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CARBON FOOTPRINT CALCULATOR FOR PRODUCT STRUCTURE DATA

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THESIS
Abstract

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Abstract

This thesis was a practical project that developed a functional tool designed to calculate the carbon footprint based on the structure of the product. To create this calculator, extensive research was needed to establish a comprehensive knowledge base. The purpose of this project was to help the client company have a truthful display of their products' carbon footprint.

The project began with an exploration of the concept of carbon footprint, its relationship with products, and the existing standards and formulas used to calculate CO_2 emissions. The cradle-to-gate approach was chosen from the product's life cycle. This approach made it easier to have, more accurate and efficient calculation of a product's carbon footprint. The primary factors that influence the products' carbon footprint are components, production, transport, storage, packaging, marketing, sales, research, and development. An Excel spreadsheet was created to catalog all the components and necessary information for calculating CO_2 emissions. This spreadsheet was then used in conjunction with the products structure to create a comprehensive table that serves as both a data source and a repository for results. Once the calculations were done and all Excel tables were created the data was imported into a Power Bi dashboard for easy visualization and interpretation. During the software development process, emphasis was placed on clean, understandable, and efficient code to facilitate future upgrades and improvements. During the testing phase of the calculator, it was determined that most of a product's carbon footprint results from the components and transport footprint.

As a result of this thesis, a software tool was developed that can calculate the CO2 values of the product and visualize those results. During the software development process, the focus was on producing clean, understandable, and efficient code to facilitate future upgrades and improvements. The testing phase revealed that a products' carbon footprint was most significantly influenced by the components used and transport requirements. Thus, this tool was designed to assist companies in making more environmentally conscious decisions in these critical areas.

ACKNOWLEDGMENTS

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1   INTRODUCTION

1.1   Background and motivation

In today's world, the urgency of addressing climate change and reducing greenhouse gas emissions "GHG" has become a global priority. Companies across various industries are taking steps to access and minimize their environmental impact. As part of these efforts, understanding the products' footprint from their structure to get as accurate as possible view has become increasingly important.

A product's carbon footprint refers to the total amount of GHG emissions generated throughout its life cycle, from raw material extraction to disposal. In this context, the development of carbon footprint calculators are instrumental in helping companies make informed decisions regarding sustainable methods of production.

This thesis aims to develop a carbon footprint calculator specifically tailored for the products of the company that has requested the project. The calculator will enable the company to assess the environmental impact arising from the products' structure and method of production. By doing so it will ultimately help them to monitor and reduce their carbon footprint and communicate their efforts to consumers and stakeholders.

Calculating the products' footprint based on the products structure will require getting an extensive knowledge on the products components, production process as well as company infrastructure. Contracting another company to do this process would complicate it and make it difficult to do a tailor made product in a short amount of time without endangering sensitive information and accuracy. This fact makes it necessary for the company to build an in-house calculator.

At the start of this project, it was known that the information related to it were scarce but the research had to be done and calculator build even if everything started from scratch. This is a first for the company when it comes to using the product structure to calculate in detail the carbon footprint.

1.2   Research objectives

The primary objective of this thesis is to develop and implement a carbon footprint calculation tool for the company's product portfolio. To achieve this objective, several specific research objectives have been identified.

Firstly, a comprehensive review of the existing literature on carbon footprint and Life Cycle Assessment (LCA) methodologies will be conducted, with a particular focus on the company's product type. This review will provide the necessary theoretical foundation and knowledge for the subsequent stages of the research.

Secondly, an overview of available carbon footprint calculators, with a specific emphasis on the applicability of these tools to the company's needs. This analysis will help create a framework for the calculator and its features.

Thirdly, a calculation method and software tool will be developed that can accurately calculate the carbon footprint based on the product structure. This tool will be developed with a focus on ease of use and flexibility to ensure that it can be integrated into the company's existing infrastructure.

Fourthly, the developed tool will be used to calculate the carbon footprint for the company's product portfolio. This will provide a baseline measurement of the company's carbon emissions and enable the identification of areas where reductions can be made.

Finally, the developed calculation tool will be integrated into the company's infrastructure to enable the ongoing monitoring and management of carbon emissions. This will ensure that the company can track its progress in reducing its carbon footprint over time and adjust its processes and products where necessary.

In summary, this thesis aims to create and implement a carbon footprint calculation tool for a company's product portfolio, facilitating continuous monitoring and management of emissions. This will contribute to the company's sustainability goals and global climate change mitigation efforts.

1.3 Scope and limitations

The scope of this study is primarily focused on creating a carbon footprint calculation tool for the company's products. The intended users of this tool will include the company's management, product developers, and sustainability teams, who will use it to gain a better understanding of the impact of various factors on the product's carbon footprint, including the product structure, production methods, and infrastructure.

The development of this tool will enable the company to calculate its carbon emissions and identify areas where improvements can be made more accurately. The tool will also provide means for the company to monitor its progress in reducing its carbon footprint over time and make data-driven decisions to drive sustainability improvements. Overall, the scope of this study is focused on developing practical and effective carbon footprint calculation tools that will enable the company to make informed decisions and drive improvements in its sustainability performance.

While the primary objective of this research is to develop a comprehensive and versatile carbon footprint calculation tool, it is important to acknowledge that certain limitations may arise. These limitations may include constraints on data availability, the complexity of supply chains, the integration tool into the company's infrastructure, and variations in regional regulations and practices.

To ensure a thorough and rigorous analysis, this thesis will explore these limitations and their potential implications on the accuracy and applicability of the developed calculator. Specifically, the research will discuss how these limitations may impact the precision and reliability of the tool's outputs and how they may affect the tool's overall usefulness for the company's sustainability efforts. By acknowledging and addressing these limitations, the research aims to provide a complete understanding of the potential benefits and challenges associated with the use of a carbon footprint calculation tool for product assessment and management.

2   LITERATURE REVIEW

2.1   Carbon footprint calculation approaches

2.1.1 Life cycle assessment (LCA)

Life Cycle Assessment (LCA) is a systematic method to quantify the environmental impacts associated with a product, process, or service throughout its entire life cycle (ISO 14040 2006). LCA evaluates the environmental burdens associated with a product or service from raw material extraction to end-of-life disposal (Crawford 2011). Figure 1 shows the life cycle assessment stages diagram.
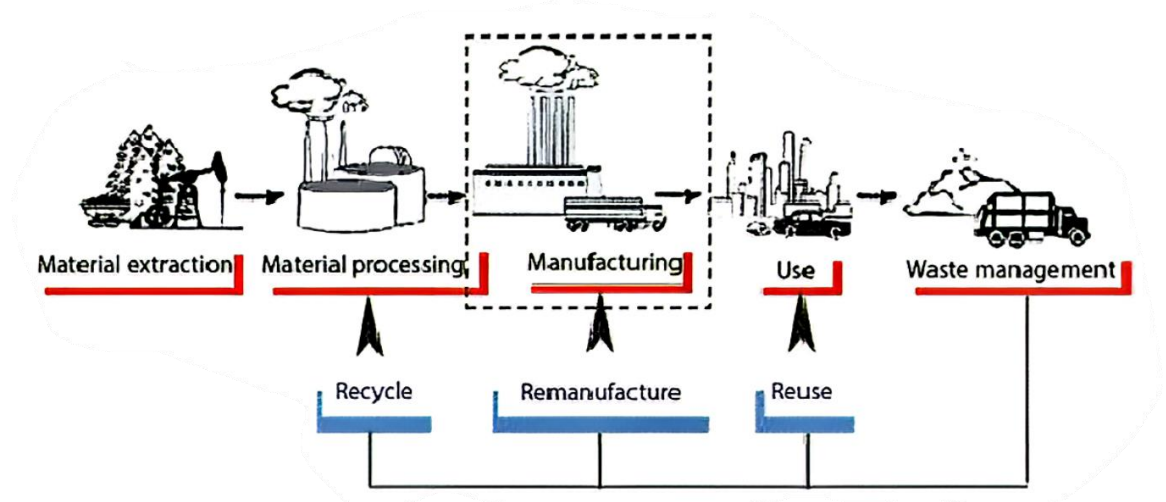
Figure 1. Life cycle assessment stages diagram (Curran & Mary Ann LCA student Handbook 2015)

One the most important qualities of LCA is the fact that it can identify the transfer of environmental impacts from one media to another and from one cycle to another (Curran & Mary Ann 2015). This quality of LCA was used to do the division of factor emissions on this project and to keep track of all the factors that affected the products.

2.1.2 Greenhouse gas protocol

The Greenhouse Gas Protocol (GHGP), a widely used international accounting tool for quantifying and managing GHG emissions, was developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WRI & WBCSD 2004). As per the product life cycle standard developed by WRI for developing sustainable products, certain skills are essential, which include defining the scope of a product lifecycle, identifying the life cycle stages to include in the inventory, understanding the difference between a cradle-to-gate and cradle-to-grave inventory, collecting data, assessing data quality, and credibly reporting performance to stakeholders.

Given the importance of these skills, it is crucial for this thesis to remain mindful of them throughout the research process. By doing so, this study aims to develop a comprehensive and effective carbon footprint calculation tool that adheres to the WRI's product life cycle standard and promotes sustainable product development practices.

2.1.3 Input-output analysis

Input-output analysis provides a means to understand the intricate interconnections within an economy by illustrating how alterations in one sector can induce changes in another. (Leontief 1986). It is particularly useful in estimating the carbon footprint of products or services, as it examines the flows of goods and services between industries and their associated GHG emissions. (Lenzen 2001.)

The input-output analysis process utilizes a Leontief matrix to explore the exchange of goods and services across economic sectors. This process commences with the construction of an input-output table, succeeded by data collection on sectoral purchases and sales. A key component of this process is the calculation of technical coefficients, which indicate the amount of input required from one sector to produce a unit of output in another sector. These coefficients aid in estimating changes in demand for sector outputs. This iterative procedure continues until output changes become negligible, revealing the interdependencies among sectors, the impacts of demand alterations, and the contributions of different sectors to the economy.

In this project, a similar approach was adopted to identify the emission factors that contribute to the carbon footprint of products. The input-output analysis principles were applied to trace emissions' flow throughout the production process, thereby providing a comprehensive view of the products' environmental impact.

2.1.4 Cradle-to-gate approach

The cradle-to-gate approach is a partial LCA that evaluates the environmental impacts of a product or service from raw material extraction up to the point when the product leaves the production facility (i.e., the "gate"). It excludes the use phase and end-of-life disposal, focusing on the impacts associated with the production process. The cradle to gate approach offers the opportunity to be very fast and accurate in the calculations since the information that there is for a products cradle to gate phase is a lot more, is accurate and easier to find than if the cradle to grave approach is taken. This will make the software less complicated, smaller, and more efficient. If later more information is required to be included in the calculation gate to grave part can be calculated separately. The products for which the calculations are being done are built to last a long time, many years into the future. This feature makes the cradle-to gate the favorite approach.(Mary Ann Curran 2012.)

2.1.5 Cut-off rules

In the context of Life Cycle Assessment (LCA), cut-off rules are used to determine which processes, materials, or emissions should be included or excluded from the scope of the assessment. Cut-off rules are important for simplifying the LCA by reducing complexity and ensuring that the analysis focuses on the most significant aspects of the product or system being evaluated (Baumann & Tillman 2004).

Cut-off rules can be based on several factors, such as mass, energy, environmental impact, and economic value. However, it is essential to apply these rules with caution as arbitrary thresholds may lead to incomplete or biased results. Therefore, the choice of cut-off rules should be docu-

mented and justified in the LCA report, and any potential implications for the assessment's conclusions should be discussed. Additionally, sensitivity analysis can be used to evaluate the impact of different cut-off rules on the LCA results to ensure the robustness of the analysis (Guinée et al. 2011).

Process optimization is an effective strategy for reducing emissions, energy consumption, and waste by identifying inefficiencies in production processes and implementing improvements. This may involve the use of lean production principles, automation, or other process improvement techniques (Kurdve et al. 2015).

Waste management and recycling practices are also crucial for reducing environmental impacts. But since this project focuses in cradle to gate approach it will go more in depth in that direction.

Overall, these strategies can help promote sustainable production and consumption practices, reduce environmental impacts, and facilitate the development of more sustainable products and systems.

2.2 Emission factors and allocation methods

2.2.1 Emission factors: sources and calculation methods

Emission Factors and Allocation Methods play a critical role in carbon footprint calculations, as they allow for the estimation of greenhouse gas (GHG) emissions associated with various processes and the distribution of these emissions among different products or services.

To accurately calculate a product's total carbon footprint, it is crucial to understand the environmental impacts of printed circuit boards (PCBs) Kanth et al. (2011a) conducted a life cycle assessment of printed antennas and analyzed their comparative environmental impacts. Their study found that the materials and production processes used in printed antennas significantly contribute to their overall carbon footprint. In another study, Kanth et al. (2011b) highlighted the need for careful consideration of PCBs when determining a product's carbon footprint, emphasizing the importance of quantitative environmental emission analysis. Additionally, Kanth et al. (2012) quantified the environmental footprint of rigid substrate printed antennas, providing valuable data for assessing the environmental impact of this specific component.

By considering the environmental impacts of components such as PCBs, carbon footprint calculations can be made more accurate and comprehensive. Such insights can guide the development of strategies and interventions to reduce the carbon footprint of products and promote sustainability across the entire value chain.

Emission factors are coefficients that represent the amount of GHG emissions released per unit of activity, such as per kilowatt-hour of electricity produced or per kilometer driven. They are used to convert the quantity of a specific activity into the associated GHG emissions.

Emission factors can be sourced from various organizations, such as the Intergovernmental Panel on Climate Change (IPCC), national governments, or industry-specific databases (IPCC 2006). The

appropriate emission factors units should be selected or converted to base on the information available for a product in a company.

2.2.2 Allocation methods: process-based, economic, and hybrid approaches

Allocation methods are used in Life Cycle Assessment (LCA) to distribute the environmental impacts, including greenhouse gas (GHG) emissions, among multiple products or services that share common inputs, processes, or resources (ISO 14044 2006). Three primary allocation approaches are process-based allocation, economic allocation, and system expansion.

Process-based allocation assigns emissions to individual products or services based on the specific processes used in their production (Frischknecht et al. 2007). Economic allocation distributes emissions based on the economic value of the products or services, considering factors such as market prices or production costs. System expansion accounts for the potential environmental impacts that may arise due to increased demand for products or services because of the production process. (Ekvall & Weidema 2004).

Applying appropriate methods in LCA can result in more accurate environmental impact assessments of products and services (ISO 14044 2006). This can help promote sustainable production practices and contribute to mitigating climate change. In the current case the process-based allocation method will be used to distribute the environmental impacts.

2.3 Facility and process evaluation

Facility and process evaluation is an essential aspect of assessing the environmental impact of tech products. This involves analyzing the manufacturing facilities and various processes involved in creating the product, from raw material extraction to production, assembly, and disposal. The goal is to identify opportunities for reducing energy consumption, emissions, and waste while improving efficiency and sustainability. Key elements of facility and process evaluation include:

Energy consumption: Analyzing energy use patterns in manufacturing facilities can help identify inefficiencies and opportunities for improvement. This may involve monitoring energy consumption by various processes, equipment, and systems (Sorrell et al. 2010).

Process optimization: Identifying inefficiencies in manufacturing processes and implementing improvements can lead to reduced emissions, energy consumption, and waste. This can involve the use of lean manufacturing principles, automation, or other process improvement techniques (Kurdve et al. 2015).

2.4 Existing carbon footprint calculators: an overview

Existing carbon footprint calculators offer a variety of methods to estimate the greenhouse gas (GHG) emissions associated with different products, services, and activities. These tools can be web-based or software applications, and they are designed for various users, such as individuals, businesses, and organizations. Some of the widely used carbon footprint calculators are:

GHG Protocol Corporate is a widely used standard for calculating corporate GHG emissions, which offers a comprehensive framework for businesses to measure, manage, and report their emissions

consistently (World Resources Institute & World Business Council for Sustainable Development 2004.

SimaPro is a Life Cycle Assessment (LCA) software that enables users to calculate the environmental impacts of products and services throughout their life cycle. It offers a compare. (SimaPro 2023)

Ecoinvent is a widely recognized LCA database that provides emission factors and life cycle inventory data for a wide range of products, services, and processes. It can be used in conjunction with various LCA tools to estimate the carbon footprint of products and services. This database is a great tool to be used as a source of data for the calculation of CO_2 for this project. (Ecoinvent 2023)

2.5 Relevant standards

ISO 14067 This international standard provides guidelines for the quantification and communication of the carbon footprint of products. It covers life cycle assessment requirements, data collection, and communication of results. The company can use this standard to assess and report the carbon footprint of their products. (ISO 14067:2018)

3 METHODOLOGY

3.1 System boundaries and cut-off criteria

3.1.1 Cradle-to-gate approach

This calculator employs a modified cradle-to-gate approach within the LCA framework to estimate the carbon footprint of the product (Leontief 1986; IPCC 2006). The modification is necessary because comprehensive information on factors affecting the product's carbon footprint is scarce, and the

calculations involved can be both time-consuming and complex (Ekvall & Weidema 2004).

To address this issue, CO_2 values for each component will be obtained from suppliers, consultants, and various online databases. These CO_2 values will encompass all factors influencing the CO_2 impact of the components, and this value will be referred to as Source CO_2.

3.1.2 Cut-off rules

As discussed in the Literature Review, it is essential to establish clear criteria to determine the processes, emission factors, or data that should be included or excluded from the scope of the carbon footprint assessment (ISO 14040 2006; ISO 14044 2006). To this end, the following cut-off rules have been established for this study:

First, the source CO_2 emissions of components will not be calculated but obtained from suppliers, consultants, or derived from similar components with known CO_2 values.

Second, the CO_2 emissions generated by employees involved in the product's production will be approximated based on their working hours and a predetermined coefficient.

Third, elements that have minimal impact on the product's carbon footprint but are difficult to calculate will be omitted. However, the total impact of these elements may be accounted for in other approximations during the calculations.

Fourth, the CO_2 emissions resulting from the consumption of tools used during production and storage of components and parts will be excluded since their impact is negligible.

Fiftht, CO_2 emissions from electricity will be assumed to be zero since they come from renewable sources. It is true that even renewable sources emit a small quantity of CO_2, but the percentage that trickles down to the product is insignificant. Finally, the CO_2 emissions resulting from the period of research and development, sales, and advertisement of the product will be approximated based on the hours used and a coefficient. They will not be calculated in detail since these elements have a marginal effect on the product's carbon footprint.

The application of these cut-off rules will help simplify the carbon footprint assessment by reducing complexity and focusing on the most significant aspects of the product's production. The selection of these cut-off rules will be documented and justified in the report, and their potential implications for the conclusions of the assessment will be discussed.

3.2   CO$_2$ emission factors and assumptions

After defining the scope and establishing the cut-off rules, identifying the main emission factors is a critical step in calculating a product's carbon footprint Emission factors refer to the activities or processes that contribute to greenhouse gas (GHG) emissions during the product's life cycle. (Frischknecht et al. 2004).

To facilitate this process, in this project the emission factors can be categorized into six groups, namely: components, production, storage, packaging, transport, and research and development (R&D), marketing, and sales.

The components group includes the materials used in the product, while the production group covers the energy consumed during production. Storage refers to the energy used to keep the product in storage, while packaging includes the materials used to package the product. Transport covers the GHG emissions associated with the transportation of the product from the manufacturing site to the end-user. Finally, the R&D, marketing, and sales group covers the GHG emissions associated with the development, marketing, and sale of the product. Figure 2 illustrates a schematic representation of all the factors influencing the product's carbon footprint, along with their respective subdivisions. To find the CO$_2$ of the product addition values for each one of the products subgroups CO$_2$ values will do. The calculation formulas for each subgroup will be detailed on each subgroup.

Identifying and quantifying these emission factors is crucial for calculating the product's carbon footprint accurately. Once identified, efforts can be focused on reducing the emissions associated with these factors, leading to more sustainable products and a reduced carbon footprint.
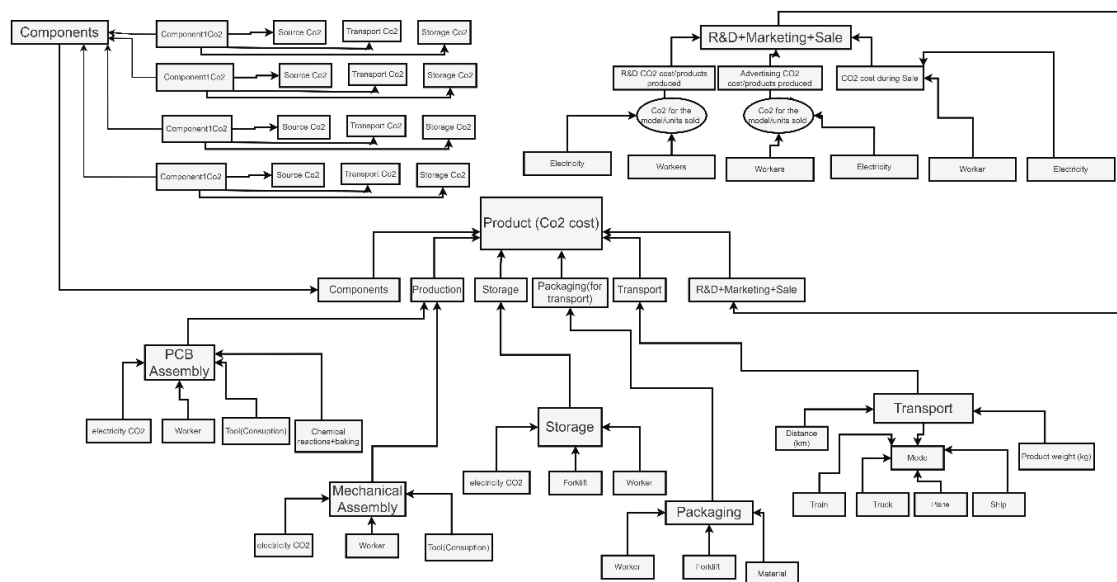
Figure 2. Factor emissions diagram

To simplify the calculations and to capture the most significant contributors to the product's carbon footprint, the emission factors are categorized into six groups, namely components, production, storage, packaging, transport, and research and development (R&D), marketing, and sales. This grouping enables easy calculation since the processes within each group are closely related and distinct from those in other groups. The six groups will represent six functions that calculate CO$_2$.

In addition, clear information on the factors contributing to the emissions is crucial in developing effective strategies to reduce the carbon footprint. Having the total CO_2 value for a product is important but understanding the hierarchy and different elements within the results is equally crucial in identifying intervention points. Thus, the six groups were chosen to enable a clear hierarchy of the factors contributing to the product's carbon footprint.

The diagram in Figure 3 provides a more detailed view of the six groups and their subdivisions. The thesis will delve further into the calculation process and the reasoning behind selecting these six groups as the major contributors to the products' carbon footprint.
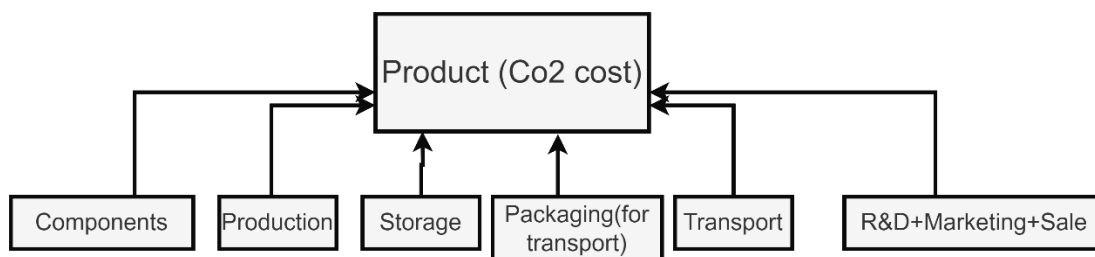
Figure 3. Factor emissions diagram for product

In accordance with the established cut-off rules, the emission factors that influence the CO_2 emissions of the components are divided into three sub-groups: source CO_2, transport, and storage. These sub-groups were selected because they are the main factors that affect the carbon footprint of components, and their related information can be obtained relatively easily. Figure 4 provides a more detailed view of the component emission factors and their interrelationships.
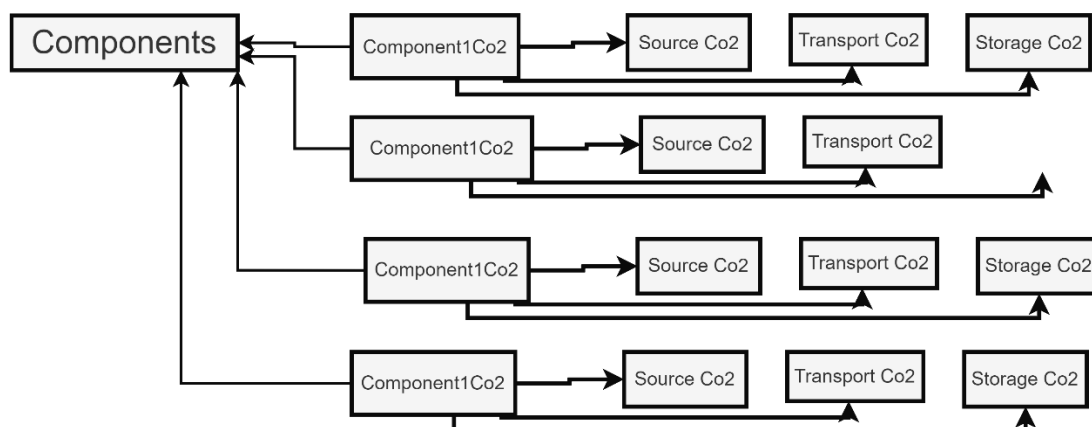
Figure 4. Factor emissions diagram for components

By adding together the total CO_2 for each component or each component type, in case there are multiple numbers of same component it will give the CO_2 values of the Components subgroup which will later be added to the other subgroups of the same level and give the product's CO_2 as a result.

The source CO_2 sub-group refers to the CO_2 emissions associated with the extraction and production of the raw materials used in the components. These emissions will be provided by suppliers or third-party consultants or databases.

The transport sub-group includes the CO_2 emissions associated with the transportation of the components from the supplier to the production site. The transport CO_2 for the components will be added by using the freight method where there is a need to multiply the distance the product makes with method of transport weight and finally the coefficient for the chosen mode of transport. In the event different modes of transport are used then the calculations will be done for each mode of transport and added together.

Finally, the storage sub-group includes the CO_2 emissions associated with the storage of the components before production. The calculation method of this stage consists in multiplying the number of days the components will stay in the storage with the coefficient that determines how much CO_2 is released by storing the product for one day. The size and weight of the component will not be included in this calculation because the effect that it has on the CO_2 results are minimal.

Dividing the component emission factors into these sub-groups enables a more detailed understanding of the sources of CO_2 emissions and facilitates the identification of potential areas for intervention. By focusing on these sub-groups, it is possible to develop targeted strategies for reducing the carbon footprint of components.

The latter sections of the thesis will discuss in more detail the calculation and analysis of the emission factors within the components sub-groups. The discussion will also cover the limitations and potential biases associated with this approach and provide recommendations for future research in this area.
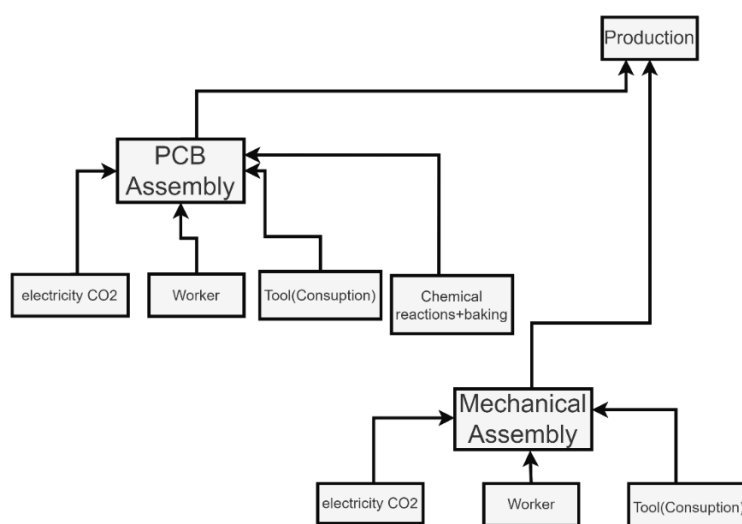
Figure 5. Factor emissions diagram for production

The production factor is a crucial element in calculating the carbon footprint of a product. It involves various processes, including printed circuit board assembly, mechanical assembly, worker and tool consumption, electricity consumption, and other materials consumption. The level of detail in the production factor was increased due to the availability of accurate information about the in-house production processes.

Figure 5 illustrates the interconnection of the subgroups of the production factor. Each of these subgroups contributes to the carbon footprint of the product. The calculation process requires

careful consideration of the cut-off rules to determine which processes should be excluded or represented as a coefficient due to their insignificant impact on the carbon footprint of the product.

The calculations of the production CO_2 consist of adding the CO_2 values of the PRINTED CIRCUIT BOARD assembly with the mechanical assembly. The CO_2 for the PRINTED CIRCUIT BOARD assembly and mechanical assembly comes from adding the CO_2 values generated by electricity consumption, workers, and tool consumption respectively.

In order to calculate the CO_2 generated by electricity there is a need to know how much electricity goes into a product and what is the emission coefficient for energy so they can be multiplied. Same with the worker CO_2 there will be a need to multiply the number of hours a worker spends with a product with the coefficient of CO_2 for each hour. So, from here can be seen that the information needed from the company is the hours a product spends on printed circuit board assembly and mechanical assembly and external coefficients for electricity and worker CO_2 respectively. It is important to note that the accuracy of the coefficients can be improved with time and improved calculations.

The storage subgroup, depicted in Figure 6, was given due attention to assess the impact of storage on the product's carbon footprint. As the factory primarily relies on renewable sources of energy, the factors of electricity and electric forklift were not considered significant contributors. However, if necessary, they have been included as sub-factors to have the flexibility to include them. The three factors that were determined to have a notable impact on the product's carbon footprint during storage are electricity, forklift usage, and worker impact.
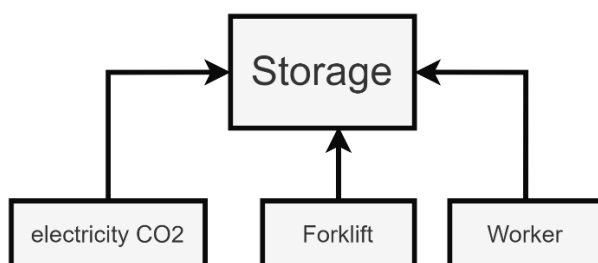
Figure 6. Factor emissions diagram for storage

The inclusion of worker impact is important as factors such as heating, food, and travel contribute to the worker's carbon footprint. Like the calculation done above about the storage of components in a similar way will the storage of the product be calculated. In the table that holds all the needed data for the calculation there is the place holder for this data, and they are included in the calculation. When calculating the CO_2 for electricity and workers, it was discussed in the previous chapter. As for the calculation of the CO_2 generated by the forklift, since the forklift uses green energy and has a long life then a coefficient will be inserted in the calculations to consider the consumption of the forklift and its maintenance. The forklift effect is not too big but to be as truthful as possible it will be included.

The carbon emissions of a product are influenced by several factors, including its packaging. The packaging of a product and its components play a crucial role in determining the product's carbon footprint. In order to calculate the packaging CO_2 there will be the multiplication of number of hours

that takes to package a component with the worker CO_2 coefficient and then adding this value to the CO_2 value that packaging holds on itself as a material based on its weight.

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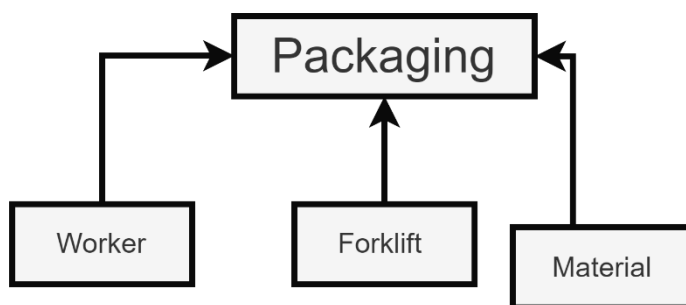
Figure 7. Factor emissions diagram for packaging

The emissions resulting from the packaging production process vary depending on the material used, and the packaging's transportation and storage can also significantly impact the product's carbon footprint. Therefore, it is essential to carefully consider these factors during the carbon footprint calculation process to obtain a more accurate and comprehensive result.

One of the most significant factors affecting carbon emissions is transport. The use of fossil fuels in transportation leads to a large release of CO_2 into the atmosphere (IPCC 2014). Transport not only directly affects the product but also its components, which may be transported from various locations (Sathre & O'Connor 2010).

Furthermore, the mode of transport plays a crucial role in the environmental impact of transportation. As shown in Figure 8, there are different ways in which transportation can be carried out, including by train, truck, plane, or ship (IPCC, 2014). Each mode of transportation has its own unique environmental impact, which must be considered when calculating the carbon footprint of a product.

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    │ Distance │      │   Mode     │     │ Product weight   │
    │  (km)    │      └────────────┘     │     (kg)         │
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    ┌────────┐  ┌────────┐  ┌────────┐  ┌────────┐
    │ Train  │  │ Truck  │  │ Plane  │  │  Ship  │
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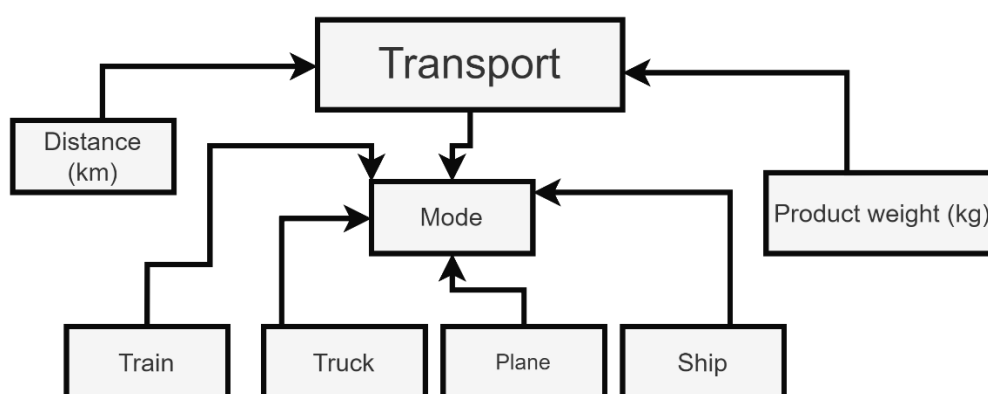
Figure 8. Factor emissions diagram for transport

Transport is a significant contributor to carbon emissions due to its reliance on fossil fuels (Gota et al., 2021). The mode of transportation used, such as trains, trucks, planes, and ships, can have varying levels of carbon emissions (Chang et al., 2017). To accurately calculate the product's carbon footprint, it is crucial to consider the specific transport mode used and the corresponding emissions coefficients for each mode (Gota et al., 2021). However, as with other factors, the cut-off rules

should be kept in mind to avoid including insignificant factors that may complicate the calculations (Frischknecht et al., 2004).

Freight data is often used to calculate the carbon footprint of transport (Zhang et al., 2019). The GHG Protocol, a widely used international accounting tool for GHG emissions, provides a formula and data for calculating emissions from freight transport (GHG Protocol, 2015). It is essential to use reliable and accurate data sources for transport emissions to ensure the robustness of the carbon footprint calculations.

As for the calculation method of transport it is explained in detail when the explanation of the calculations for the transport of components from supplier to factor y is used. Besides the direction in which the product goes there is no other difference. Even the functions in the software that calculate the transport CO_2 are the same.
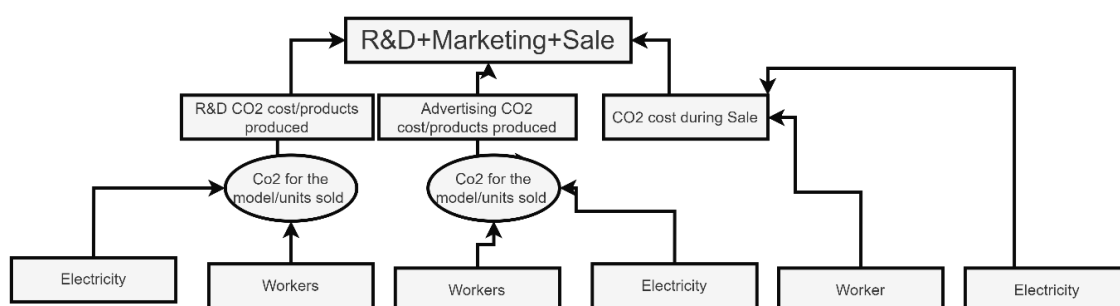
Figure 9. Factor emissions diagram for R&D-marketing-sale

The carbon emissions that are generated during the research and development (R&D), marketing, and sales phases of the product life cycle are significant factors that should not be overlooked. These phases involve a prolonged period of human effort and activity, and they also involve several supportive structures like heating, transport, food, and electricity, which contribute to the carbon footprint of the product. It is important to note that the carbon emissions resulting from this stage of the product life cycle must be distributed among all the units produced. As the number of units of the same product increases, the weight of this phase in the product's carbon footprint decreases. Figure 9 illustrates the factors that contribute to the carbon footprint during the R&D, marketing, and sales phases of the product life cycle.

To do this calculation there is a need to have in the Excel file to columns respectively the column about the CO_2 released for the R&D, marketing and sales of the product type and how many units of this type are sold. So, the calculation is a simple division of the CO_2 for the type of product with the number of products produced from this type.

It is crucial to keep in mind that the accuracy of the carbon footprint calculations for this phase of the product life cycle depends heavily on the availability of data. The more data that is available, the more accurate the calculations will be. Therefore, efforts should be made to obtain reliable data on factors such as heating, electricity, and transport to ensure the accuracy of the carbon footprint calculations for this phase. The sources used for data collection for this phase are various documents, including payroll data for employees, bills for electricity and heating, and receipts for transport costs, among others.

3.3 Data collection and processing

The data collection and processing phase of the carbon footprint calculation involves obtaining data from both internal and external sources (ISO 14044, 2006). Internal data sources include information about the product's structure, weights, components, and production processes, as well as information from the company's logistics and management departments about transportation, storage, energy use, and infrastructure.

External data sources are also critical in obtaining information about the carbon footprint of the product (Finnveden et al. 2009). These sources include emission factors for the components and transportation modes used in the product, as well as emission factor coefficients for worker hours, tool consumption, and packaging materials. Additionally, emission factors based on the type of energy and heating used in the company and relevant to the printed circuit board assembly process are considered.

Excel sheets were chosen for data storage and organization due to their flexibility and accessibility (Sangwon Suh,2010). Given that this is the company's first endeavor of this kind, data collection is not yet consolidated, necessitating a thorough search and processing of data. The data is then organized in a manner that ensures easy access for the carbon footprint calculator.

Overall, both internal and external data sources are essential in accurately calculating the product's carbon footprint, and the data collected must be processed and organized in a way that is easily accessible and ready for use in the carbon footprint calculator.

4   CO$_2$ CALCULATOR DESIGN

4.1   Technological aspect of CO$_2$ calculators

4.1.1   Programming languages and libraries

In the development of CO$_2$ calculators, a variety of programming languages can be employed, including Python, JavaScript, and Java. These languages offer a multitude of libraries and frameworks that aid in the manipulation, processing, and analysis of data.

Python is a versatile and widely used language for data manipulation and analysis, particularly due to its readability, scalability, and the extensive availability of libraries (VanderPlas 2016). Data manipulation in Python involves several steps, including data cleaning, transformation, and visualization. Libraries such as pandas and NumPy are often used for these tasks (McKinney 2011; Oliphant 2006).

Pandas is a powerful open-source data analysis and manipulation library. It provides data structures and functions needed to manipulate structured data, including functionality for manipulating and aggregating data, handling missing data, and merging datasets. Pandas is very suited for working with tabular data, such as data stored in spreadsheets or databases (McKinney 2011) and since on this thesis Excel will be used to store data until the integration with the system is possible this is the best library that can be used.

Once the data is cleaned and transformed, libraries such as Matplotlib can be used for data visualization. This library provides a wide array of options to display data, ranging from basic plots like bar graphs and scatter plots to more complex visualizations like heat maps and 3D plots (D. Hunter 2007). In the context of this project, Python can be used to process and analyze the collected data, perform calculations for the carbon footprint, and visualize the results during the programming phase. Further practical information is gathered from the documentation of the above libraries.

4.1.2   Data storage and management solutions

In the early phases of developing this CO$_2$ calculator, Excel sheets were utilized for data storage and management due to their flexibility and ease of use. Excel is a widely recognized tool that provides the capability to manage the kind of data required for CO$_2$ calculations (Chandan, 2021). It also allows for straightforward organization, sorting, filtering, and visualization of data, making it accessible to individuals from diverse backgrounds (Walkenbach, 2010).

However, as the scope and complexity of the CO$_2$ calculations in this project evolve, it is anticipated that more advanced data storage and management systems may need to be employed. Structured data storage solutions such as relational databases like MySQL, PostgreSQL, or SQLite could offer the ability for more intricate queries and efficient data handling (Date, 2015; Kriegel et al., 2010). Alternatively, unstructured, or semi-structured data could be managed using NoSQL databases like MongoDB or CouchDB, which provide scalability and flexibility for data storage and management (Banker 2011; Edlich 2011).

4.1.3 Data visualization techniques

Presenting the results of CO_2 calculations in a manner that is visually appealing and easily comprehensible is a key consideration in this work. Effectively communicating the outputs of the CO_2 calculator can foster better understanding and engagement from diverse stakeholders.

Several data visualization tools are available that can facilitate this process. Libraries in Python like Matplotlib and Plotly, or JavaScript libraries like D3.js, offer capabilities for creating static or interactive graphs, charts, and maps (Tufte 2001;McKinney 2017; VanderPlas 2016).

However, for this particular project, the choice was made to use Microsoft Power BI. Power BI is a business analytics tool that offers interactive visualizations and business intelligence capabilities with an interface that is easy to use for creating reports and dashboards (Dan Clark 2016). The primary reason behind this choice was Power BI's capability to seamlessly integrate with Excel, the chosen data storage tool for this project. This integration ensures that the results of the CO_2 calculations can be easily imported into Power BI, where they can be visually represented in a manner that is clear, comprehensive, and accessible to a broad audience.

4.1.4 Best practices for code documentation

The essence of maintaining and scaling CO_2 calculators lies in proper code documentation (McConnell 2004). This includes in-line comments elucidating the code's functionality, comprehensive descriptions of functions and classes, and user guides that clarify the usage and customization of the calculator (Pilone & Miles 2008).

4.1.5 Principles of clean code and modular design

The maintainability, extensibility, and reusability can be ensured by adhering to principles of clean code and modular design (Martin 2008). This encompasses the use of consistent naming conventions, adherence to the single responsibility principle (where each function or class is assigned a single, well-defined task), and designing software components with precise and clear interfaces (Fowler & Beck 1999).

This software was divided in four different python files. More information about the software will be explained in the software architecture.

4.2 Python and Excel integration.

4.2.1 Python libraries for Excel automation.

Figure 10 shows a part of the code from the software. This part of the code is the function that calculates the Co2 for the transport of the product. From the picture there can be seen the integration of python .

```
#Function that calculates the co2 for the transport of the product to delivery points

def calculate_transport_co2_emissions(product, filepath):
    try:
        product_table_workbook = load_workbook(filepath.product_table, data_only=True)
        product_table_sheet = product_table_workbook[filepath.sheetnumber]

        transportMode = objects.get_transport_emission_factors(filepath.transport_emissionFactors)

        # Dictionary with distances and modes
        distances_and_modes = {
            'shipping': {'distance': product.ship, 'mode': transportMode['Watercraft - Large RoPax Ferry']},
            'truck': {'distance': product.truck, 'mode': transportMode['Road Vehicle - HGV - Rigid - Engine Size 3.5 - 7.5 tonnes']},
            'train': {'distance': product.train, 'mode': transportMode['Rail']},
            'air': {'distance': product.air, 'mode': transportMode['Air - Long Haul']}
        }

        # Calculate CO2 emissions using a dictionary comprehension
        CO2 = sum((distances_and_modes[key]['distance'] * distances_and_modes[key]['mode']) for key in distances_and_modes) * float(product.weight)

        # Store the CO2 value in the product table
        product_table_sheet.cell(row=2, column=18).value = CO2        #Transport total km //we get this data from logistics

        return CO2

    except KeyError as ke:
        print(f"Error: Missing key in the input data: {ke}")
    except Exception as e:
        print(f"Error: An unexpected error occurred: {e}")
```

Figure 10 . Snapshot of code from the software that shows transport CO_2 calculation.

During the development of the CO_2 calculator software, various libraries were utilized to accomplish different tasks and streamline the overall process. These libraries were essential for the efficient handling of data, file organization, and visualization of results.

• Pathlib: The pathlib library was employed to effectively manage and organize the file paths for numerous Excel files used in the project. (Pathlib 2023). By utilizing pathlib, the creation of new file paths and modifications to existing paths could be centrally managed through the code, resulting in increased flexibility and maintainability.

• Openpyxl: The openpyxl library allowed for precise control over individual Excel files, cells, and the creation of various tables throughout the development process (Eric Gazoni 2010)This library enabled developers to access, modify, and save Excel files while ensuring that data integrity was maintained.

• Pandas: The pandas library provided agility for processing large amounts of data with a simplified and more efficient process. (pandas 2023). Pandas' versatility allowed developers to manipulate and analyze data quickly and easily, significantly enhancing the software's capabilities.

• Matplotlib.pyplot: The matplotlib library was utilized to visualize calculation results during the programming process, enabling the team to monitor progress and ensure that programming errors did not alter the desired outcomes. (Matplotlib 2023). This visualization tool served as a valuable resource for validating the accuracy and correctness of the calculated results.

In conclusion, these libraries played an essential role in the development of the CO_2 calculator software by simplifying various tasks, increasing efficiency, and enabling developers to manage and analyze data effectively. The use of these libraries contributed to the successful creation of a reliable and accurate CO_2 calculator.

4.2.2 Data processing workflow

Figure 11 shows a representation of the Data processing workflow.
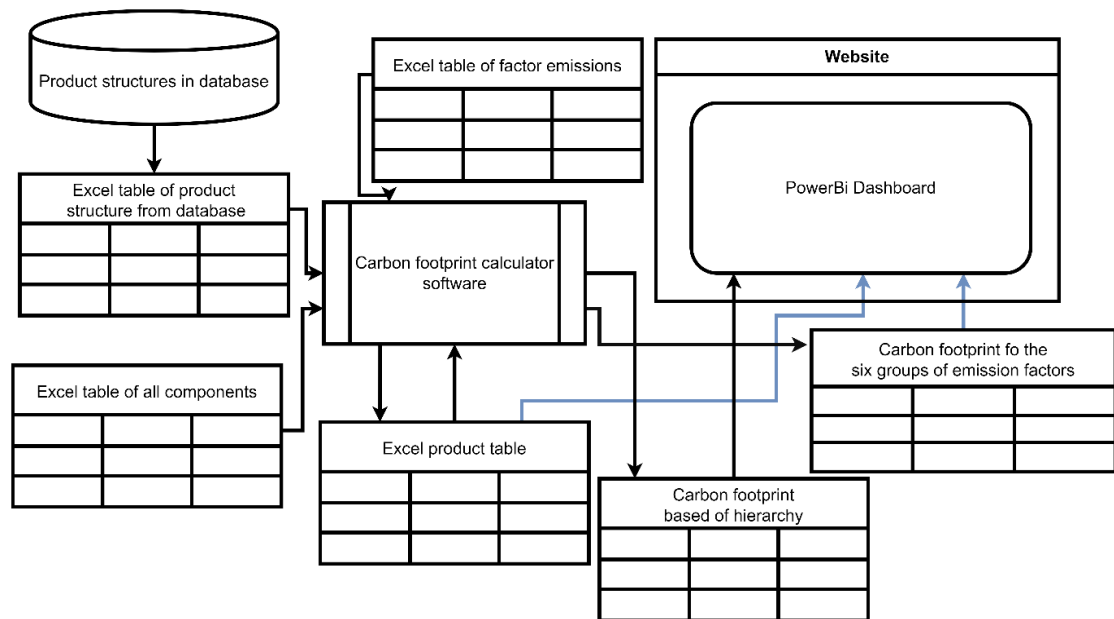
Figure 11. Representation of Data Processing Workflow

The way the data flows is as follows: First the software accesses the data from the Excel file that holds the products structure downloaded from the company's database manually. After getting the product structure that holds the codes of all the components of the product it accesses all components Excel file.

The all-components Excel file contains all components that the company uses in all its products. But not only that, it contains all the features needed to calculate the carbon footprint for the components and the products. Using panda's libraries and merging the components from the first Excel file with the data from all components file create a new Excel file called the product table.

The product table contains the code, the name of the product with its features and all the components that comprise that product with the necessary information to calculate the carbon footprint.

The software goes through the table and uses the information there to calculate the carbon footprint for the product. Some of these results like total CO_2, transport CO_2 and each individual components CO_2 are added by the software to the same table.

Besides saving some of the information on the product table the software creates new Excel sheets on the same Excel file with the information that is desired to display to display. The information saved in the Excel file will depend on what data needs to be displayed on the Power BI. This dashboard can later be displayed on a website.

4.3 Power Bi dashboard development

For the calculator, Excel tables were created containing the required information derived from the collected data. These tables served as inputs for the Power BI dashboard. To import the data into

Power BI, the Excel tables were connected as data sources, allowing for seamless integration and data up-dates.

Various visualization techniques were employed in the Power BI dashboard to effectively represent the carbon footprint data. These included bar charts, line charts, pie charts, and treemaps to show-case trends, comparisons, and proportions. Additionally, slicers and filters were incorporated to ena-ble users to easily navigate through the data and focus on specific aspects of the carbon footprint calculations.

The design of the Power BI dashboard adhered to several key principles to ensure a user-friendly and visually appealing interface, which allowed users to effectively interact with the carbon footprint data and make informed decisions based on the insights provided:

Clarity: The dashboard was designed with a focus on easy comprehension, incorporating clear la-bels, legends, and titles for each visual element. The use of simple, concise language facilitated quick understanding of the presented information (Few 2009).

Hierarchy: Emphasizing the most crucial information, the dashboard displayed it prominently, with other related details accessible through drill-down features or secondary visuals. This approach ena-bled users to concentrate on high-level insights while still having access to detailed data when needed (Cairo 2013).

Consistency: Consistent color schemes, fonts, and visual elements throughout the dashboard con-tributed to a cohesive and polished appearance, which in turn aided users in quickly identifying and interpreting different aspects of the data (Few 2009).

Interactivity: Interactive features such as filters, slicers, and tooltips empowered users to explore the data and gain insights tailored to their specific needs or areas of interest (Murray 2017).

Responsiveness: The dashboard was designed to work seamlessly across various devices, including desktops, tablets, and mobile phones, ensuring accessibility and usability for a wide range of users (Heer & Agrawala 2006).

The dashboard's content and appearance will evolve based on the changing requirements of the company, incorporating input from different stakeholders within the organization to determine the necessary information to display. Figure 12 is a representation of what the final dashboard may look like, subject to further input and refinement from the company's stakeholders.

Figure 12. Example of dashboard for the visualization of carbon emissions.

4.4   Software architecture

Figure 13 shows a schematic of the CO_2 calculator software architecture that explains the flow of the data inside the calculator.
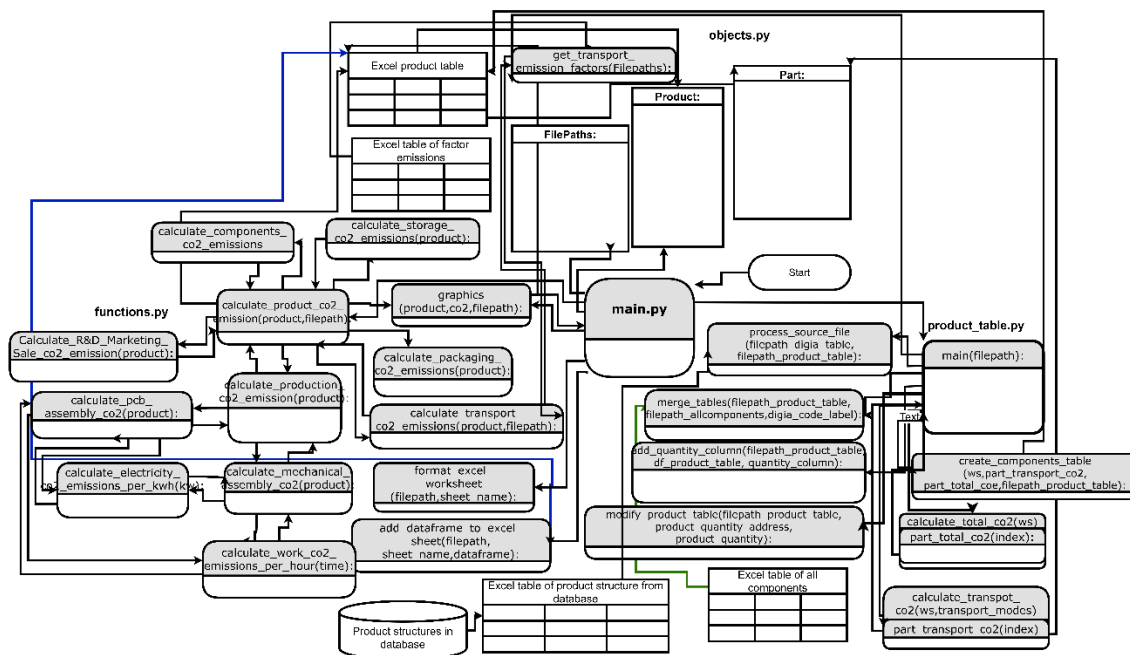
Figure 13. Software architecture diagram.

The way this software was intended to be used and the process of what it had to do has influenced the way it was designed. When designing it, making it easy to maintain so that later it could be updated, modified, and grown. That is the reason why the software is divided into four python files. Each one of those files has a distinct function. Those files are organized into different   purposes. Each one of those functions has a distinct objective and can work on its own if the other functions have issues. The variable meaning, the file paths, the objects make it possible to gather all the labeling in one central place.

This way if need arises to modify some of those features the source of the data, the quantity of the da-ta there will suffice to change the information on this central location without going through hundreds of lines of code to find each individual variable.

The following lines have a detailed description of each of the files that are part of this project and their function in the code. The method of calculations are described in the detail.

The software is organized in 4 python files:

main.py

The main Python file serves as the central point from which all other files are called. User inputs are entered here, and the file manages the execution sequence and hierarchy of other files. functions.py

This file contains all functions responsible for performing calculations on input data, processing results, and creating tables to store those results. The functions encompass various aspects, including transport, electricity, work, production, storage, parts, packaging, and R&D, marketing, and sales

car-bon footprint calculations. In addition, the file has functions for formatting and creating visuali-zations of the results. Figure 14. shows a diagram of the functions in functions.py file and their in-terconnectedness.
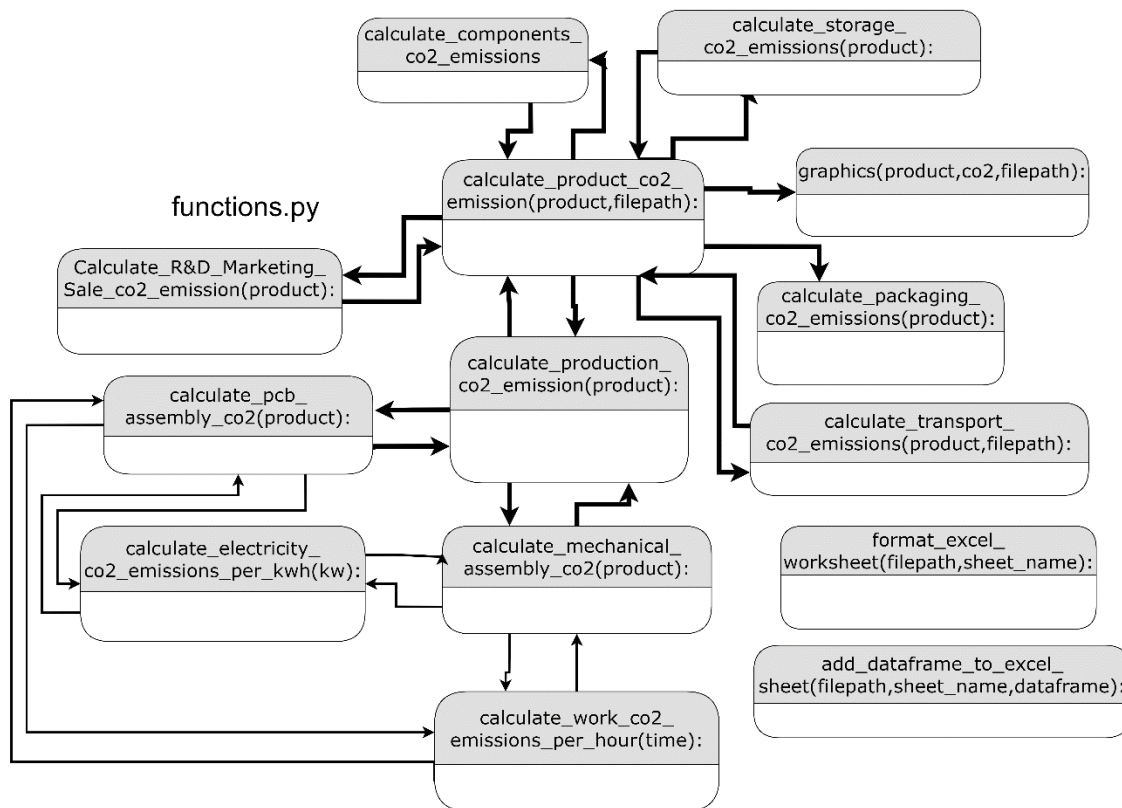

Figure 14. Diagram of functions.py file

product_table.py

This Python file generates the product table, which is used by the functions file to perform the nec-essary calculations and produce the desired outputs. Figure 15 shows a diagram of the functions on product_table.py file and their interconnected-ness.
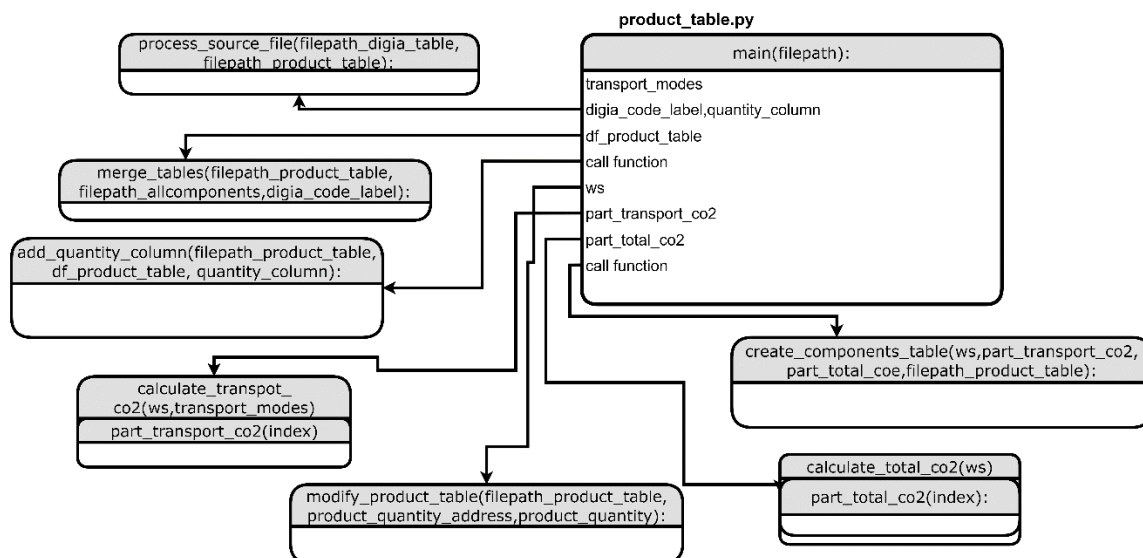
Figure 15. Diagram of product_table.py file

objects.py

This Python file contains all the objects whose values are derived from the tables and are used across the different Python files in the project. To enhance the code's readability, all the functions are in this file. Any changes made here will propagate throughout the code without getting lost. The objects in this file include:

Filepaths: This object holds all the file paths used throughout the project. If a file path needs to be changed for a specific table, it can be done here without manually adjusting it in the code wherever it is used.

Product: This object contains all the product features required to calculate its carbon footprint. The object retrieves data from the products table and is called throughout the code to perform the necessary calculations.

Part: This object stores the values for all the components, with data sourced from the product table. The table's structure includes product data first, followed by the components data. As the product can be treated as a component, it is kept in the same table, anticipating that the components' carbon footprints may be calculated independently in the future. Figure 16 shows a diagram of the objects and functions inside the object.py file.
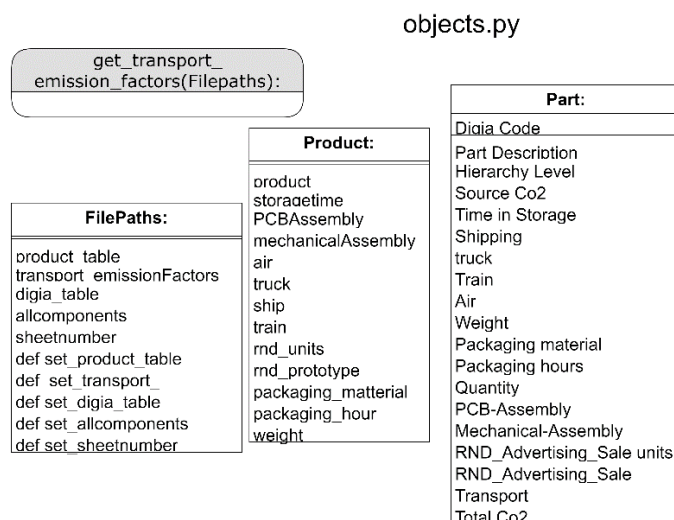
Figure 16.Diagram of object.py

4.5 User interface design

4.5.1 Input data collection interface

The all-components table will act as the Input Data Collection Interface. Different members of the company, depending on what data they are responsible for, will add those data to the all components table and to the factor emissions table. If the program is run after the data is changed then also the calculations will be changed

4.5.2 Output data presentation

The output data will be in different Excel files that will be uploaded to Power Bi where there can be displayed the information that wanted. The biggest output table will be the product table which will

have the input data and output of the calculations in one table. This file for the moment holds to sheets where the first has the table with all the data and the second has extracted results based on the emission factors division in six subgroups. More sheets can and will be made but it is something that will have to be consulted in the upcoming months with different parts of the company.

4.6 Input data management

Below are forms that these tables contain the input and output data have. It is crucial information because the software was built around the layout of these tables and the tables were design by having in mind different factor emissions for the six subgroups defined in the previous chapter. The tables were designed to have the exact necessary information needed for the calculation of the CO_2 for the product to high accuracy but also keeping in mind the way this information can be read and accessed by power bi or other actors inside the company.

Table 1. Form of product table

Code	Part Descripti	Hyrearcy Level	Source Co2	Time in Storage	Shipping km	Truck km	Air km	Weight tonne	Packaging (patterial	Packaging hours	Quantity	PCB - Assembly	Mechanic al	R&D-Marketin	Transport Co2	Total Co2
Product																
Component 1																
Component 2																
Component 3																
Component 4																

As seen in Table 1 the product and all components that comprise it with the necessary information for calculations. The reason they can fit in same table is the fact that components are a different kind of product, so they also can contain the same information type as product, and it gives the possibility that at a later time if the company needs more accuracy, it can calculate itself the components CO_2 too. The last two columns are the results for certain calculations and input for other calculations.

What it means is that to calculate total CO_2 for product there is a need to calculate total CO_2 for components and also other processes and in order to calculate total CO_2 for components there is a need to calculate the CO_2 for the transport. So, output of a calculation is the input of another calculation.

Table 2. Form of all components table

Code	Part Descripti	Hyrearcy Level	Source Co2	Time in Storage	Shipping km	Truck km	Air km	Weight tonne	Packagin g(patteri	Packagin g hours
Product										
Component 1										
Component 2										
Component 3										
Component 4										

Table 2 is the table that will need to be filled by management to be able to run the calculations. It has columns for all the necessary information to have a very accurate calculation of product CO_2. If the information inserted in this calculation is accurate the calculations will be accurate.

Table 3. Form of factor emissions table for transport

	Region	Co2	Co2 unit numerator	Co2 unit denumerator
Ship				
Truck				
Air				
Truck				

Table 3 is a form that will hold the transport emissions coefficients for different modes of transport that is used by the software. If this is updated the calculations will be more accurate

When it comes to the table that holds the results for different subdivisions it will be shown in the next chapter with anonymized data. There will be the subdivisions calculations results.

4.7 Calculation Algorithm

4.7.1 Component-based emissions calculation

To calculate the CO_2 for components there is a need to know, source CO_2, distance travelled, mode of transport, coefficient for that mode of transport and weight. The source CO_2 is at the suppliers. This information is taken from third parties and different online datasets. The distance, mode of transport, coefficient for that mode of transport and weight of the components so that the transport CO_2 the components can be calculated.

The storage CO_2 for each product. To be safe and full of supplies in case of logistic problems companies keep components in stock for a while. That period of stocking will emit CO_2 which can be calculated depending on heating and the number of employees.

The source CO_2 as it was stated above is taken from suppliers and external resources which means that information was written manually in all components Excel file. Now this information for the components of specific products is in the product table Excel file.

The next step to calculate is the carbon footprint that each component generates during the storage time. The storage time is information taken from the logistics department and manually put on all component's files. The coefficient of how much CO_2 is generated for each day of storing the component is calculated and put in the emission factors Excel file. This information is taken by the software to multiply and calculate the storage CO_2.

Another big factor stated during this thesis is transporting these components from the suppliers to the factory. The calculations will be done by using the freight way, which means calculating the CO_2 by multiplying the distance in kilometers with the components weight in tons with the coefficient per mode of transport. The reason why mode of transport is used is because based on the mode of transport the released CO_2 quantity per kilometer per ton changes. An example of this would be transporting this component with an electric train or by plane, in this case the carbon footprint would be different.

After these calculations the results are saved in a product table the software will add them together in a total CO_2 for each component. These values can be added later when there is a need to find the total carbon footprint of all components and after that carbon footprint of the product.

4.7.2 Total product emissions calculation

At the beginning of this thesis, it was established that to calculate a product's total carbon footprint, it is essential to determine the carbon footprint of various aspects, including components, production, transport, storage, packaging, and R&D, marketing, and sales of the product.

From the main.py file the product _ CO_2 function from functions.py file is called. This function calculates the product's carbon footprint. The way It calculates the carbon footprint is by adding the values from all the other functions in this file that calculate different factors that affect the products carbon footprint. These factors are shown above. The total carbon footprint of the product as well as the individual factors CO_2 value are saved in a new sheet of the product table Excel file.

4.8 Output data visualization

Figure 17 shows a visualization of the data output as a pie chart. This visualization is used during programming to keep track of the calculations, so no errors were made. It can be seen how the result of the calculations will change based on each change made to the data. This way the calculator works and each of those pieces of data is considered. This is not the final visualization but just an intermediary method until it is finalized in a dashboard. The dashboard will be finalized later while the requests for the information that dashboard needs to display is gathered. Until then, the Excel table will serve as the tool to visualize the results.

5 APPLICATION OF CO_2 CALCULATOR WITH ANONYMIZED DATA

5.1 Overview of anonymized data

Table 4.Product table for example product

Code	Part Descripti	Hyrearcy Level	Source Co2	Time in Storage	Shipping km	Truck km	Air km	Weight tonne	Packaging (patterial	Packaging hours	Quantity	PCB - Assembly	Mechanic al	R&D-Marketin	Transport Co2	Total Co2
component	NA	0	0	50	20000	474	0	0	0,002	0,5	0,5	1	2	0,5	9000	2000
component	NA	1	0,1	273	20000	474	0	0	0,000014	0,1	0,2	1				
component	NA	1	0,1	273	20000	474	0	0	0,000014	0,1	0,2	1				
component	NA	1	0,1	273	20000	474	0	0	0,000014	0,1	0,2	1				
component	NA	1	0,1	273	20000	474	0	0	0,000014	0,1	0,2	1				

Table 5. All components table.

Digia Code	Part Descripti	Hirearcy Level	Source Co2(kg)	Time in Storage(	Shipping(km)	Truck(km)	Train(km)	Air(km)	Weight(t one)	Packagin g/Logistic
componet	Na	1	0,1	273	20000	474	0	0	0,000014	0,1
componet	Na	1	0,1	273	20000	474	0	0	0,000014	0,1
componet	Na	1	0,1	273	0	474	0	0	0,000014	0,1
componet	Na	1	0,1	273	20000	474	0	0	0,000014	0,1
componet	Na	1	0,1	273	20000	474	0	0	0,000014	0,1

Table 6. Table of factor emissions table for transport

Vehicle a	Region	CO2	CO2 Unit -	CO2 Unit - Denominator
Air - Dome	Other	1,96073	Kilogram	Tonne Kilometer
Air - Short	Other	1,47389	Kilogram	Tonne Kilometer
Air - Long	Other	0,61324	Kilogram	Tonne Kilometer

5.2 Comparison with existing calculators

Since there is no existing calculator that can do the calculations for this product type the only method is to try to compare to a similar product. Since most companies don't show those data the ability to compare in this case is difficult. There is a lack of information or standard of CO_2 emissions for technology products of this type.

5.3 CO_2 emissions calculation

Table 7. Table with calculation results for example product

parts_co2	production	storageCo2	packagingCo2	transportCo2	r&d_marketing_salesCo2	Co2Total
64kg	2,7kg	0,05kg	1kg	2,6kg	0,22kg	70,57kg

In Table 7 as can be seen there is a display of the results for different categories of emission factors.

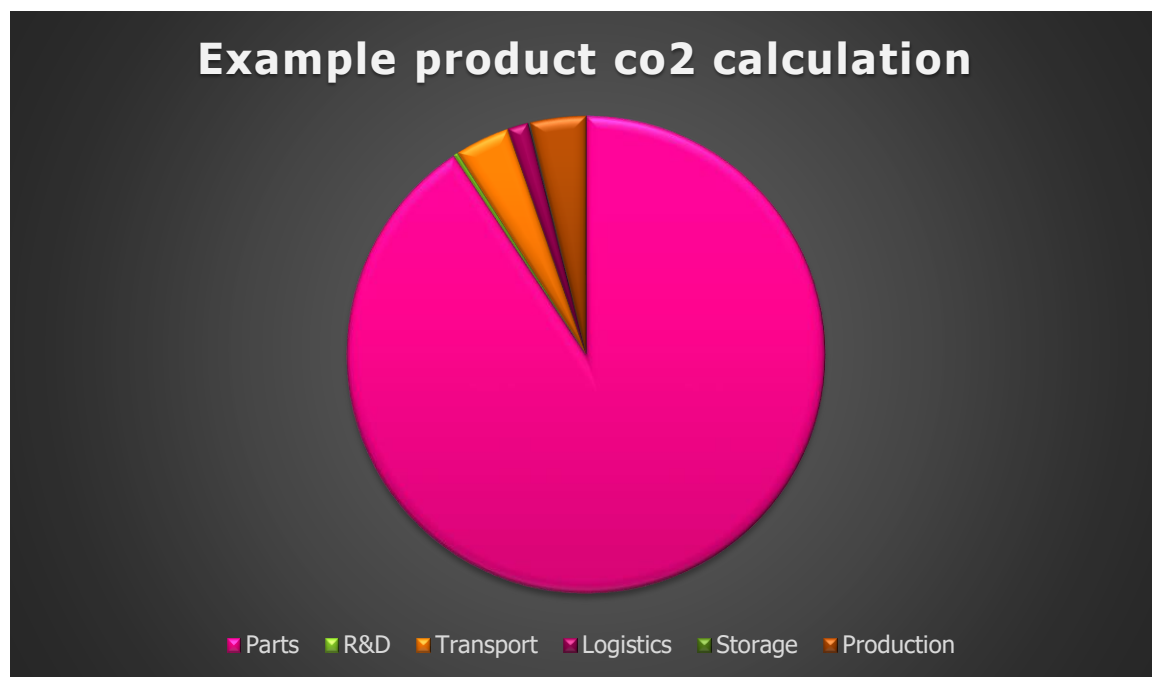## 5.4   Interpretation of results and recommendations

Figure 17 .Pie chart of calculation with data for a certain product

As illustrated in Figure 17, After the calculations for one of the products was done there can be seen that most of the carbon footprint, around 93% was released by the components that make the product. And if you go one layer deeper on the components carbon footprint further divisions most of the carbon footprint that comprises the components comes from the transport of the components. Since some of the components come from different suppliers around the world then most of the CO_2 is released during transport.

From the pie chart can be seen that using renewable energy in running the facility has made the weight of the factory in the carbon footprint significantly smaller than the components.

It is vital for more accurate data to be made available for the calculator to show a representation as close to the truth as possible.

As illustrated in Figure 17. After the calculations for one of the products were done there can be seen that most of the carbon footprint, around 93%, was released by the components that make the product. And if you go one layer deeper on the components carbon footprint further divisions most of the carbon footprint that comprises the components comes from the transport of the components. Since some of the components come from different suppliers around the world then most of the CO_2 is released during transport.

From the pie chart can be seen that using renewable energy in running the facility has made the weight of the factory in the carbon footprint significantly smaller than the components.

It is vital for more accurate data to be made available for the calculator to show a representation as close to the truth as possible.

6   DISCUSSION

The CO_2 calculator's validation is a crucial aspect that requires expert evaluation. However, due to incomplete data, expert evaluation is presently not feasible. The calculator's sensitivity to data changes signifies the importance of accurate input data and coefficient calibration.

Uncertainty in input data and variability in emission factors can significantly affect the accuracy of CO_2 calculations. As such, data quality improvement and refinement of emission factors are recommended. These include vigilant monitoring for new data, obtaining component-related information from suppliers, and deconstructing emission factors for increased accuracy. However, these steps may increase the complexity of calculations.

Further integration of the calculator with the database holding the component information is necessary, despite current compatibility issues requiring manual data transfer.

For future work, expanding the calculator's scope to include raw materials, product usage, and end-of-life recycling stages is suggested. This expansion would provide a more comprehensive view of a product's environmental impact. Integrating with other environmental impact metrics or using IoT devices to gather accurate GHG data throughout the product's life cycle is another potential improvement.

Continuous updates and improvements are essential to keep up with evolving data, standards, and regulations, and to enhance the calculator's functionality and relevance.

7   CONCLUSION

7.1   Summary of findings

Most of the CO_2 in the products comes from the components and the transport of those components from supplier to production facility. There is a lack of data when it comes to finding CO_2 for electronic components. To build a CO_2 calculator you will have to build a large program but not very complicated.

7.2   Contributions and impact

This calculator has a big impact on the ability that the company has to understand the factors that influence CO_2 and, the quantity and distribution of CO_2. Being able to view all the information in a comprehensible and easy to understand format makes it easier to undertake actions during development or after to lower the CO_2 cost for product.

7.3   Final remarks

In this project, was developed a product CO_2 calculator for the company's products, which serves as a first step in the process of registering and calculating CO_2 emissions associated with these devices. The calculator's potential impacts include raising awareness, driving behavioral changes, promoting sustainable product development, and supporting policymaking. Future work should focus on expanding the calculator's scope, integrating it with other environmental impact metrics or IoT devices, and continuously improving and updating the tool to keep pace with advances in data, standards, and regulations. By doing so, the company hopes to contribute to the ongoing efforts towards a more sustainable future and inspire further research and innovation in the field of sustainable technology.

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