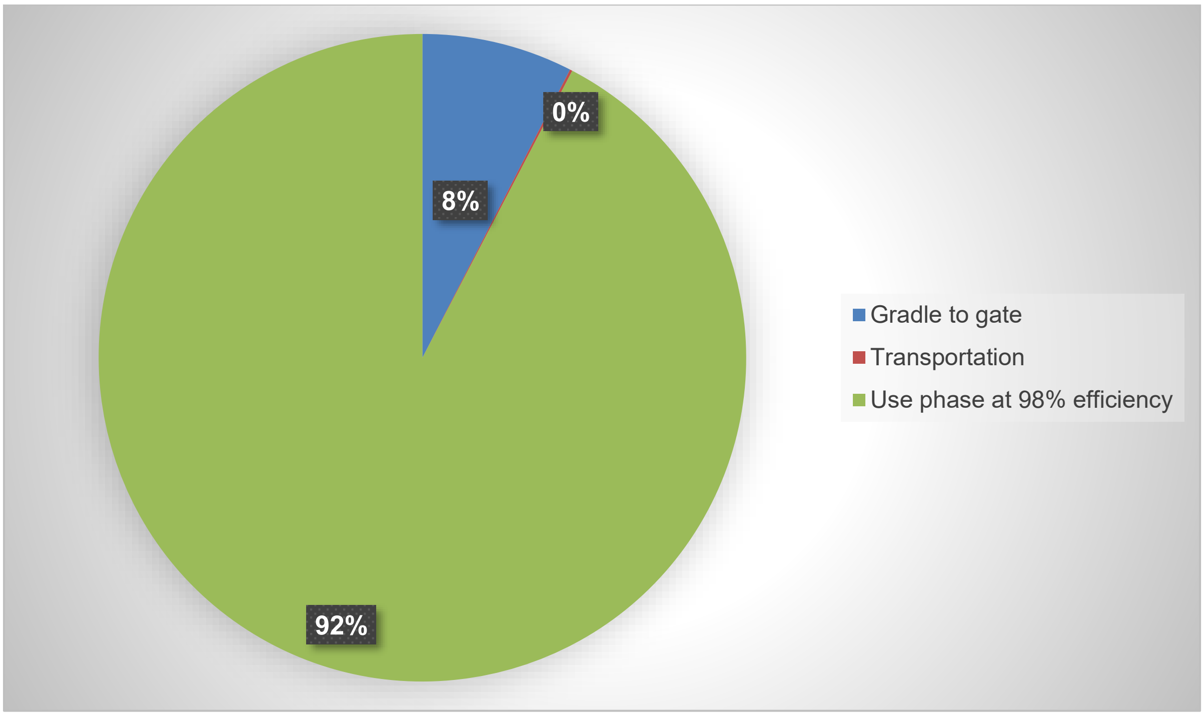


Figure 20 Contribution of each process on GWP in percentage.

As shown in figure 20, the losses in the use phase contribute the largest amount in the total footprint of the power supply at different efficiencies.

Noticed here as a significant contribution of increasing efficiency, which resulted impact of GWP dropped to half if we increase efficiency by 2% as shown in figure 21.

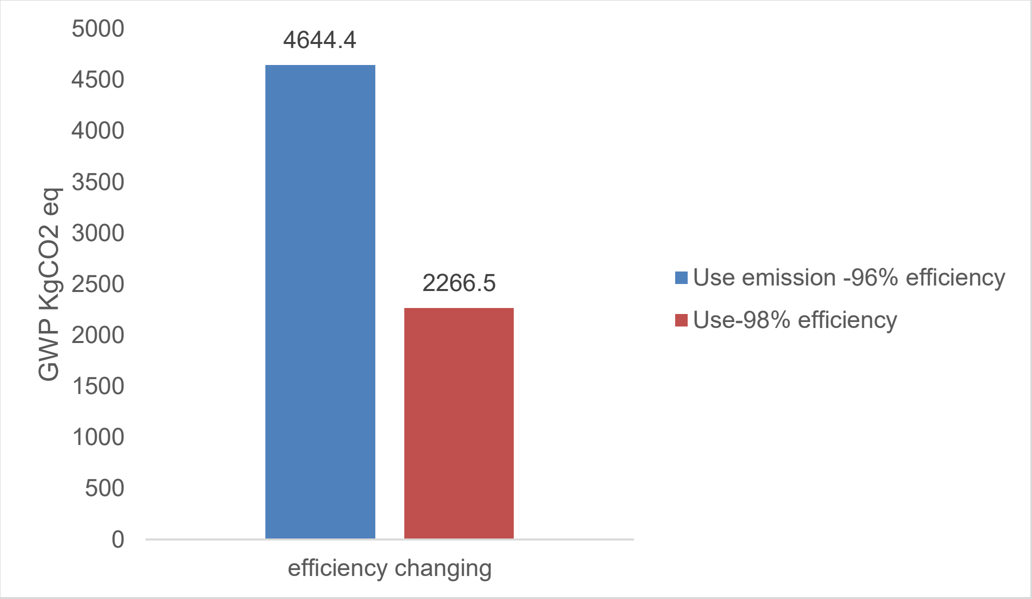


Figure 21 Climate change impact at different efficiency in the use stage.

As shown in figure 21, the GWP in KgCO2eq in the use stage dropped to the half to 2266.5 KgCO2eq at higher efficiency 98% compared to 4644.4 KgCO2eq at efficiency 96%.

The total impact assessment of the power supply for the climate change category at different two efficiencies are summarized in Table 7

Table 7 The total impact assessment of the power supply.

Environmental footprint EF	Cradle to gate	Transportation	Use	Total	Unit
96 %	181.8	3.1	4644.4	4829.3	kg CO2eq.
98 %	181.8	3.1	2266.5	2451.4	kg CO2eq.

The total GWP impact from the power supply, excluding the EOL phase, at 96% efficiency is calculated as 4829.3 kg CO2-e and decreased to 2451.4 kg CO2-e at higher efficiency.

The contribution of the cradle to gate stage including the manufacturing of different raw materials and power supply manufacturing electricity can be seen in Figure 22. Aluminium & alloys have the highest contribution (37%) in the cradle to gate phase with 67.1 kg CO2-eq and next is PWB contribution (29%) with 52.6 kg CO2-eq, following by manufacturing electricity with 48.4 kg CO2-equivalent of GWP (27%), finally polymeric nylon and other materials with 13.7 kg CO2-eq (7%) of total footprint emissions.

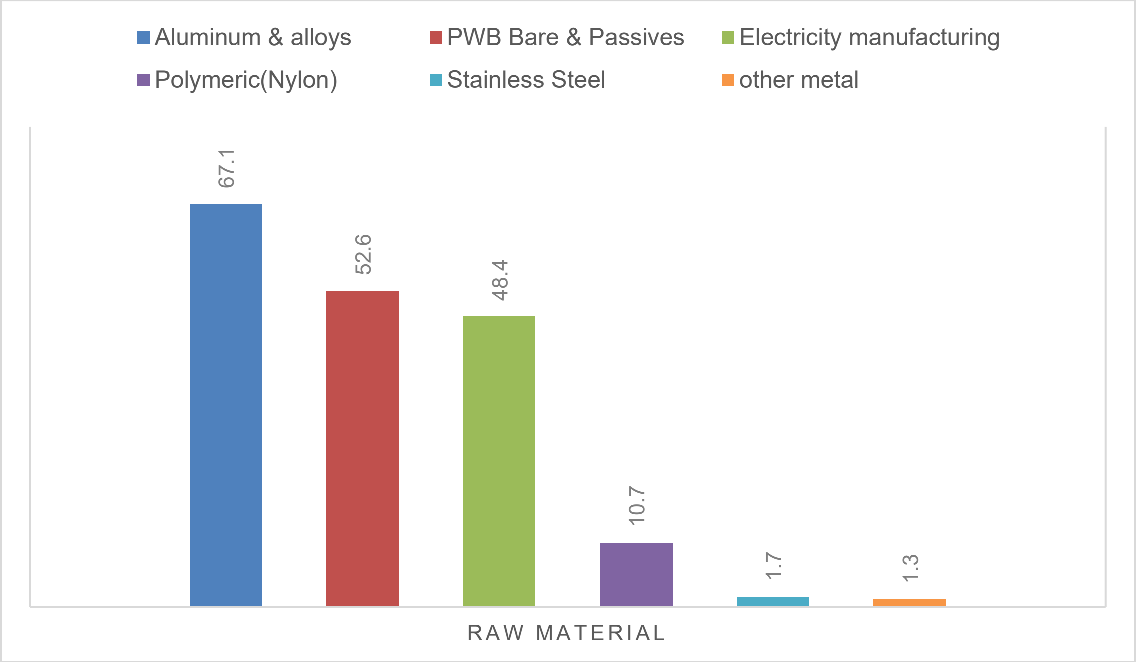


Figure 22 The GWP emission in KgCO2e of raw materials extraction, processing, and manufacturing.

As shown in figure 22, the first highest contributor in the total footprint emission is aluminium &alloys, the second is printed wiring board and third major contributor is the manufacturing electricity.

Improvements can be made by:

1. Redesign and reduce the weight of the aluminum & alloys by 30%suggested, total emission from raw material manufacturing will be decreased. That could be done by increasing the efficiency from 96% up to 98%, which will decrease losses and alternatively decreases aluminum used in the cooling parts.

2. Changing the types of electricity production and suggest clean sources such as wind or solar systems, using in the power supply manufacturing or in the using phases as it has low emission factors compared to traditional production types.
3. Finally, focusing on the recycling amount of different raw materials especially the metallic parts, as it also with lower emission factor will decrease the total footprint emissions in the cradle to gate stage.

The contribution of each process in percentage with the detailed raw materials included metallic parts, printed wiring board PWB, manufacturing electricity and polymeric (nylon) for the overall climate change impact is shown in Figure 23.

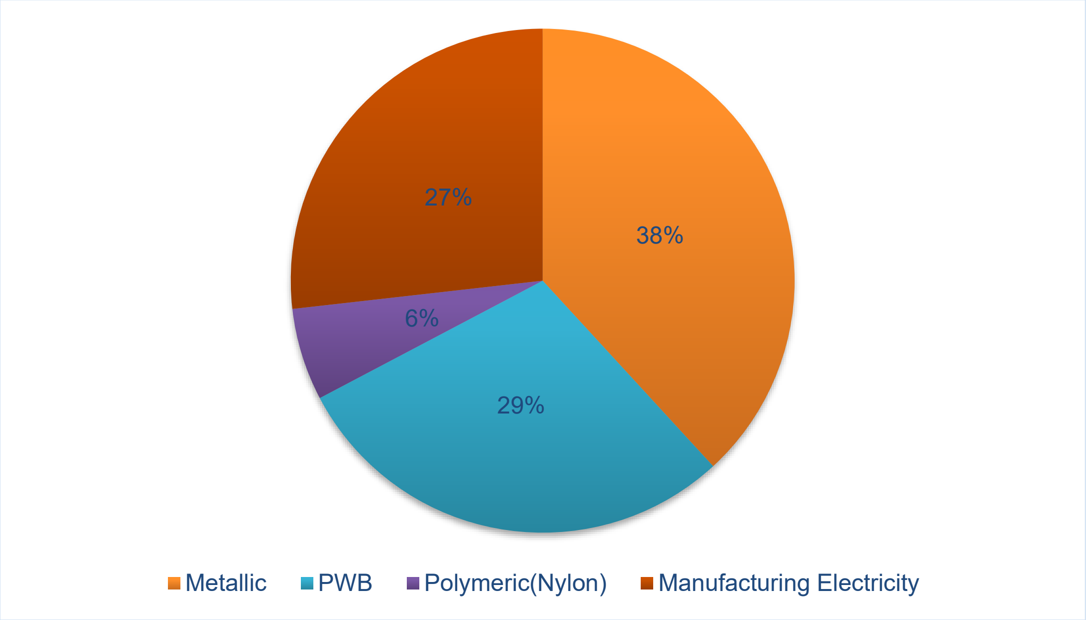


Figure 23 The contribution of each process in the cradle to gate phase.

As shown in figure 23, the highest contribution is from metallic parties of raw material with 38% from total GWP of the cradle to gate stage, following by PWB with 29% then the manufacturing electricity with 27% and the rest polymeric and others with 6% percentage of all cradles to gate emissions.

6.3.2 LCIA of datasets and databases in manual calculation

Manual calculations done by excel sheets, the life cycle inventory method used is process flow diagram for process-based modelling which using plain algebra and manual calculations.

The contribution of different raw materials manufacturing and power supply manufacturing electricity in the Cradle to gate stage shown in Figure 24. With total GWP from cradle to gate stage of 264.8kg CO2-eq ,again here from metallic , Aluminium & alloys , China market , have the highest contribution with 156.9 kg CO2-eq and PWB bare and passives contribution 53.7 kg CO2-eq from the total footprint , the third larger contributor is power supply manufacturing electricity with 38.4 kgCo2eq, the rest contribution is from (Polyamide) 6 Polymer with footprint 12.8 kgCo2eq . The other components with about 3 kgCo2eq from total impact emissions.

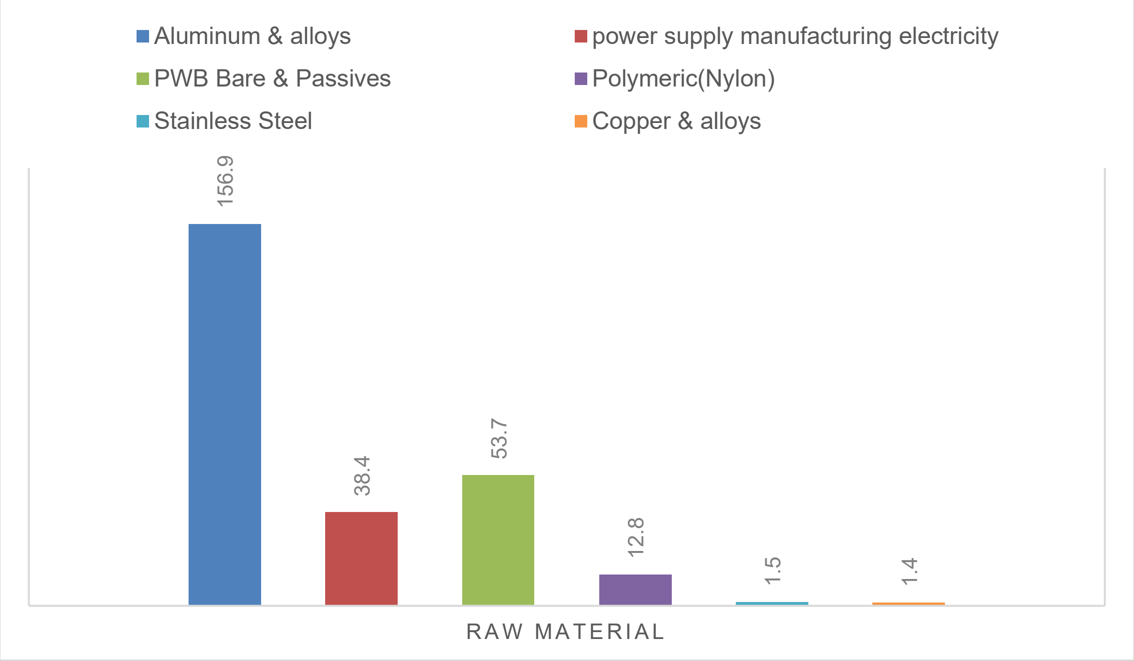


Figure 24 The GWP of cradle to gate phase with hand calculation Ef.

As shown in figure 24, the contribution of aluminium & alloys in the China market at cradle to gate stage has the highest emission factor and the top contributors. Noticed here that the carbon footprint 156.9 kg CO2-eq is higher compared to that resulted from OpenLCA software.

In the hand calculation the result trusted more as detailed specification for the raw material dataset is taken in consideration like allocation of China market and related to electricity used in the assembly and manufacturing.

The cradle to gate stage, transport, and the use losses stage with the results for the impact category scenario 1and scenario 2 shown in figure 25. The raw material manufacturing is metallic- China market. Transport -Freight and shipping emissions. Average Europe Market per kWh for uses phase, at efficiency 96% and scenario two efficiency use 98%.

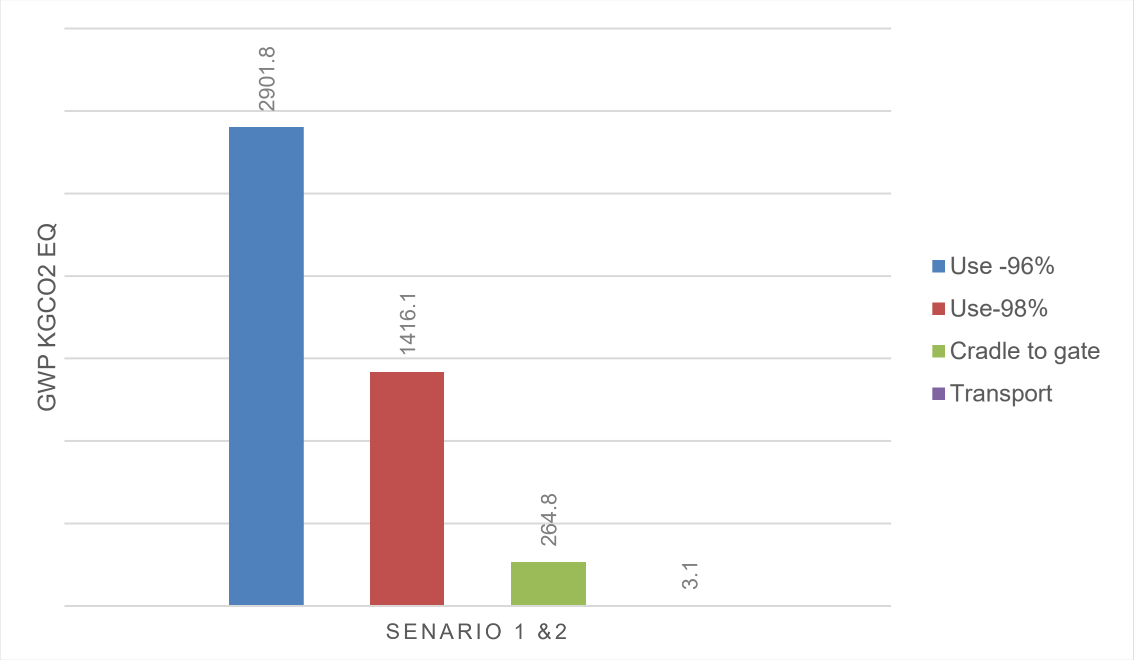


Figure 25 GHG emissions for all stages by hand calculation scenario 1&2.

As noticed here from Figure 25, the total impact from use stage losses is 2901.8 kgCO2e and drop down to 1416.1 kgCO2e at 96%& 98% efficiency consequently.

Generally, the results are in the same range with that from software OpenLCA. Again, here the result trusted more as detailed specification of type of electricity mix used in Europe market specified related to this product and more specific detailed dataset of raw material manufacturing with total emission 264.8 kgCO2e.

The relative GHG emission by phase in percentage % shown in figure 26,

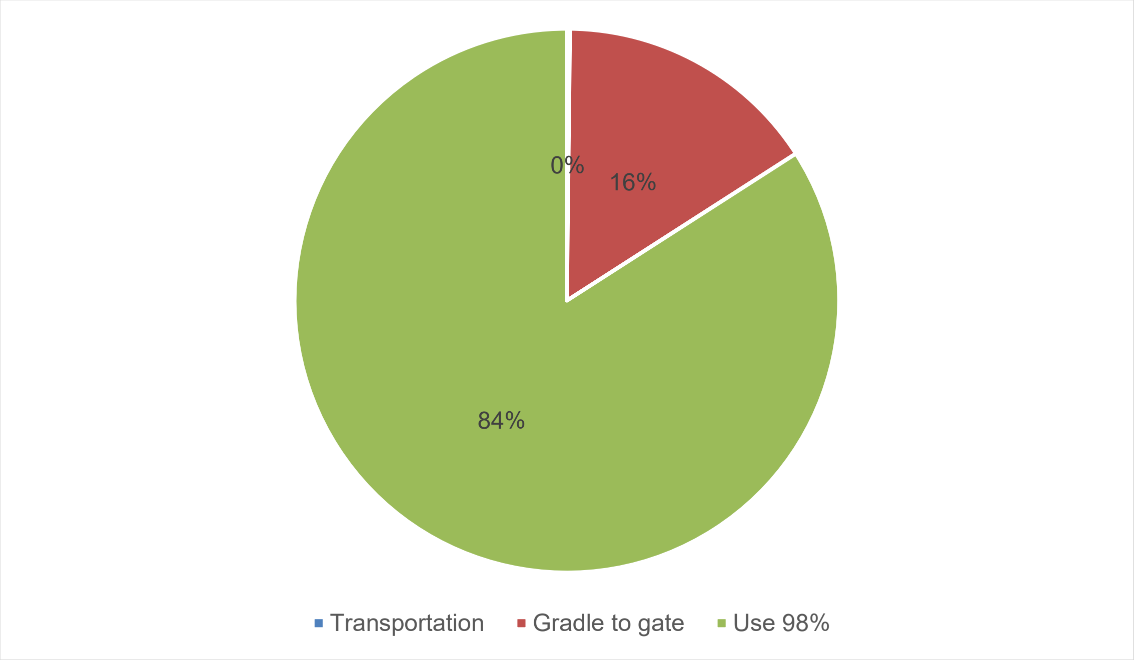


Figure 26 Percentage contribution of each process on GWP by hand calculation.

Two observations can be made from figure 26:

1. The largest contribution is from the use phase with 84% of the total GWP impact at different efficiency.
2. The Cradle to gate and the transportation phase collectively contributes percentage is 16% of the total impact.

The different resulted total GWP for all stages cradle to gate, transport and use stages from suggested scenarios are summarized in table 8.

These scenarios suggested average Europe market for electricity per kWh, other scenario of average electricity production in Finland per kWh. Different production types of electricity as globally electricity production, natural gas, combined cycle power plant /CO2 or lignite power plants. Finally suggested recycled contents in the raw material inputs shown in figure 28.

Table 8 Emissions for all stages with suggested different scenarios.

	Efficiency	Cradle -to-Gate Stage	Distribution Stage	Use Stage	Product Eco-impact - All Stages
Scenario 1: Raw material Cradle -to-gate. Metallic-China market. Transport -Freight and shipping emissions. **Average Europe Market per KWh**	, at 96%.	264.8	3.1	2901.8	**3169.6**
	, at 98%.	264.8	3.1	1416.1	1683.9
Scenario 3: Raw material Cradle -to-gate. Metallic-China market. Transport -Freight and shipping emissions. **Average electricity production in Finland per KWh**	, at 96%.	264.8	3.1	2562.3	2830.2
	, at 98%.	264.8	3.1	1250.4	1518.3
Scenario 5: Raw material Cradle -to-gate. Metallic-China market. Transport -Freight and shipping emissions. **GLO-Electricity production, natural gas,**	, at 96%.	264.8	3.1	3974.9	4242.7

combined cycle power plant /CO2					
	, at 98%.	264.8	3.1	1939.7	2207.6
Scenario 7: Raw material Cradle -to-gate. Metallic-China market. Transport -Freight and shipping emissions. **GLO-Electricity production, lignite power plants**	, at 96%.	264.8	3.1	13797.0	14064.9
	, at 98%.	264.8	3.1	6732.9	7000.8
Scenario 9: Raw material Cradle -to-gate. Metallic-China market. Transport -Freight and shipping emissions. Average Europe Market per KWh, at Efficiency 96%. **Recycled content**	, at 96%.	175.7	3.1	2901.8	**3080.5**
	, at 98%.	175.7	3.1	1416.1	1594.8

Average Europe market of electricity per KWh used in the losses of the using phase with the same characteristic of raw material cradle -to-gate, metallic-China market and same suggested transport -freight and shipping emissions, resulted footprint 3169.6 kg CO2-eq at 96% and down to 1683.9 kg CO2-eq at higher efficiency 98%.

Scenario 3 and scenario 4 with average electricity production in Finland per KWh, same characterized of raw material cradle to gate and same transportation type of freight and shipping. The total resulted GWP is 2830.2 kg CO2-eq and 1518.3 kg CO2-eq at 96% and 98% efficiency consequently.

Other two suggestions, scenario 5 and scenario 6 with globally - electricity production, natural gas, combined cycle power plant /CO2, resulted total footprint is 4242.7 kg CO2-eq and 2207.6 kg CO2-eq at 96% and 98% efficiency consequently.

The same characteristic of raw material cradle -to-gate, metallic- China market and same suggested transport -freight and shipping emissions but globally market -electricity production, lignite power plants, GWP is the highest emission jumped up to 14064.9 and 7000.8 kg CO2-eq at 96% and 98% efficiency consequently in scenarios 7&8.

Finally, scenario 9&10 with recycled contents of input raw materials in the Cradle to gate stage the footprint is dropped to 175.7 kg CO2-eq and at two efficiency 96% &98% consequently their total footprint for all stages is 3080.5 kg CO2-eq and 1594.8 kg CO2-eq.

As shown in table 9 with raw material Cradle -to-gate, metallic- China market. Transport -Freight and shipping emissions. Average Europe Market per KWh. Recycled content, GWP for cradle to gate is decreased to 175.7 kg CO2-eq compared to 264.8 KgCO2eq of GWP without recycled contents.

Table 9 Scenario 9&10raw material, recycled content and GWP.

Scenario 9&10		175.7
	Metallic, Aluminum & alloys, China market, Cragle to gate, globally recycled 40%	71.7
	Metallic, 85% of stainless-steel scrap collected for recycling at the end-of-life, ‘Cradle to Gate’ emissions	0.5
	Metallic, Copper & alloys, Primary copper production within the pyrometallurgical route, of Copper Concentrate (28% Cu)	0.4

	Metallic, Zinc, Recycled content of general Zinc 30%	0.0
	Metallic, Magnesium	0.0
	PWB Bare & Passives	53.7
	Polymeric (Nylon), (Polyamide) 6.6 Polymer, 50.7 MJ/kg Feedstock Energy (Included). Doesn’t include final fabrication.	11.1
	Power supply manufacturing Electricity	38.4

As shown in table 9, suggested scenarios of the added value of recycled content of the scrap and material characteristic resulted decrease in the cradle to gate footprints.

Thees suggested scenarios from 1-10 at two efficiency 96 %and 98% and their environmental impact of GWP KgCO2eq shown below in figure 27.

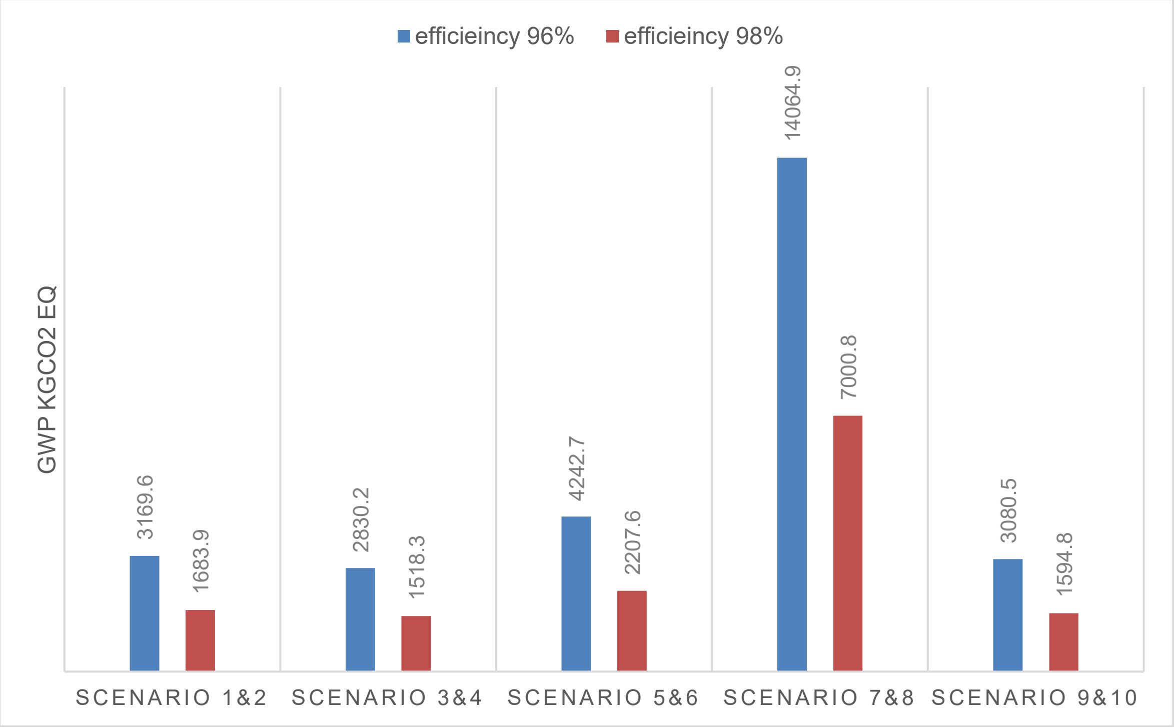


Figure 27 GWP for all stages cradle to gate, transport and use stages result from suggested scenarios.

As shown in figure 27, and as discussed before of each scenario from different source of electricity mix market and different key direct emission factors for each type of electricity production , it shows quite near range environmental impact and contribution of (2830.2-4242.7) KgCO2eq at 96% efficiency and range footprint (1518.3 – 2207.6) KgCO2eq at high efficiency 98% , excluded the GLO-Electricity production, lignite power plants results .

By hand calculation and by OpenLCA software, the GHG emissions are quite in the same range at two 96% & 98% efficiencies. excluded the GLO-Electricity production, lignite power plants results.

Noticed the impact of different type of electricity production as when used global electricity production, lignite power plants the total footprint increased to 14064.9 kg CO2-eq and 7000.8 kg CO2-eq at 96% and 98% efficiency so.

The GHG emissions factors can be vary from one reference to other and by different dataset and properties of raw materials used in the manufacturing, these investigate the difference between aluminium &alloy footprint in environmental footprint database Ef by OpenLCA software (67.1 KgCO2eq) and by hand calculation Ef (156.9 KgCO2eq).

Depending on the province, the electricity market and the electricity mix production type, datasets and related emission factors widely ranged and resulted difference in the total footprint emissions. As an average China market per KWh estimated by a factor between (0.534 - 0.96) KgCO2eq/kWh. from different references, while in Europe Market per KWh, in Finland and globally electricity production is with emission factor range (0.265 - 0.363) KgCO2eq/kWh. Excluded EF for lignite power plants production source of electricity mix.

There is insufficient information to explain the stark difference of footprint result from use stage and cradle to gate stage. The footprint emission in the use stage is due to the assumptions of the definition of uses stage as representation of the loss's energy with its amount and related high Ef.

7 Results and discussion

We performed simplified LCAs studies on a power supply to detect the sources of variation across their results, considering the impact on global warming potential over one hundred years (GWP100), focussing on life cycle phases and processes causing the greatest contribution to GWP.

The aim of these LCAs is to corroborate the importance of the most contributing processes, and to be able to compare the results of different database sources by using different calculation basis (LCI data sets and relative EF).

Requirements specified for finding the system boundary, the sources of GHG emissions associated with this power supply which fall inside the system boundary, the data requirements for conducting the analysis, and the calculation of the results.

This research addresses the single impact category of global warming, and does not assess other potential social, economic, and environmental impacts arising from the provision of products, such as non-greenhouse gas emissions, acidification, eutrophication, toxicity, biodiversity, labour standards or other.

The life cycle GHG emissions of products, calculated using PAS 2050 and ISO standards (ISO 14040:2006, ISO 14044:2006, ISO/TR 14047:2003, ISO/TS 14048:2002)

It is one of the intentions of this research to allow for the comparison of GHG emissions between cradle to gate, transformation and use stages either by using OpenLCA results or by hand calculations. This study analysed the environmental impact of an uninterruptible power supply (UPS) system based on context 6000W - PSU.

This study found the climate change impact of the power supply with the exclusion of the end-of-life phase. By hand calculations, this product emits about (2830.2-4242.7) KgCO2eq at 96% efficiency and dropped down to the half (1518.3 – 2207.6) KgCO2eq at higher efficiency 98%.

More than 88% of this emission comes from the use phase within Europe markets of electricity mix.

The use phase followed by Cradle to gate phase with footprint 264.8 kg CO2eq and transportation phase footprint 3.1 kg CO2eq. However, the net GHG emissions of the Cradle to gate phase footprint emission are far lower to 175.7 kg CO2eq if recycled contents added in the input raw materials.

Environmental footprint data base from software source openLCA resulted a quite same range to that done by hand calculation, with Cradle to gate stage footprint emissions is 181.8 kg CO2eq and transportation phase footprint 3.1 kg CO2eq.While the uses phases losses contribute 92% from total emissions.

Otherwise, both hand calculation and OpenLCA software from metal parts - the aluminium &alloys components have the highest contribution in the cradle to gate stage.

Considering the same type of the transportation - Freight and shipping transportation. Both the hand calculation and OpenLCA sources have the same range of GHG emissions of 3.1kg CO2-eq.

Unfortunately, it was challenging to find a reliable source for the end-of-life model of the power supply since only few related studies and reference data from supplies are available. Thus, this study skipped the end-of-life stage of the power supply in this case study.

To conclude, there is a consistent lack of LCI datasets and data sources of the power supplies. Variety databases and related emission factors and conditions, leading to uncertainties and a wide range of results.

It would be a big step forward to have a complete analysis of the different technologies and their impacts.

Redesign and reduce the weight of the aluminium & alloys, which will decrease total emission from raw material productions. Increasing the efficiency from 96% up to 98%, will decreases total amount of aluminium used in the cooling parts which guide to the goal.

Energy efficiency is an equally important part of the EU's climate neutrality, increasing the efficiency will decreases the related footprint emission in the use stage (losses affect). A suggested clean source such as wind or solar systems could use in the power supply manufacturing.

Focusing on the recycling amount of different raw materials input also another suggested development of the power supply.

Based on these developments and this research platform, the presented total GHG emission of this power supply product will decrease, that meeting the Paris agreement goal -which aligned with Efore Telecom Finland Oy sustainability public target.

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Title of the Appendix

Appendix1

Appendix 2

Appendix1

Table 1 Description and boundaries of scope 3 categories [1]

Upstream scope 3 emissions

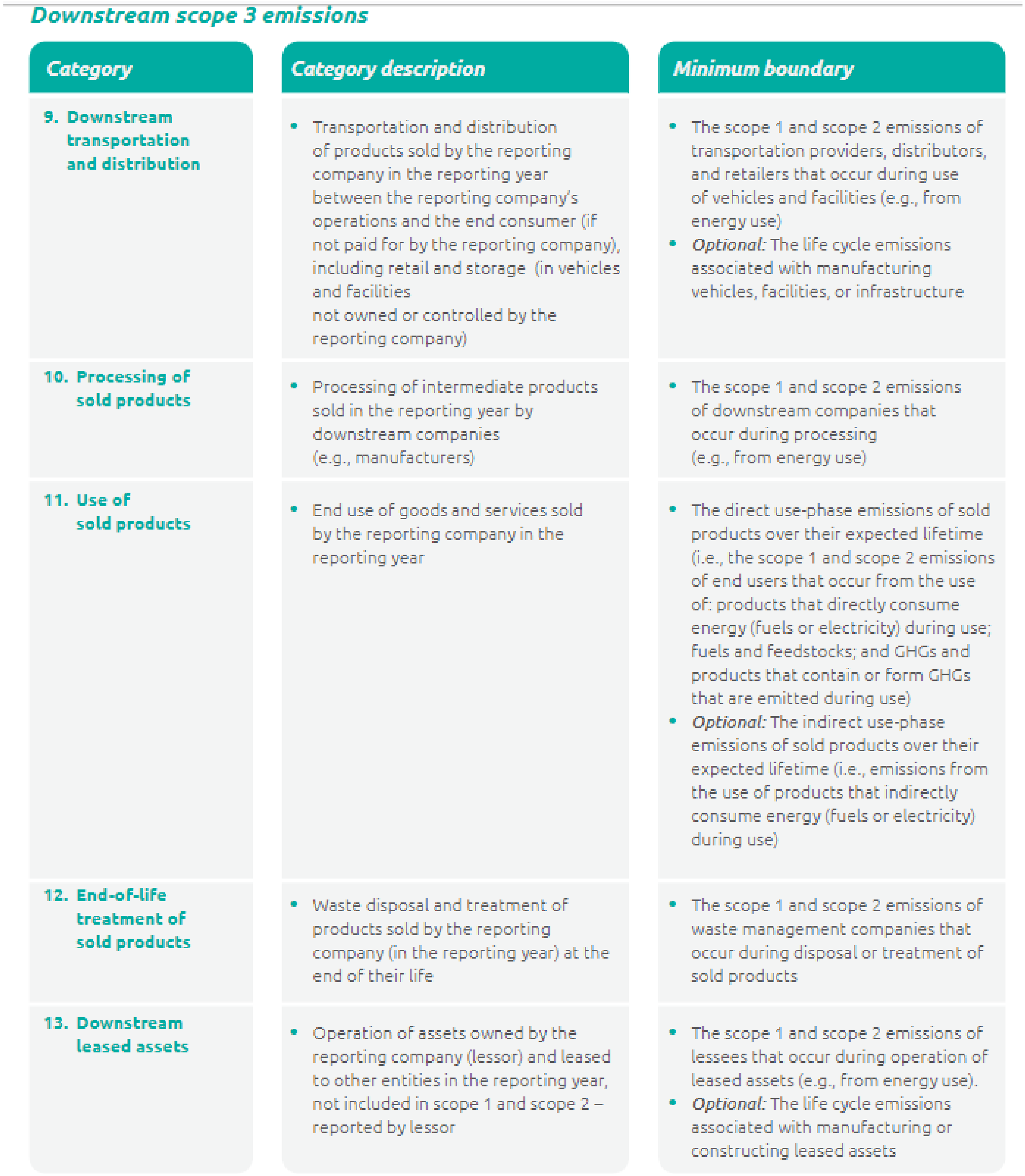
Category	Category description	Minimum boundary
1. Purchased goods and services	- Extraction, production, and transportation of goods and services purchased or acquired by the reporting company in the reporting year, not otherwise included in Categories 2 - 8	- All upstream (cradle-to-gate) emissions of purchased goods and services
2. Capital goods	- Extraction, production, and transportation of capital goods purchased or acquired by the reporting company in the reporting year	- All upstream (cradle-to-gate) emissions of purchased capital goods
3. Fuel- and energy-related activities (not included in scope 1 or scope 2)	- Extraction, production, and transportation of fuels and energy purchased or acquired by the reporting company in the reporting year, not already accounted for in scope 1 or scope 2, including: **a.** Upstream emissions of purchased fuels (extraction, production, and transportation of fuels consumed by the reporting company) **b.** Upstream emissions of purchased electricity (extraction, production, and transportation of fuels consumed in the generation of electricity, steam, heating, and cooling consumed by the reporting company) **c.** Transmission and distribution (T&D) losses (generation of electricity, steam, heating and cooling that is consumed (i.e., lost) in a T&D system) – reported by end user **d.** Generation of purchased electricity that is sold to end users (generation of electricity, steam, heating, and cooling that is purchased by the reporting company and sold to end users) – reported by utility company or energy retailer only	**a.** For upstream emissions of purchased fuels: All upstream (cradle-to-gate) emissions of purchased fuels (from raw material extraction up to the point of, but excluding combustion) **b.** For upstream emissions of purchased electricity: All upstream (cradle-to-gate) emissions of purchased fuels (from raw material extraction up to the point of, but excluding, combustion by a power generator) **c.** For T&D losses: All upstream (cradle-to-gate) emissions of energy consumed in a T&D system, including emissions from combustion **d.** For generation of purchased electricity that is sold to end users: Emissions from the generation of purchased energy

Table 1 Description and boundaries of scope 3 categories (continued)

Upstream scope 3 emissions

Category	Category description	Minimum boundary
4. Upstream transportation and distribution	• Transportation and distribution of products purchased by the reporting company in the reporting year between a company's tier 1 suppliers and its own operations (in vehicles and facilities not owned or controlled by the reporting company) • Transportation and distribution services purchased by the reporting company in the reporting year, including inbound logistics, outbound logistics (e.g., of sold products), and transportation and distribution between a company's own facilities (in vehicles and facilities not owned or controlled by the reporting company)	• The scope 1 and scope 2 emissions of transportation and distribution providers that occur during use of vehicles and facilities (e.g., from energy use) • *Optional:* The life cycle emissions associated with manufacturing vehicles, facilities, or infrastructure
5. Waste generated in operations	• Disposal and treatment of waste generated in the reporting company's operations in the reporting year (in facilities not owned or controlled by the reporting company)	• The scope 1 and scope 2 emissions of waste management suppliers that occur during disposal or treatment • *Optional:* Emissions from transportation of waste
6. Business travel	• Transportation of employees for business-related activities during the reporting year (in vehicles not owned or operated by the reporting company)	• The scope 1 and scope 2 emissions of transportation carriers that occur during use of vehicles (e.g., from energy use) • *Optional:* The life cycle emissions associated with manufacturing vehicles or infrastructure
7. Employee commuting	• Transportation of employees between their homes and their worksites during the reporting year (in vehicles not owned or operated by the reporting company)	• The scope 1 and scope 2 emissions of employees and transportation providers that occur during use of vehicles (e.g., from energy use) • *Optional:* Emissions from employee teleworking
8. Upstream leased assets	• Operation of assets leased by the reporting company (lessee) in the reporting year and not included in scope 1 and scope 2 – reported by lessee	• The scope 1 and scope 2 emissions of lessors that occur during the reporting company's operation of leased assets (e.g., from energy use) • *Optional:* The life cycle emissions associated with manufacturing or constructing leased assets

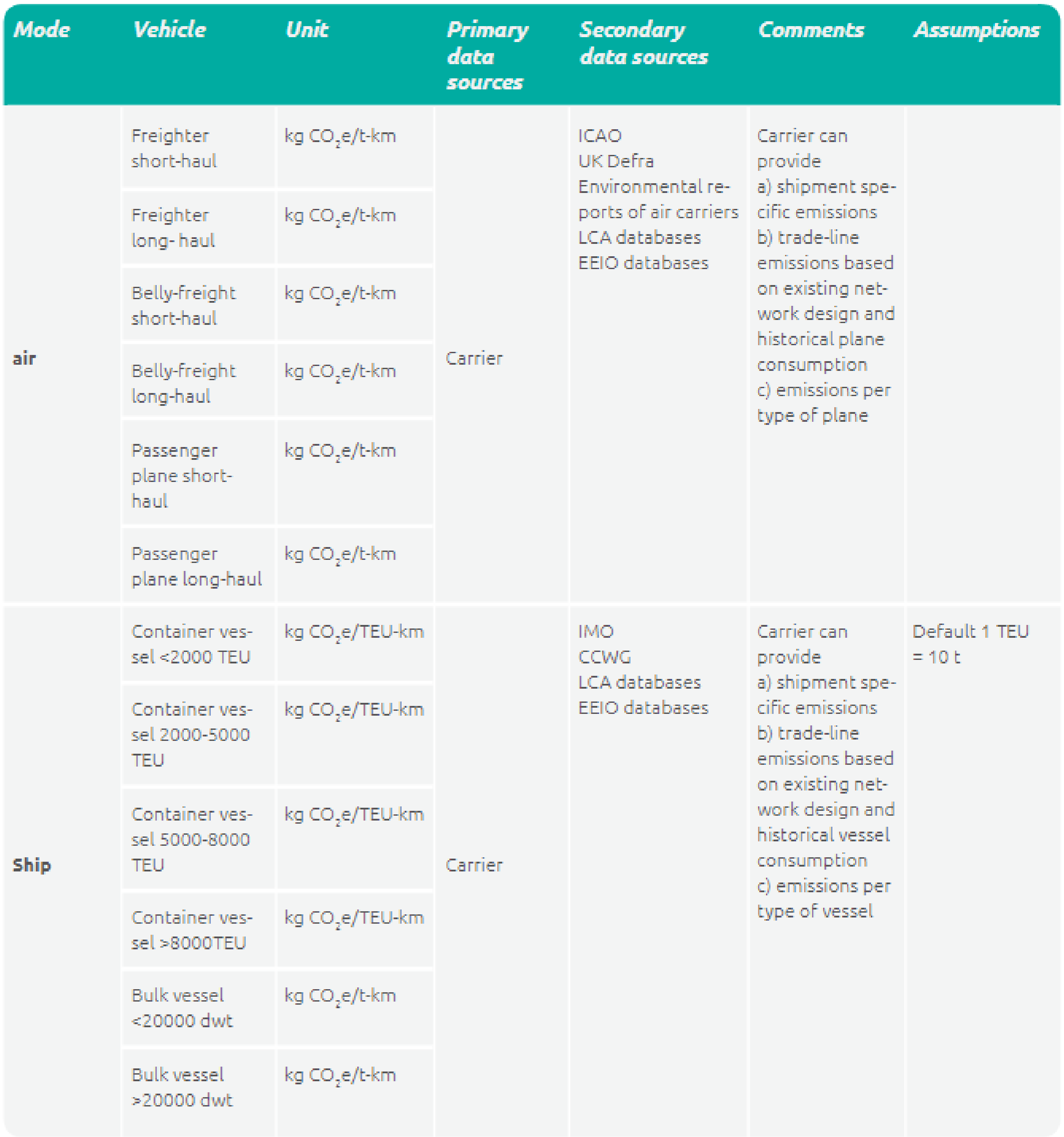
Table 1 Description and boundaries of scope 3 categories (continued)



Downstream scope 3 emissions

Category	*Category description*	*Minimum boundary*
9. Downstream transportation and distribution	• Transportation and distribution of products sold by the reporting company in the reporting year between the reporting company's operations and the end consumer (if not paid for by the reporting company), including retail and storage (in vehicles and facilities not owned or controlled by the reporting company)	• The scope 1 and scope 2 emissions of transportation providers, distributors, and retailers that occur during use of vehicles and facilities (e.g., from energy use) • *Optional:* The life cycle emissions associated with manufacturing vehicles, facilities, or infrastructure
10. Processing of sold products	• Processing of intermediate products sold in the reporting year by downstream companies (e.g., manufacturers)	• The scope 1 and scope 2 emissions of downstream companies that occur during processing (e.g., from energy use)
11. Use of sold products	• End use of goods and services sold by the reporting company in the reporting year	• The direct use-phase emissions of sold products over their expected lifetime (i.e., the scope 1 and scope 2 emissions of end users that occur from the use of: products that directly consume energy (fuels or electricity) during use; fuels and feedstocks; and GHGs and products that contain or form GHGs that are emitted during use) • *Optional:* The indirect use-phase emissions of sold products over their expected lifetime (i.e., emissions from the use of products that indirectly consume energy (fuels or electricity) during use)
12. End-of-life treatment of sold products	• Waste disposal and treatment of products sold by the reporting company (in the reporting year) at the end of their life	• The scope 1 and scope 2 emissions of waste management companies that occur during disposal or treatment of sold products
13. Downstream leased assets	• Operation of assets owned by the reporting company (lessor) and leased to other entities in the reporting year, not included in scope 1 and scope 2 – reported by lessor	• The scope 1 and scope 2 emissions of lessees that occur during operation of leased assets (e.g., from energy use). • *Optional:* The life cycle emissions associated with manufacturing or constructing leased assets

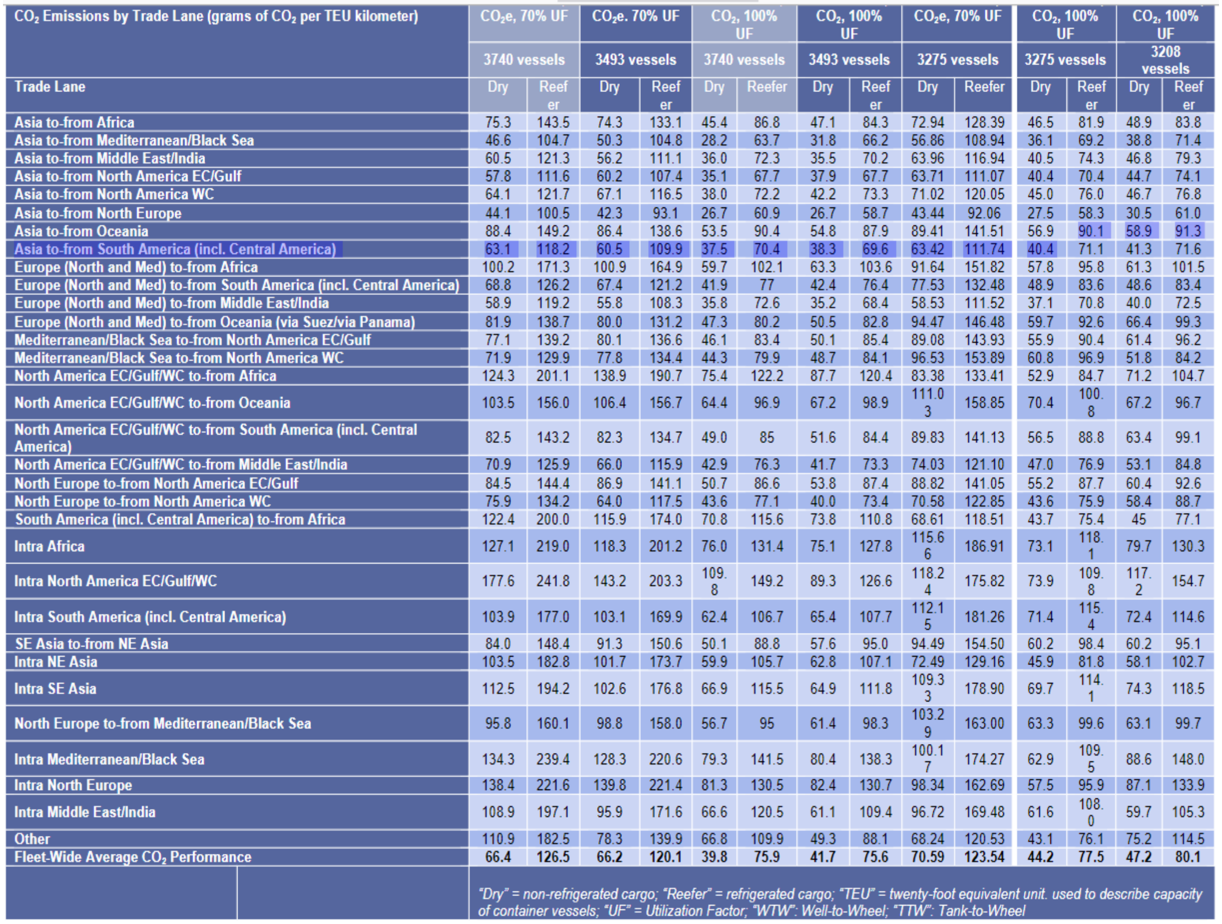
Table 2: Data collection guidance for the distance-based method [1]



Mode	Vehicle	Unit	Primary data sources	Secondary data sources	Comments	Assumptions
air	Freighter short-haul	kg CO$_2$e/t-km	Carrier	ICAO UK Defra Environmental reports of air carriers LCA databases EEIO databases	Carrier can provide a) shipment specific emissions b) trade-line emissions based on existing network design and historical plane consumption c) emissions per type of plane	
	Freighter long- haul	kg CO$_2$e/t-km				
	Belly-freight short-haul	kg CO$_2$e/t-km				
	Belly-freight long-haul	kg CO$_2$e/t-km				
	Passenger plane short-haul	kg CO$_2$e/t-km				
	Passenger plane long-haul	kg CO$_2$e/t-km				
Ship	Container vessel <2000 TEU	kg CO$_2$e/TEU-km	Carrier	IMO CCWG LCA databases EEIO databases	Carrier can provide a) shipment specific emissions b) trade-line emissions based on existing network design and historical vessel consumption c) emissions per type of vessel	Default 1 TEU = 10 t
	Container vessel 2000-5000 TEU	kg CO$_2$e/TEU-km				
	Container vessel 5000-8000 TEU	kg CO$_2$e/TEU-km				
	Container vessel >8000TEU	kg CO$_2$e/TEU-km				
	Bulk vessel <20000 dwt	kg CO$_2$e/t-km				
	Bulk vessel >20000 dwt	kg CO$_2$e/t-km				

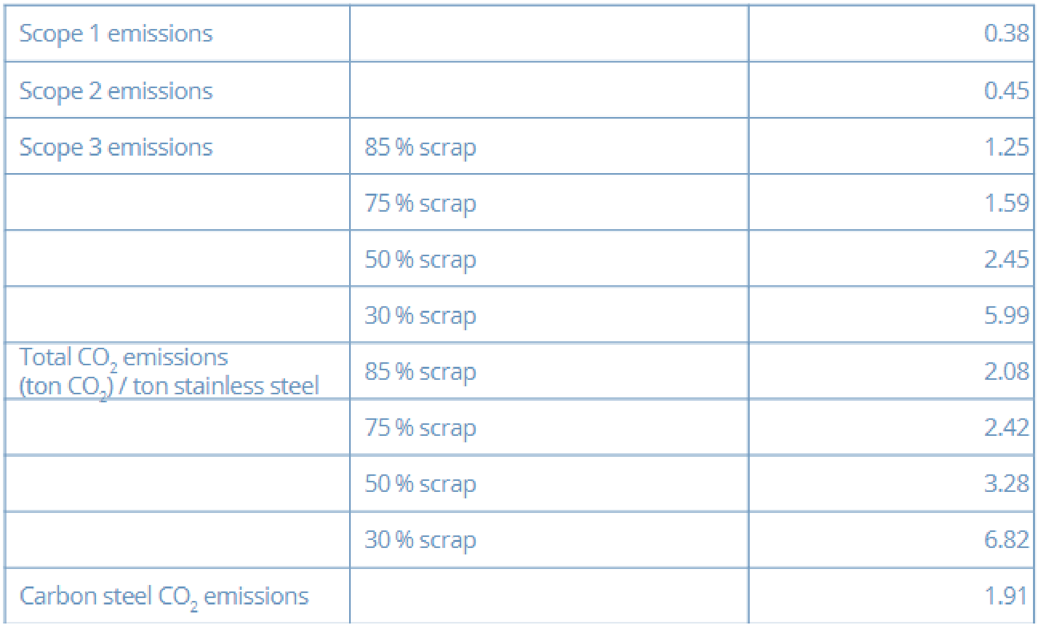
Appendix 2

Table 1 2020 Global Container Shipping Trade Lane Emissions Factors, Clean Cargo, October 2021.[24]



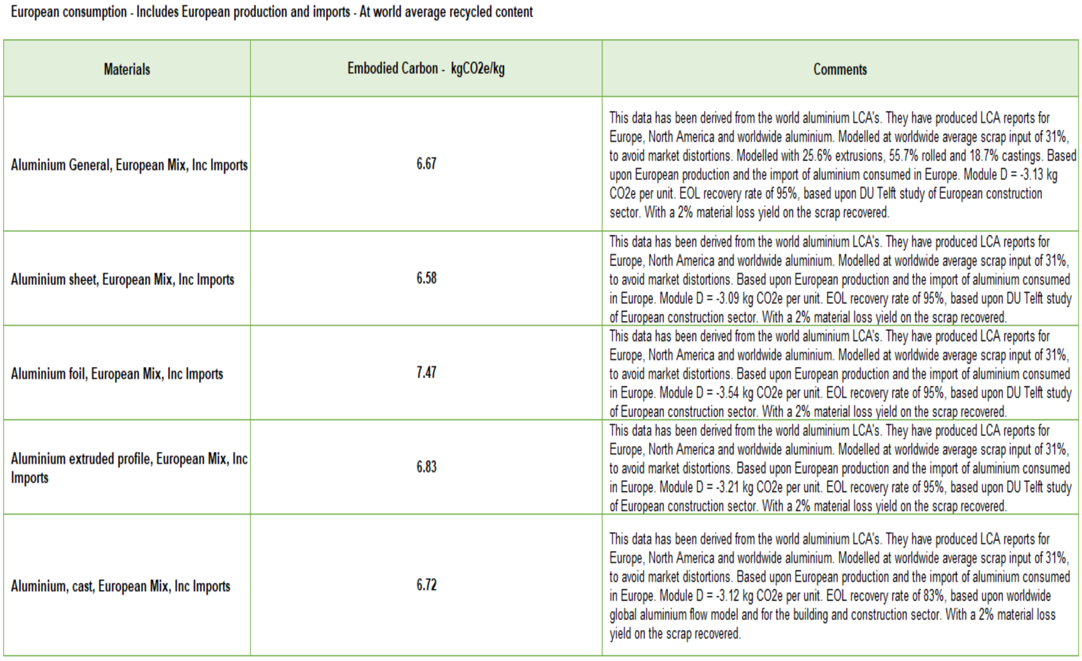
CO_2 Emissions by Trade Lane (grams of CO_2 per TEU kilometer)	CO_2e, 70% UF		CO_2e. 70% UF		CO_2, 100% UF		CO_2, 100% UF		CO_2e, 70% UF		CO_2, 100% UF		CO_2, 100% UF	
	3740 vessels		3493 vessels		3740 vessels		3493 vessels		3275 vessels		3275 vessels		3208 vessels	
Trade Lane	Dry	Reefer	Dry	Reefer	Dry	Reefer	Dry	Reefer	Dry	Reefer	Dry	Reefer	Dry	Reefer
Asia to-from Africa	75.3	143.5	74.3	133.1	45.4	86.8	47.1	84.3	72.94	128.39	46.5	81.9	48.9	83.8
Asia to-from Mediterranean/Black Sea	46.6	104.7	50.3	104.8	28.2	63.7	31.8	66.2	56.86	108.94	36.1	69.2	38.8	71.4
Asia to-from Middle East/India	60.5	121.3	56.2	111.1	36.0	72.3	35.5	70.2	63.96	116.94	40.5	74.3	46.8	79.3
Asia to-from North America EC/Gulf	57.8	111.6	60.2	107.4	35.1	67.7	37.9	67.7	63.71	111.07	40.4	70.4	44.7	74.1
Asia to-from North America WC	64.1	121.7	67.1	116.5	38.0	72.2	42.2	73.3	71.02	120.05	45.0	76.0	46.7	76.8
Asia to-from North Europe	44.1	100.5	42.3	93.1	26.7	60.9	26.7	58.7	43.44	92.06	27.5	58.3	30.5	61.0
Asia to-from Oceania	88.4	149.2	86.4	138.6	53.5	90.4	54.8	87.9	89.41	141.51	56.9	90.1	58.9	91.3
Asia to-from South America (incl. Central America)	63.1	118.2	60.5	109.9	37.5	70.4	38.3	69.6	63.42	111.74	40.4	71.1	41.3	71.6
Europe (North and Med) to-from Africa	100.2	171.3	100.9	164.9	59.7	102.1	63.3	103.6	91.64	151.82	57.8	95.8	61.3	101.5
Europe (North and Med) to-from South America (incl. Central America)	68.8	126.2	67.4	121.2	41.9	77	42.4	76.4	77.53	132.48	48.9	83.6	48.6	83.4
Europe (North and Med) to-from Middle East/India	58.9	119.2	55.8	108.3	35.8	72.6	35.2	68.4	58.53	111.52	37.1	70.8	40.0	72.5
Europe (North and Med) to-from Oceania (via Suez/via Panama)	81.9	138.7	80.0	131.2	47.3	80.2	50.5	82.8	94.47	146.48	59.7	92.6	66.4	99.3
Mediterranean/Black Sea to-from North America EC/Gulf	77.1	139.2	80.1	136.6	46.1	83.4	50.1	85.4	89.08	143.93	55.9	90.4	61.4	96.2
Mediterranean/Black Sea to-from North America WC	71.9	129.9	77.8	134.4	44.3	79.9	48.7	84.1	96.53	153.89	60.8	96.9	51.8	84.2
North America EC/Gulf/WC to-from Africa	124.3	201.1	138.9	190.7	75.4	122.2	87.7	120.4	83.38	133.41	52.9	84.7	71.2	104.7
North America EC/Gulf/WC to-from Oceania	103.5	156.0	106.4	156.7	64.4	96.9	67.2	98.9	111.03	158.85	70.4	100.8	67.2	96.7
North America EC/Gulf/WC to-from South America (incl. Central America)	82.5	143.2	82.3	134.7	49.0	85	51.6	84.4	89.83	141.13	56.5	88.8	63.4	99.1
North America EC/Gulf/WC to-from Middle East/India	70.9	125.9	66.0	115.9	42.9	76.3	41.7	73.3	74.03	121.10	47.0	76.9	53.1	84.8
North Europe to-from North America EC/Gulf	84.5	144.4	86.9	141.1	50.7	86.6	53.8	87.4	88.82	141.05	55.2	87.7	60.4	92.6
North Europe to-from North America WC	75.9	134.2	64.0	117.5	43.6	77.1	40.0	73.4	70.58	122.85	43.6	75.9	58.4	88.7
South America (incl. Central America) to-from Africa	122.4	200.0	115.9	174.0	70.8	115.6	73.8	110.8	68.61	118.51	43.7	75.4	45	77.1
Intra Africa	127.1	219.0	118.3	201.2	76.0	131.4	75.1	127.8	115.66	186.91	73.1	118.1	79.7	130.3
Intra North America EC/Gulf/WC	177.6	241.8	143.2	203.3	109.8	149.2	89.3	126.6	118.24	175.82	73.9	109.8	117.2	154.7
Intra South America (incl. Central America)	103.9	177.0	103.1	169.9	62.4	106.7	65.4	107.7	112.15	181.26	71.4	115.4	72.4	114.6
SE Asia to-from NE Asia	84.0	148.4	91.3	150.6	50.1	88.8	57.6	95.0	94.49	154.50	60.2	98.4	60.2	95.1
Intra NE Asia	103.5	182.8	101.7	173.7	59.9	105.7	62.8	107.1	72.49	129.16	45.9	81.8	58.1	102.7
Intra SE Asia	112.5	194.2	102.6	176.8	66.9	115.5	64.9	111.8	109.33	178.90	69.7	114.1	74.3	118.5
North Europe to-from Mediterranean/Black Sea	95.8	160.1	98.8	158.0	56.7	95	61.4	98.3	103.29	163.00	63.3	99.6	63.1	99.7
Intra Mediterranean/Black Sea	134.3	239.4	128.3	220.6	79.3	141.5	80.4	138.3	100.17	174.27	62.9	109.5	88.6	148.0
Intra North Europe	138.4	221.6	139.8	221.4	81.3	130.5	82.4	130.7	98.34	162.69	57.5	95.9	87.1	133.9
Intra Middle East/India	108.9	197.1	95.9	171.6	66.6	120.5	61.1	109.4	96.72	169.48	61.6	108.0	59.7	105.3
Other	110.9	182.5	78.3	139.9	66.8	109.9	49.3	88.1	68.24	120.53	43.1	76.1	75.2	114.5
Fleet-Wide Average CO_2 Performance	**66.4**	**126.5**	**66.2**	**120.1**	**39.8**	**75.9**	**41.7**	**75.6**	**70.59**	**123.54**	**44.2**	**77.5**	**47.2**	**80.1**
	"Dry" = non-refrigerated cargo; "Reefer" = refrigerated cargo; "TEU" = twenty-foot equivalent unit. used to describe capacity of container vessels; "UF" = Utilization Factor; "WTW": Well-to-Wheel; "TTW": Tank-to-Wheel													

Table 2 CO2 emission report, World stainless, scope3 emission different scrap [25]



Scope 1 emissions		0.38
Scope 2 emissions		0.45
Scope 3 emissions	85 % scrap	1.25
	75 % scrap	1.59
	50 % scrap	2.45
	30 % scrap	5.99
Total CO_2 emissions (ton CO_2) / ton stainless steel	85 % scrap	2.08
	75 % scrap	2.42
	50 % scrap	3.28
	30 % scrap	6.82
Carbon steel CO_2 emissions		1.91

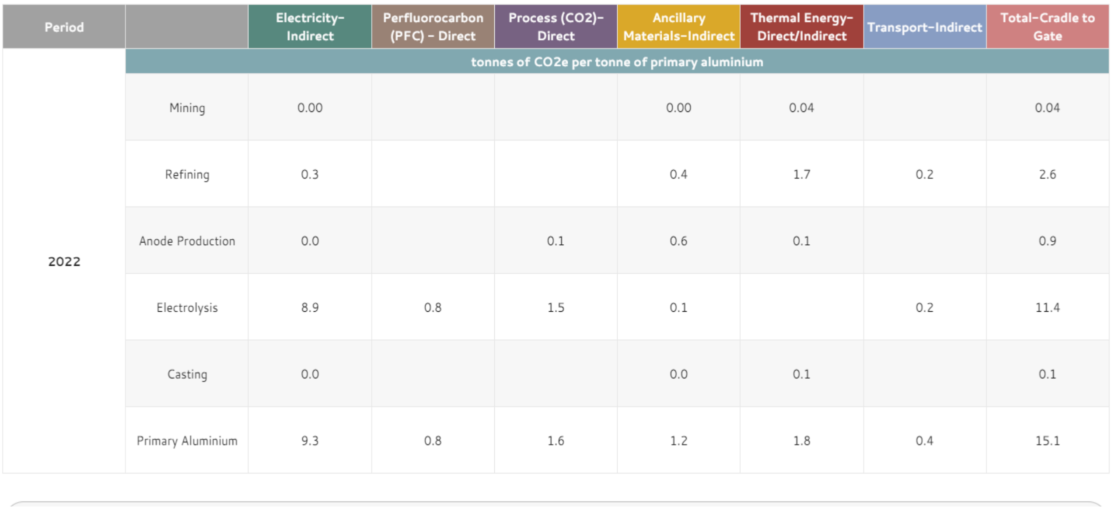
Table 3 Aluminium components, EU production, world average recycled content [26]



European consumption - Includes European production and imports - At world average recycled content

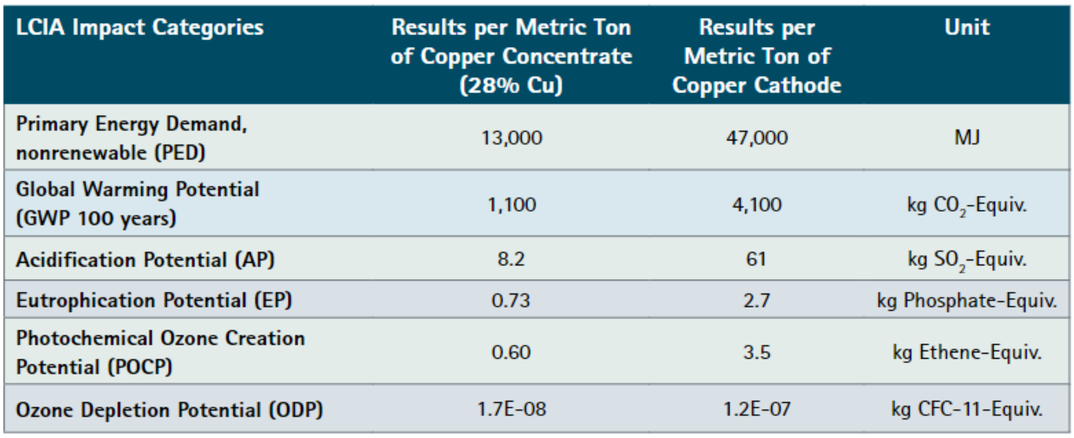
Materials	Embodied Carbon - kgCO2e/kg	Comments
Aluminium General, European Mix, Inc Imports	6.67	This data has been derived from the world aluminium LCA's. They have produced LCA reports for Europe, North America and worldwide aluminium. Modelled at worldwide average scrap input of 31%, to avoid market distortions. Modelled with 25.6% extrusions, 55.7% rolled and 18.7% castings. Based upon European production and the import of aluminium consumed in Europe. Module D = -3.13 kg CO2e per unit. EOL recovery rate of 95%, based upon DU Telft study of European construction sector. With a 2% material loss yield on the scrap recovered.
Aluminium sheet, European Mix, Inc Imports	6.58	This data has been derived from the world aluminium LCA's. They have produced LCA reports for Europe, North America and worldwide aluminium. Modelled at worldwide average scrap input of 31%, to avoid market distortions. Based upon European production and the import of aluminium consumed in Europe. Module D = -3.09 kg CO2e per unit. EOL recovery rate of 95%, based upon DU Telft study of European construction sector. With a 2% material loss yield on the scrap recovered.
Aluminium foil, European Mix, Inc Imports	7.47	This data has been derived from the world aluminium LCA's. They have produced LCA reports for Europe, North America and worldwide aluminium. Modelled at worldwide average scrap input of 31%, to avoid market distortions. Based upon European production and the import of aluminium consumed in Europe. Module D = -3.54 kg CO2e per unit. EOL recovery rate of 95%, based upon DU Telft study of European construction sector. With a 2% material loss yield on the scrap recovered.
Aluminium extruded profile, European Mix, Inc Imports	6.83	This data has been derived from the world aluminium LCA's. They have produced LCA reports for Europe, North America and worldwide aluminium. Modelled at worldwide average scrap input of 31%, to avoid market distortions. Based upon European production and the import of aluminium consumed in Europe. Module D = -3.21 kg CO2e per unit. EOL recovery rate of 95%, based upon DU Telft study of European construction sector. With a 2% material loss yield on the scrap recovered.
Aluminium, cast, European Mix, Inc Imports	6.72	This data has been derived from the world aluminium LCA's. They have produced LCA reports for Europe, North America and worldwide aluminium. Modelled at worldwide average scrap input of 31%, to avoid market distortions. Based upon European production and the import of aluminium consumed in Europe. Module D = -3.12 kg CO2e per unit. EOL recovery rate of 83%, based upon worldwide global aluminium flow model and for the building and construction sector. With a 2% material loss yield on the scrap recovered.

Table 4 Greenhouse Gas Emissions Intensity- Primary Aluminium, November 2023.[26]



Period		Electricity-Indirect	Perfluorocarbon (PFC) - Direct	Process (CO_2)-Direct	Ancillary Materials-Indirect	Thermal Energy-Direct/Indirect	Transport-Indirect	Total-Cradle to Gate
		tonnes of CO2e per tonne of primary aluminium						
2022	Mining	0.00			0.00	0.04		0.04
	Refining	0.3			0.4	1.7	0.2	2.6
	Anode Production	0.0		0.1	0.6	0.1		0.9
	Electrolysis	8.9	0.8	1.5	0.1		0.2	11.4
	Casting	0.0			0.0	0.1		0.1
	Primary Aluminium	9.3	0.8	1.6	1.2	1.8	0.4	15.1

Table 5 Copper Environmental Profile, International Copper Association [27]

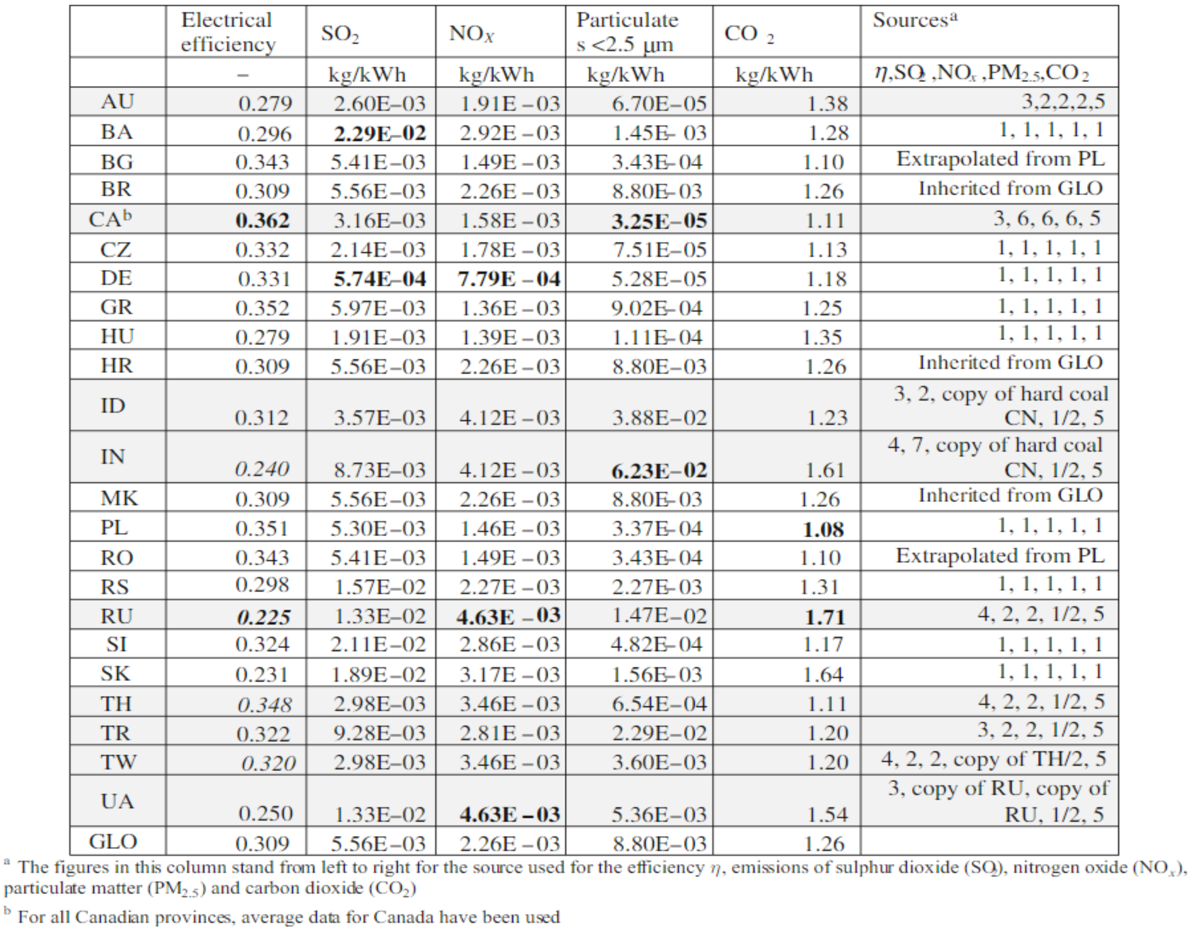


LCIA Impact Categories	Results per Metric Ton of Copper Concentrate (28% Cu)	Results per Metric Ton of Copper Cathode	Unit
Primary Energy Demand, nonrenewable (PED)	13,000	47,000	MJ
Global Warming Potential (GWP 100 years)	1,100	4,100	kg CO_2-Equiv.
Acidification Potential (AP)	8.2	61	kg SO_2-Equiv.
Eutrophication Potential (EP)	0.73	2.7	kg Phosphate-Equiv.
Photochemical Ozone Creation Potential (POCP)	0.60	3.5	kg Ethene-Equiv.
Ozone Depletion Potential (ODP)	1.7E-08	1.2E-07	kg CFC-11-Equiv.

Table 6 Hard coal power plants, electricity generation.[28]

		Electrical efficiency	SO_2	NO_x	Particulates <2.5 µm	CO_2	Sources [a]
		–	kg/kWh	kg/kWh	kg/kWh	kg/kWh	η,SO_2,NO_x, $PM_{2.5}$,CO_2
Austria	AT	**0.404**	**4.12E−04**	5.46E−04	2.42E−05	0.838	1, 1, 1, 1, 1
Australia	AU	0.310	3.58E−03	2.55E−03	6.78E−05	1.109	3, 2, 2, 1/2, 5
Bosnia and Herzegovina	BA	0.322	6.06E−03	3.04E−03	3.32E−04	1.057	Inherited from GLO
Belgium	BE	0.360	3.47E−03	1.57E−03	2.06E−04	0.948	1, 1, 1, 1, 1
Bulgaria	BG	0.332	6.06E−03	3.04E−03	3.32E−04	1.057	Inherited from GLO
Brazil	BR	0.332	4.72E−03	1.87E−03	2.24E−04	1.004	Copy of PL
Canada	CA[b]	0.378	6.94E−03	1.90E−03	7.60E−05	0.910	3, 6, 6, 6, 5
Chile	CL	0.335	4.12E−03	4.85E−03	**1.59E−02**	1.061	4, 2, 2, 1/2, 5
China	CN	0.357	7.81E−03	4.12E−03	4.27E−04	0.960	1, 1, 1, 1, 1
Czech Republic	CZ	0.294	6.39E−04	1.87E−03	5.84E−05	1.135	1, 1, 1, 1, 1
Germany	DE	0.359	6.56E−04	6.21E−04	4.73E−05	0.922	1, 1, 1, 1, 1
Denmark	DK	0.350	1.13E−03	**5.31E−04**	2.36E−05	**0.814**	Copy of NORDEL v2
Spain	ES	0.358	7.31E−03	3.62E−03	4.85E−04	0.960	1, 1, 1, 1, 1
Finland	FI	0.350	1.13E−03	**5.31E−04**	2.36E−05	**0.814**	Copy of NORDEL v2
France	FR	0.355	4.54E−03	1.96E−03	2.44E−04	0.949	1, 1, 1, 1, 1
Great Britain	GB	0.333	4.72E−03	1.87E−03	2.24E−04	1.004	Copy of PL
Croatia	HR	0.355	2.53E−03	2.87E−03	1.24E−04	0.949	1, 1, 1, 1, 1
Hungary	HU	0.333	4.72E−03	1.87E−03	2.24E−04	1.004	Copy of PL
Ireland	IE	0.333	4.72E−03	1.87E−03	2.24E−04	1.004	Copy of PL
India	IN	*0.239*	7.19E−03	4.12E−03	4.27E−04	1.439	4, 7, copy of CN, copy of CN, 5
Italy	IT	0.373	3.78E−03	1.89E−03	2.36E−04	0.907	1, 1, 1, 1, 1
Japan	JP	0.360	3.47E−03	1.57E−03	2.06E−04	0.948	Copy of BE
South Korea	KR	0.358	5.22E−04	2.55E−03	**1.28E−05**	0.960	3, 2, copy of AU, 1/2, 5

Table 7 Lignite power plants, electricity generation [28]

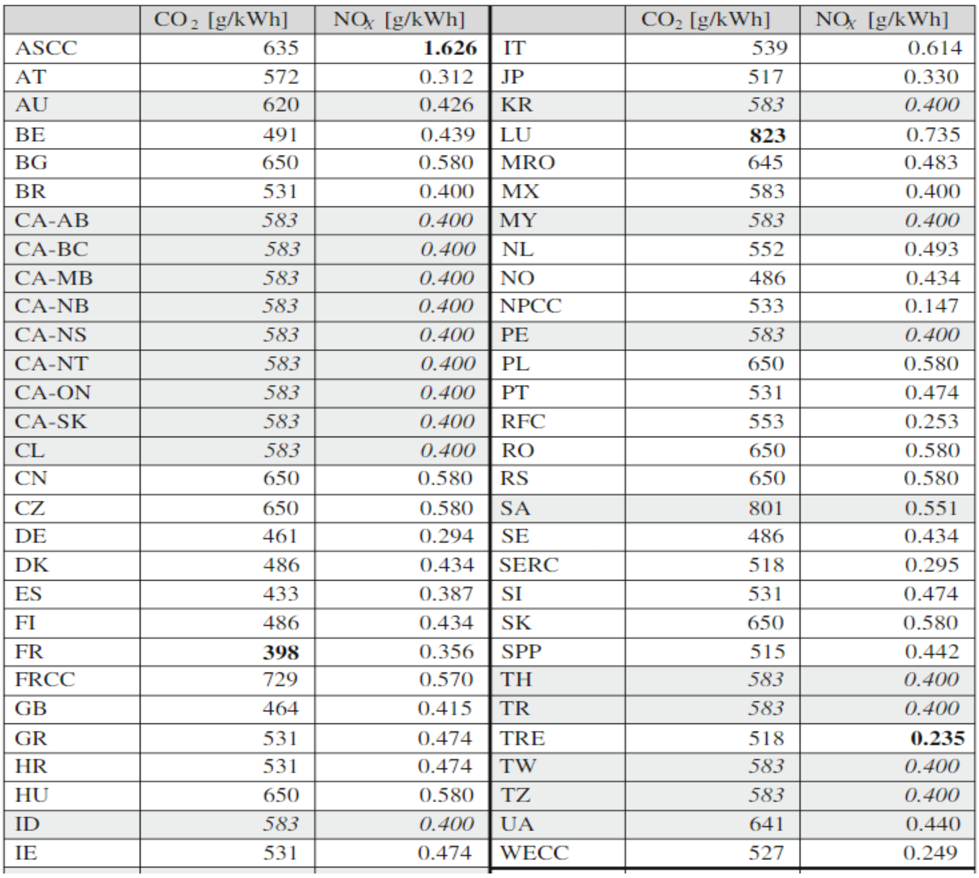


	Electrical efficiency	SO_2	NO_X	Particulates <2.5 μm	CO_2	Sources[a]
	–	kg/kWh	kg/kWh	kg/kWh	kg/kWh	η, SO_2, NO_x, $PM_{2.5}$, CO_2
AU	0.279	2.60E–03	1.91E–03	6.70E–05	1.38	3,2,2,2,5
BA	0.296	**2.29E–02**	2.92E–03	1.45E–03	1.28	1, 1, 1, 1, 1
BG	0.343	5.41E–03	1.49E–03	3.43E–04	1.10	Extrapolated from PL
BR	0.309	5.56E–03	2.26E–03	8.80E–03	1.26	Inherited from GLO
CA[b]	**0.362**	3.16E–03	1.58E–03	**3.25E–05**	1.11	3, 6, 6, 6, 5
CZ	0.332	2.14E–03	1.78E–03	7.51E–05	1.13	1, 1, 1, 1, 1
DE	0.331	**5.74E–04**	**7.79E–04**	5.28E–05	1.18	1, 1, 1, 1, 1
GR	0.352	5.97E–03	1.36E–03	9.02E–04	1.25	1, 1, 1, 1, 1
HU	0.279	1.91E–03	1.39E–03	1.11E–04	1.35	1, 1, 1, 1, 1
HR	0.309	5.56E–03	2.26E–03	8.80E–03	1.26	Inherited from GLO
ID	0.312	3.57E–03	4.12E–03	3.88E–02	1.23	3, 2, copy of hard coal CN, 1/2, 5
IN	*0.240*	8.73E–03	4.12E–03	**6.23E–02**	1.61	4, 7, copy of hard coal CN, 1/2, 5
MK	0.309	5.56E–03	2.26E–03	8.80E–03	1.26	Inherited from GLO
PL	0.351	5.30E–03	1.46E–03	3.37E–04	**1.08**	1, 1, 1, 1, 1
RO	0.343	5.41E–03	1.49E–03	3.43E–04	1.10	Extrapolated from PL
RS	0.298	1.57E–02	2.27E–03	2.27E–03	1.31	1, 1, 1, 1, 1
RU	***0.225***	1.33E–02	**4.63E–03**	1.47E–02	**1.71**	4, 2, 2, 1/2, 5
SI	0.324	2.11E–02	2.86E–03	4.82E–04	1.17	1, 1, 1, 1, 1
SK	0.231	1.89E–02	3.17E–03	1.56E–03	1.64	1, 1, 1, 1, 1
TH	*0.348*	2.98E–03	3.46E–03	6.54E–04	1.11	4, 2, 2, 1/2, 5
TR	0.322	9.28E–03	2.81E–03	2.29E–02	1.20	3, 2, 2, 1/2, 5
TW	*0.320*	2.98E–03	3.46E–03	3.60E–03	1.20	4, 2, 2, copy of TH/2, 5
UA	0.250	1.33E–02	**4.63E–03**	5.36E–03	1.54	3, copy of RU, copy of RU, 1/2, 5
GLO	0.309	5.56E–03	2.26E–03	8.80E–03	1.26	

[a] The figures in this column stand from left to right for the source used for the efficiency η, emissions of sulphur dioxide (SO_2), nitrogen oxide (NO_x), particulate matter ($PM_{2.5}$) and carbon dioxide (CO_2)

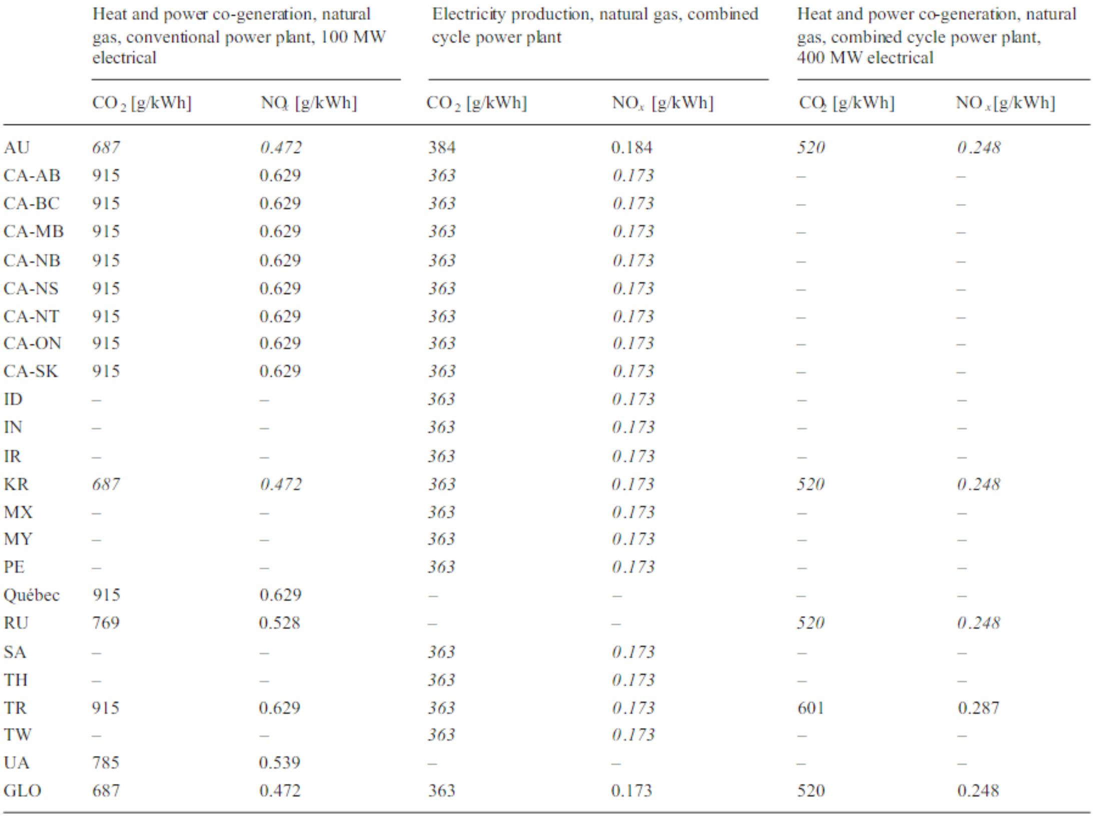
[b] For all Canadian provinces, average data for Canada have been used

Table 8 Key direct emission factors for CO2and NOx from all four-power plant types of global market [28]

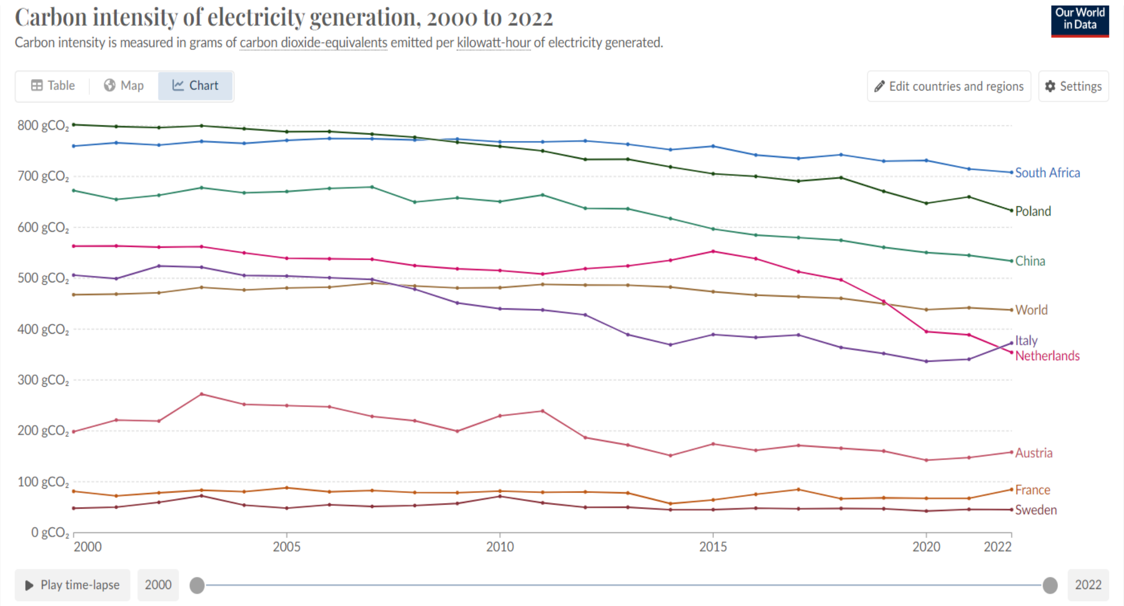


	CO$_2$ [g/kWh]	NO$_X$ [g/kWh]		CO$_2$ [g/kWh]	NO$_X$ [g/kWh]
ASCC	635	**1.626**	IT	539	0.614
AT	572	0.312	JP	517	0.330
AU	620	0.426	KR	*583*	*0.400*
BE	491	0.439	LU	**823**	0.735
BG	650	0.580	MRO	645	0.483
BR	531	0.400	MX	583	0.400
CA-AB	*583*	*0.400*	MY	*583*	*0.400*
CA-BC	*583*	*0.400*	NL	552	0.493
CA-MB	*583*	*0.400*	NO	486	0.434
CA-NB	*583*	*0.400*	NPCC	533	0.147
CA-NS	*583*	*0.400*	PE	*583*	*0.400*
CA-NT	*583*	*0.400*	PL	650	0.580
CA-ON	*583*	*0.400*	PT	531	0.474
CA-SK	*583*	*0.400*	RFC	553	0.253
CL	*583*	*0.400*	RO	650	0.580
CN	650	0.580	RS	650	0.580
CZ	650	0.580	SA	801	0.551
DE	461	0.294	SE	486	0.434
DK	486	0.434	SERC	518	0.295
ES	433	0.387	SI	531	0.474
FI	486	0.434	SK	650	0.580
FR	**398**	0.356	SPP	515	0.442
FRCC	729	0.570	TH	*583*	*0.400*
GB	464	0.415	TR	*583*	*0.400*
GR	531	0.474	TRE	518	**0.235**
HR	531	0.474	TW	*583*	*0.400*
HU	650	0.580	TZ	*583*	*0.400*
ID	*583*	*0.400*	UA	641	0.440
IE	531	0.474	WECC	527	0.249

Table 9 Key direction Ef in conventional natural gas power plants with CHP [28]



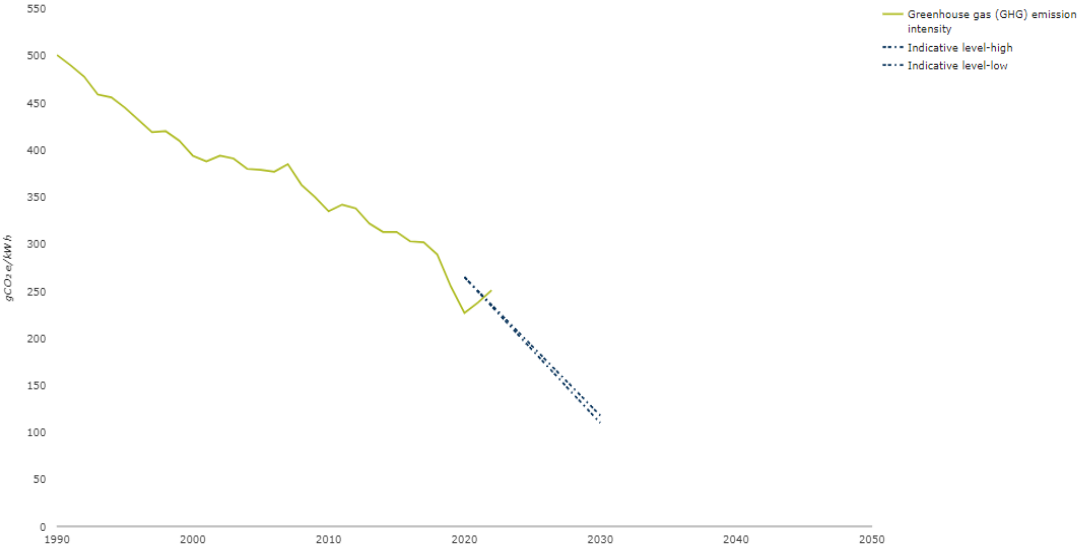
	Heat and power co-generation, natural gas, conventional power plant, 100 MW electrical		Electricity production, natural gas, combined cycle power plant		Heat and power co-generation, natural gas, combined cycle power plant, 400 MW electrical	
	CO$_2$ [g/kWh]	NO$_x$ [g/kWh]	CO$_2$ [g/kWh]	NO$_x$ [g/kWh]	CO$_2$ [g/kWh]	NO$_x$ [g/kWh]
AU	*687*	*0.472*	384	0.184	*520*	*0.248*
CA-AB	915	0.629	*363*	*0.173*	–	–
CA-BC	915	0.629	*363*	*0.173*	–	–
CA-MB	915	0.629	*363*	*0.173*	–	–
CA-NB	915	0.629	*363*	*0.173*	–	–
CA-NS	915	0.629	*363*	*0.173*	–	–
CA-NT	915	0.629	*363*	*0.173*	–	–
CA-ON	915	0.629	*363*	*0.173*	–	–
CA-SK	915	0.629	*363*	*0.173*	–	–
ID	–	–	*363*	*0.173*	–	–
IN	–	–	*363*	*0.173*	–	–
IR	–	–	*363*	*0.173*	–	–
KR	*687*	*0.472*	*363*	*0.173*	*520*	*0.248*
MX	–	–	*363*	*0.173*	–	–
MY	–	–	*363*	*0.173*	–	–
PE	–	–	*363*	*0.173*	–	–
Québec	915	0.629	–	–	–	–
RU	769	0.528	–	–	*520*	*0.248*
SA	–	–	*363*	*0.173*	–	–
TH	–	–	*363*	*0.173*	–	–
TR	915	0.629	*363*	*0.173*	601	0.287
TW	–	–	*363*	*0.173*	–	–
UA	785	0.539	–	–	–	–
GLO	687	0.472	363	0.173	520	0.248



Carbon intensity of electricity generation, 2000 to 2022

Carbon intensity is measured in grams of carbon dioxide-equivalents emitted per kilowatt-hour of electricity generated.

Figure 1 Ember - Yearly Electricity Data (2023); Ember - European Electricity Review (2022); Energy Institute.[29]



Year	Member State	Greenhouse gas (GHG) emission intensity	Greenhouse gas (GHG) emission intensity	Indicative level-high	Indicative level-low
2020	EU-27			265	265
2030	EU-27			118	110

Figure 2 GHG emission of electricity generation [30]