Researching the environmental impact of operations

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Abstract

Climate action has been a topic of discussion for many years and its importance has only been growing. Hence, not only individuals, but also companies are paying incrementally more attention to it. Climate change may influence governmental policies and laws, and being aware of the current trends is essential for good performance.

Therefore, the objectives the work was set to accomplish were related to company X's environmental impact, specifically that relating to the production process of one of their products. Thus, the task was to measure that environmental impact. The research was implemented by thorough consideration of the available theory and previous, data gathering and mathematical calculation.

As a result, the production process analysis was conducted and the emissions calculations were performed. The company received a tool for further calculation and analysis, as well as directions on where the effort should be. This allowed for further work in the direction of sustainable operations and ensured transparency of the company's environmental impact.

Keywords/tags (subjects)

Climate change, carbon dioxide, emissions

Miscellaneous (Confidential information)

All attachments are confidential, and they have been removed from the public version. Grounds for secrecy: Act on the Openness of Government Activities 621/1999 24 §, section 24: information on technological or other development work and its evaluation. Period of secrecy is twenty-five (25) years and it ends on 31.12.2047.

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1 Introduction.

Nowadays it is becoming increasingly important for any company to work towards a sustainable future and strive to make a positive impact on the world we live in, which undoubtedly includes decreasing carbon emissions, as well as greenhouse gas emissions in general. As stated by Alan McKinnon, today's business is widely influenced by the public and the government in such a way that companies, while caring for their profits, have to consider the impact of their operations on the environment. Even though the carbon footprint of companies' operations is understandably the most well-known impact of logistics among the general public, other factors, such as air and noise pollution. Not only is it a good means by which companies can make the world a better place, but it can also result in financial gains. (McKinnon, 2015)

Given that the company's clients and partners are also interested in protecting the environment, they will be more eager to work with someone who shares their beliefs. And the contrary is true as well, if a company has a bad image because of its policies in terms of the environment or other social issues, it is likely to lose some customers and those willing to partner with it, since associating with a bad actor may impact your own reputation in a bad way. Hence, by having a good reputation companies can make themselves more desirable work partners as well. Thus, keeping track of their own environmental impact, which is the first step to mitigating any negative effects, can have a potential of not only keeping the old customers, but also attracting new ones. Thus, after considering all the possible benefits working towards a sustainable future can provide, X, a Finnish company, decided to conduct a research project aimed at studying its influence on the environment. Therefore, this thesis focuses on researching the environmental impact of the company X's operations. (McKinnon, 2015)

2 Research methods

The main objective of the thesis is to determine X's environmental impact in terms of CO_2 emissions within the production of one product, that represents the most typical product of the company.

This thesis, however, was set to find the answers to the following questions:

1) What does the entire production process look like in terms of the chosen product?
2) How much carbon dioxide is emitted in each stage of the supply chain and in total?
3) How can such calculations be automated for other products?

The purpose of the first question was preparatory, because without knowing the entire production process it would be impossible to understand the scope of the project and correctly answer the other two research questions. In order to find an answer to this question, it was required to communicate with the company representatives, as well as visit the main factory and observe the production process to understand what procedures the product had to undergo. It was also important to set the right limitations. Not every single stage of the process was under control of M, thus, it would have been unreasonable to measure something one could not control and think of ways to mitigate its negative impact.

The second question was crucial to the project and accomplished the main task of the project since the idea was to calculate the CO_2 emissions within one of the company's products. This was the necessary first step for the company towards becoming completely aware of its environmental impact. Answering this question involved examining each stage of the production process separately, such as the shipment of raw materials, as well as of finished or semi-finished products, and various production processes that occurred on-site.

The third question did not only mean researching if a tool for CO_2 emissions calculations was possible to create, but also implied the creation of such a tool if a suitable alternative did not exist. When all of the questions have been answered and the tool has been created, the company would be on its way to more sustainable operations and secure deals with the partners that value environmental action.

The method of the research was mostly going to be quantitative, given that the main idea is to calculate precise numbers and calculation falls into the quantitative research category. The ultimate goal of this thesis work was to investigate the company's impact on the environment and determine, whether it was possible to mitigate its environmental impact. Therefore, the first step in this work was to obtain as much information as possible from existing sources on the topic of climate action and emissions from various operations. These sources included books, previous research papers and university theses, as well as different materials published online by respectable organizations doing climate-related work. Another source was the company itself, so various data had to be gathered by means of observation and communication with the company representatives to create a holistic picture.

The current work also had its limitations. M is an international company that has partners from different countries, especially the ones located in Europe. This, in turn, results in, for example, sourcing raw materials from other countries, such as the Netherlands. This work, however, did not focus on the emissions released outside of Finland, therefore, the environmental impact occurring during the shipment to Finland was left out. The reasons for it included both the fact that the company did not bear the sole responsibility for the emissions occurring along the entire route, meaning that other companies had their own share of the environmental impact, and the fact that the scope of the work should be limited in order for it not to become impracticable and correspond to the level of a bachelor's thesis.

3 Supply chain

In simple words, a supply chain is the entire sequence of a product life cycle starting from raw materials and ending with the product being delivered to the customer. Depending on the product, the company responsible for its production and the services associated with the product, the life cycle can also include maintenance, meaning that the process does not end with its delivery to the customer, but continues until the product either reaches the point of being unrepairable or its further use and maintenance is no longer a supplier's responsibility. As stated by Stadtler (2008), competitiveness is the final objective of supply chain management and superior customer service is how a company may increase its competitiveness. Thus, maintenance, often being an essential part of customer service, is an important stage of supply chain management which has a potential of maximizing a company's profits.

Supply chain is, however, not to be confused with value chain, which is a concept used later in the thesis. While the two terms may sound similar and even have something in common, the concepts are still different. As explained by Tarver (2021), supply chain management's focus is on the product. The production and delivery of the product are at its core. Value chain, however, focuses on adding value to the product at every stage of the process. This could include focusing on high-quality raw materials, adding innovation to the process steps and marketing the product to customers. According to Morana (2018), for a company to succeed, its supply chain management should hold value creation for the end customer as one of the key elements in the process.

There are different ways to categorize activities in supply chain management and one of them is to make a distinction between upstream and downstream logistics. Upstream logistics stands for all the activities that take place before a certain point in the chain of supplies. Hence, downstream logistics is everything that happens after that. Thus, the terms upstream and downstream logistics are relative to the point in the supply chain which is considered as a focus for such categorizations. For example, the focus is a retail store, then all the processes that led to the products sold in that store are considered upstream logistics. In this case it would be raw material extraction, such as mining iron ore or felling trees. The raw materials are then subsequently stored, in which case it requires special knowledge of the particular material, since the conditions under which different materials are stored are not necessarily the same. Wood, if not stored properly, may end up being infested by bugs. If the wood in question is firewood, it needs such special conditions as right humidity levels for it to burn properly (*Firewood Storage*, 2021). As explained by Morana (2018), the shipment to the plant where the product is either finalized or only partly assembled is also not as straightforward as one might think, since different materials require different shipping conditions, as well as economic considerations as to which mode of transport is the most financially viable. During this process the product undergoes many changes and while particular storing and shipping conditions were suitable for the raw materials, they may not be appropriate for a finished or a semi-finished product. If the product is fragile, for example, it would require special treatment, such as packaging to ensure its safety. The downstream part could include delivery to the final customer and maintenance of the product, although that would depend on the company policy.

As evident from the previous paragraph, a supply chain consists of many stages and the activities within it can be divided into several different categories. For example, a supply chain may start with the extraction of raw materials, followed by the raw materials storage and successive shipment to different storage location or directly to a production site. The product then may be shipped to another factory or to an end customer. Thus, a supply chain may be short or long depending on how many stages of production the final product has to undergo before being delivered to the final customer.

Each of the stages, in turn, has its own characteristics and requires special knowledge for the operations to be successful. For example, warehouse managers have to careful when choosing the layout for the operations to run smoothly and selecting the right approach to goods and materials storage, such as LIFO and FIFO, which stand for “last-in, first-out” and “first-in, first-out”, respectively. The LIFO principle would then be used for those products and materials that do not have a risk of expiring soon and thus can be stored for long periods of time. The FIFO principle, on the contrary, would be utilized when the focus is on minimizing the wait time for the goods and materials arriving first and thus can be used for products whose expiration date plays a crucial role in the way they are handled. According to Richards (2014), the FIFO principle is more in line with lean warehousing, which means eliminating waste. Waste is a rather broad term and while it can refer to material being unused and scrapped, a company not utilizing time or space with their decisions efficiently is also a typical example of waste to be avoided. One example could be small pallets being stored in a location that could fit bigger ones.

Warehousing, however, is a much broader field than selecting a suitable layout or ensuring the first in, first out rule. Today’s warehouse managers face a number of challenges which, among other things, include improving quality and accuracy, dealing with technological advancements and applying new technologies correctly, managing the staff, their health and safety, and taking into account the effect the operations have on the environment. (Richards, 2014)

Below are two examples of a supply chain, figure 1 is an abstract supply chain that starts with a factory manufacturing a product, which is then delivered to the final customer after being shipped by trucks and a ferry, as well stored in multiple locations along the way. Figure 2 is what such a production process may look like for a Finnish company with a factory in Tampere that purchases raw materials from an Austrian supplier.

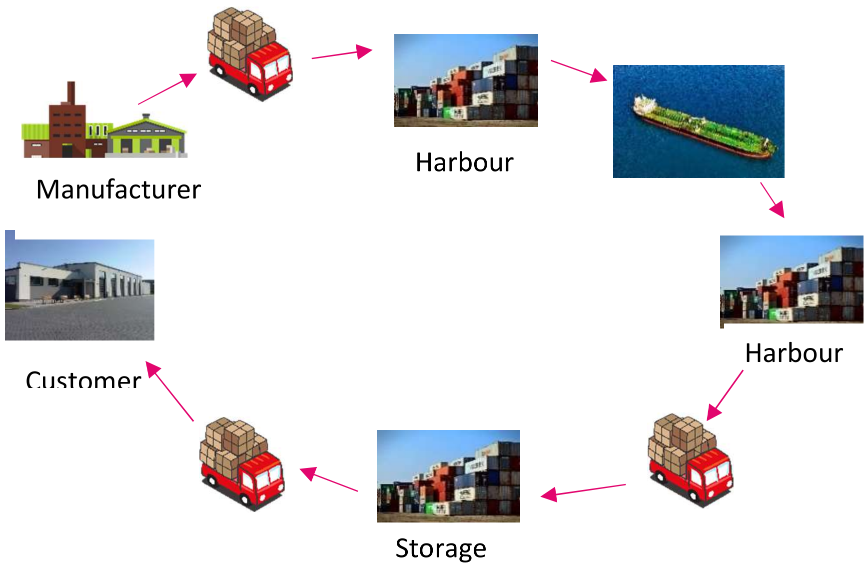

Figure 1. Abstract supply chain

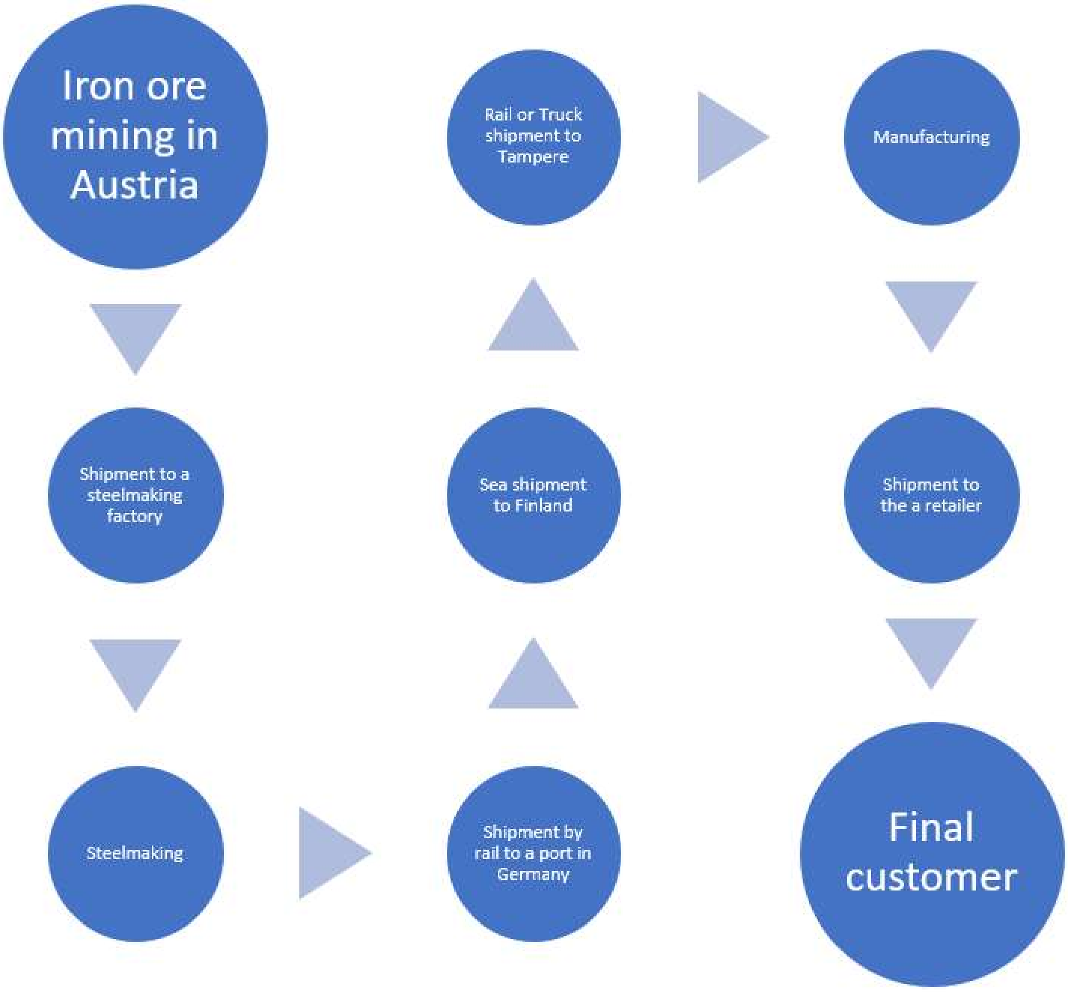

Figure 2. Example supply chain

Climate action has been gaining attention throughout the years and it comes as no surprise that the impact logistics has on climate has been studied before. Richards states, that when it comes to environmental concerns, logistics as a sector contributes 6 percent of total emissions and warehousing accounts for 10.7 percent of that amount. While fuel consumption is understandably a significant contributing factor in logistics, packaging and energy use cause a considerable environmental impact in warehousing. The energy use in warehouses mostly comes from lighting and heating, although, depending on the geographic location, heating may be replaced by cooling. Some of the solutions to dealing with the energy consumed by lighting could include utilizing energy efficient lighting systems, using sensors and motion detectors for lighting to only be used when needed and maximizing the use of sunlight. Other environmental actions involve cutting waste. Recycling waste, separating it, refusing to use disposable plastic and paper items, such as cups, can lead to a substantial decrease in waste and generate some profit. (Richards, 2014)

The same considerations concern all the other areas of logistics with many factors to take into account. When managing transportation, the task is not only to find the shortest route. It is important to select the right modes of transport for the needs at hand. Road transportation is efficient for shorter distances, whereas trains become a better option for longer routes. When considering routes for trucks, scheduling and the allocation of human resources is important because of different regulations mandating rest for drivers at certain points of their journeys and specifying how much one could drive in a day. Given the increased importance of climate action, one should also try to ensure that the company participates in this effort by optimizing the routes for trucks or by choosing the most environmentally friendly trucks in the first place.

4 CO_2 emissions

According to Mathers, Craft, Norsworthy and Wolfe (2019), out of all the greenhouse gases (GHG) present in the atmosphere, carbon dioxide (CO_2) is the most wide-spread one. In most cases its effect on climate change that results from burning transportation fuel exceeds 95 percent. (Mathers et al., 2019) In the figure below, provided by the United States Environmental Protection Agency (EPA), this number even reaches 97.1%. (Environmental Protection Agency, 2022)

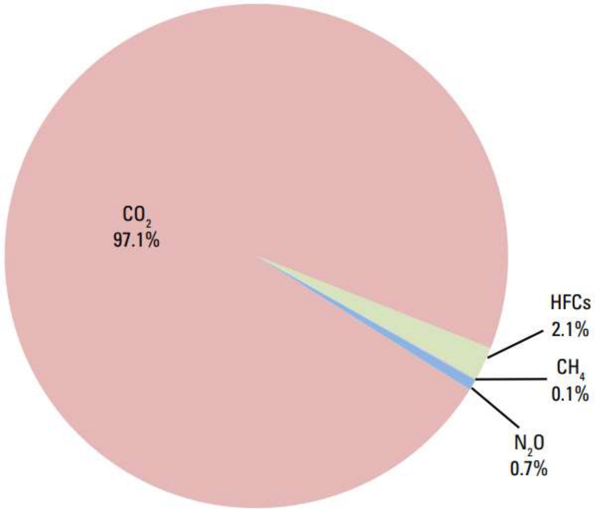

Figure 3. U.S. Transportation Sector Emissions by GHG (Environmental Protection Agency, 2022)

As explained by Mathers, among other greenhouses gases released in the process of fuel combustion are methane (CH_4) and nitrous oxide (N_2O). A common approach to GHG emissions calculations is to limit the calculations to CO_2 only because of its big share. The author argues, however, that such an approach underrates the overall impact of a company's operations, even though there's the benefit of simplified calculations. The incorporation of other GHGs could make an especially big difference when measuring the impact of alternative fuels, such as natural gas, which are associated with increased emissions of CH_4. (Mathers et al., 2019)

4.1 CO_2 emissions in transportation

Transportation as a whole significantly contributes to greenhouse gas emissions. For example, according to the United States Environmental Protection Agency, transportation's share of the greenhouse gas emissions in 2020 was 27%, which exceeds the amount of emissions produced by every other sector, such as electricity and industry, which accounted for 25% and 24% respectively. Figure 4 presents a more detailed chart. (Environmental Protection Agency, 2022)

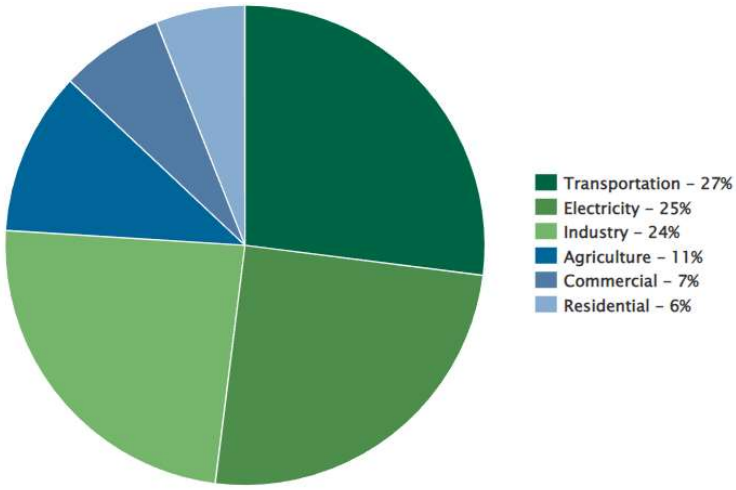

Figure 4. 2020 U.S. GHG Emissions by Sector (Environmental Protection Agency, 2022)

However, the transportation segment is itself comprised of several sections, among which light-duty vehicles are the biggest contributors to the total emissions at 57% of all the transportation and medium- and heavy-duty vehicles, i.e. trucks and buses, yield only 26% of the total amount, thus resulting in 7% of the entire greenhouse gas emissions amount. (Environmental Protection Agency, 2022)

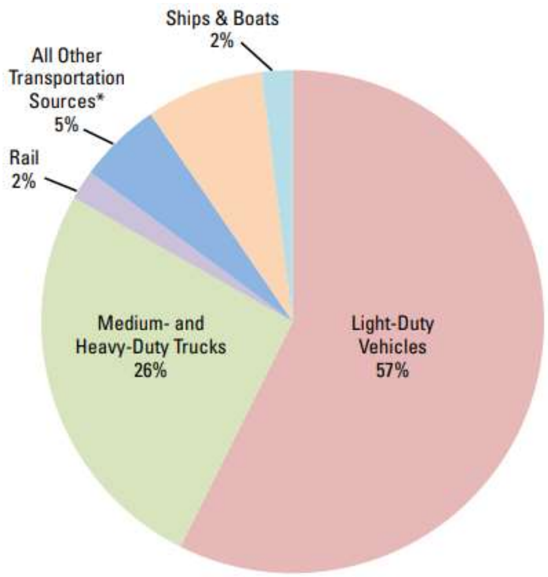

Figure 5. Share of U.S. Transportation Sector (Environmental Protection Agency, 2022)

European sources show similar data, according to which heavy-duty vehicles can generate up to 6% of all greenhouse gas emissions in some European countries. (European Commission, n.d.)

One of the factors contributing to the total carbon footprint in transportation is the tyres of the vehicles used. Tyres undergo a rather complex production process before they are ready for use, but it is not the production of those tires that affects the total amount of greenhouse gases emitted. According to the Nokian Tyres sustainability report (Corporate Sustainability Report 2020, 2021), the biggest contributor to emissions is the actual usage of the tyres which accounts for 89,5% of the total, while the share of the production process of the tires constitutes only 10%, 8% of which is comprised of the raw materials preparation and transportation and 2% of which is the result of the production, transportation and storage of the actual tires. The mass of the emissions differs depending on the source, but it stays in the range from 220 kg to 243,9 kg. For comparison, an average truck in the U.S. emits 161.8 grams of CO_2 per tonne-mile (Corporate Sustainability Report 2020, 2021; Mathers, 2015)

Since transportation emissions have been attracting researchers' and policy makers' attention for a long time, there are now many calculation methods available, which makes it easier for a company to track its carbon footprint. One such calculator is provided by the Environmental Defense Fund (Mathers, 2015). Others include but are not limited to Commercial Fleet's tools, Comcar Industry's table and Thrust Carbon's calculation instructions. (Carbon Footprint Calculator; Kg CO_2 per litre of petrol; West, 2021.)

Table 1. Carbon emissions calculation tools

Calculation method	**Description**	**Link**
EDF emissions calculator	The tool provides different ways to calculate CO_2 emissions caused by transportation. The most reliable way requires the distance, as well as the weight of the load and the emissions factor of the mode of transportation. These are then multiplied to each other.	https://business.edf.org/insights/green-freight-math-how-to-calculate-emissions-for-a-truck-move/
Commercial Fleet calculator	Provides a tool that calculates CO_2 emissions by the amount of fuel used, the money spent on fuel or mileage.	https://www.commercialfleet.org/tools/van/carbon-footprint-calculator
SunEarthTools	Allows to calculate emissions for electric vehicles, as well as for vehicles that run on petrol or diesel.	https://www.sunearthtools.com/tools/CO2-emissions-calculator.php#txtCO2_7
Comcar Industry	Provides a table with figures for cars with the highest emissions per litre of fuel used and cars that emit the least.	https://comcar.co.uk/emissions/co2litre/
CarbonCare	An automated calculator which takes two locations, cargo weight and the mode of transport as input.	https://www.carboncare.org/en/co2-emissions-calculator.html

In the field of transportation, the biggest impact on the environment in terms of emissions is caused by the mode of transport in question, and when it comes to road transportation, the emissions caused by trucks raise concerns. Therefore, various models have been created to systematize and calculate these emissions. For example, the Environmental Defense Fund (EDF) provides the following formula: Greenhouse Gas Emissions = D x W x EF, where D is the distance travelled, W is the weight of the freight and EF is the emissions factor of the mode of transport, which the EDF also provides in their handbook. (Mathers et al., 2019)

4.2 CO_2 emissions in production

The GHG protocol, which was created by World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD) and first released in 2001, provides tools and methods to manage greenhouse gas emissions, as well as instructions on how they should be reported. Its standards have become widely used throughout the years, thus making it exceptionally relevant when discussing CO_2 emissions. For example, in 2016 92% of the 500 biggest US companies used the GHG Protocol in their reporting. (Russel, 2014; Greenhouse Gas Protocol, 2017)

According to the GHG Protocol, greenhouse gas emissions can be categorized into three types called scopes, which are scope 1, scope 2 and scope 3. Scope 1 refers to the emissions directly caused at the production site. Scope 2 refers to the energy used in production. Finally, scope 3 refers to the indirect emissions in the value chain, excluding scope 2. (GHG Protocol, n.d.)

Scope 1 and 2 emissions are the ones directly related to the operations of the company happening on-site. Scope 1 emissions are usually focused on the most because of the relative straightforwardness. It could be the emissions produced by an airline’s airplanes or the ones emitted when using a furnace for manufacturing a product. Scope 3 emissions, on the other hand, are less clear and may cause confusion. However, to produce the best results, both direct and indirect emissions should be examined. (Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p.5)

As a study by Hertwich & Wood (2018) indicates, although the importance of scope 3 emissions is known, there is no consistent practice of incorporating them into decision-making. The way such emissions can be accounted for can be either production-based or consumer-based. The former approach attributing the emissions to the place where they occur and the latter considering those as the emissions of where the goods are eventually consumed. As one can see in figure 6, there is a clear relationship between the emissions calculated by the Corporate Standard, the Scope 3 Standard and the products life cycle. These emissions occur regardless of how they are being recorded, however, there is always for room different calculation methods. The scope 3 emissions may be counted as the manufacturer's responsibility when using one approach and as the final customer's responsibility when using another.

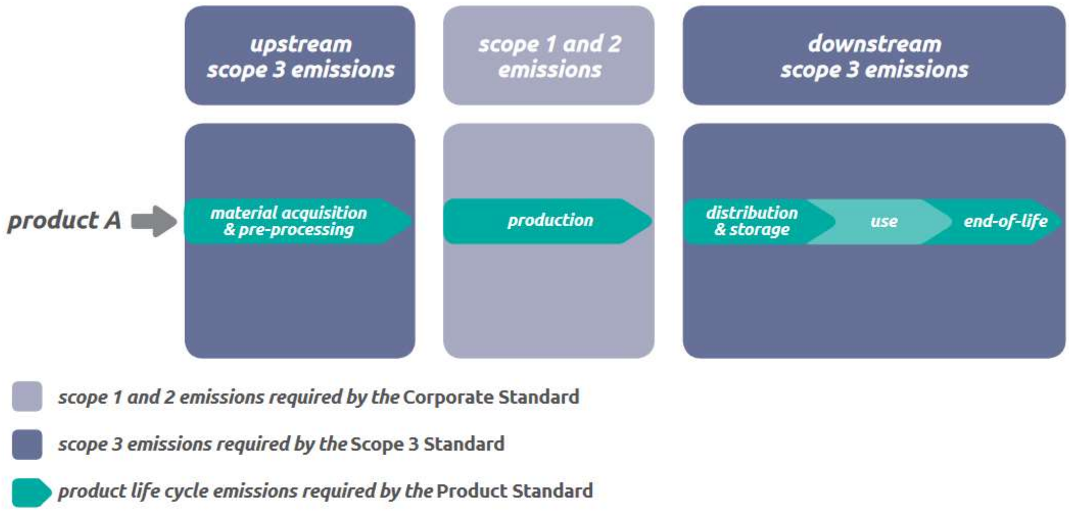

Figure 6. Relationship between a scope 3 GHG inventory and a product GHG inventory (GHG Protocol, n.d., p. 8)

4.3 Emissions in metal production

For many years there have been people interested in how metal production is affecting the environment. For example, the assessment of such environmental impact is the main focus of a study by Norgate (2007). According to the study, the emissions, which are not only gases, but liquids and solids too, fall into two categories: direct and indirect. Direct emissions are released during mining and processing of metals and indirect ones are related to the use of raw materials and utilities.

The authors of the study consider various kinds of environmental impact caused during typical processes applied to metals and the impact is divided into four categories, which are the overall energy consumed, the greenhouse gases released, although the focus is mainly on CO_2, the acidification gas emissions, as well as the solid waste. As proven by the authors, it is important to consider every stage of metal production and their cumulative impact on the environment, since in some cases an increase in energy consumed in one stage, for example the extraction stage for aluminium and magnesium compared to steel, results in lower energy consumption in the long term when the aforementioned metals are used instead of steel in lightweight motor vehicles.

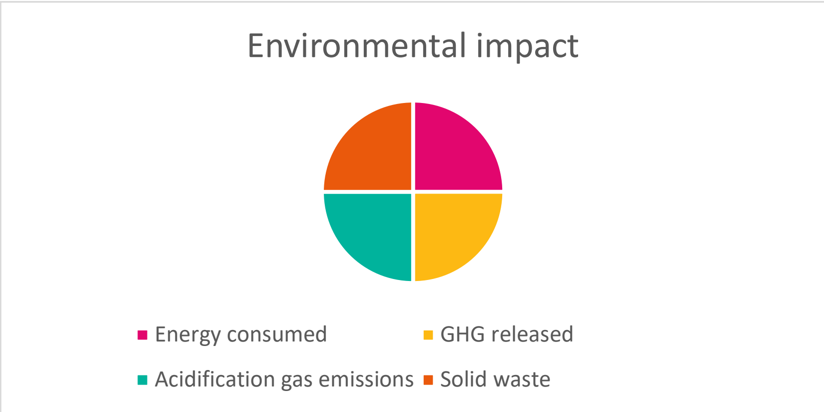

Figure 7. Categories of environmental impact

Naturally, the question of environmental impact reduction arose in the study by Norgate. and there were proposed such measures as producing stainless steel by means of bath smelting, utilizing a different process for titanium production and using vertical electrode cells to produce aluminium, which has significant energy saving potential. (Norgate et al.,2007)

5 Production processes

5.1 Production methods

As evident from history, production methods have not stayed the same at all times, but evolved. For example, Henry Ford is well-known for his invention of an assembly line which decreased the time needed for one car’s assembly, since the workers did not have to move around.

Currently, according to Business Case Studies, there are four main methods of production, namely job production, batch production, flow production and mass production. Each of these has its own characteristics. (Business Case Studies, 2019, para. 2-5)

Job production, as described by Daw, is a way of delivering unique products or services. Such services are often provided by smaller companies, or even individual specialists, and are highly valued. A typical application of such a method is when a client requires custom products or services. Such focus on one particular project usually results in better customer satisfaction, although it also comes at a higher cost. (Daw, 2022, para. 1-4)

According to Pearson, batch production is defined as a way of producing multiple items of the same product at a time. In batch production, while a batch is being processed at one stage of the manufacturing process, another cannot begin the same process phase. Batches and their specifications may, in turn, vary in terms of colours and sizes, which is the manufacturer's responsibility to decide. Quality control in such an approach to production may be implemented after each stage. (Pearson, 2021, para.1)

As stated by Pearson, there are certain advantages to batch production which make it attractive for small to medium-sized manufacturers. Such advantages include lower costs, due to machinery not being operation at all times, and discounts from sellers due to bigger purchasing batches. Another advantage is the approach's flexibility. It is possible to make changes to the product and not be left stuck with the exact same one. (Pearson, 2021, para. 3)

However, there are disadvantages as well. These include time inefficiencies, since, as mention before, machinery's downtime tends to be significant. Another aspect is the impossibility of a unique product's creation. Even though changes can be made between different batches, there are still very clear boundaries. One more disadvantage is the method's comparative expensiveness when compared to smaller-scale operations. (Pearson, 2021, para. 4)

According to Bland, flow production uses an assembly line in which the product undergoes different stages before being packaged and dispatched. This is a highly automated way of production and it is suitable for manufacturing large quantities of a standardized good. The advantages of such an approach include a consistent level of quality, a minimal need of human intervention and its ease of scalability. Its disadvantages are large initial investments and a lack of flexibility. Generally, such a production method is not utilized by small to medium-sized manufacturers. (Bland, 2022, para. 2-7)

5.2 Deep drawing

Deep drawing, being a process of forming sheet metal without material removal, does not produce greenhouse gases on its own. Hence, when considering deep drawing's contribution to the climate impact, the emphasis is to be placed on its energy consumption. Figure 8 illustrates how deep drawing transforms metal sheets.

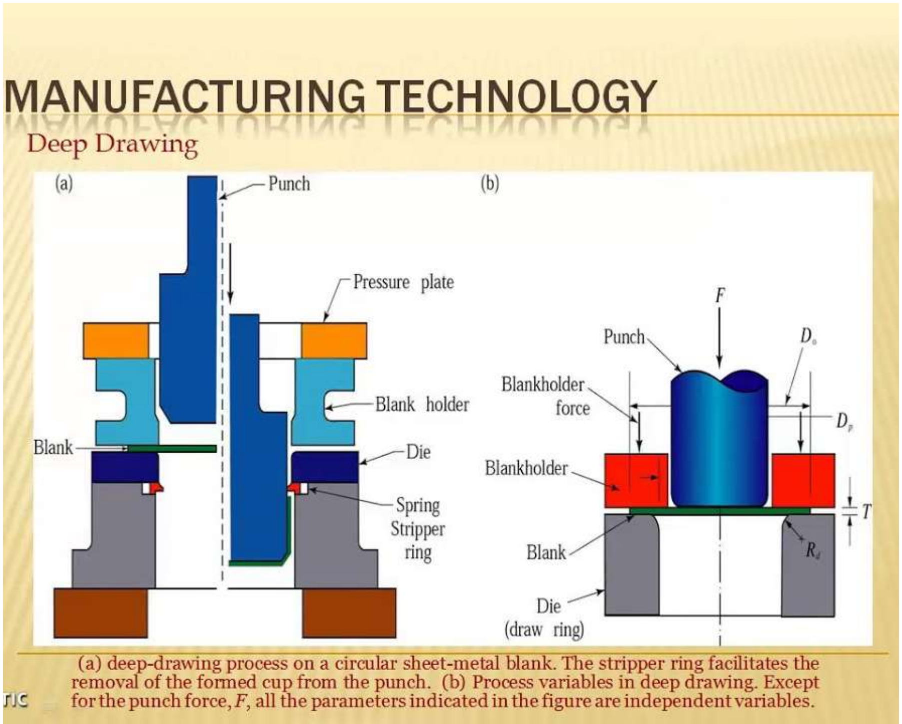

Figure 8. Deep drawing (Venkatreddy ragireddy, 2019)

Deep drawing consists of several deformation stages, as it is described by Gao (2018).

1) The internal work required to deform the object in the desired shape by the means of compression and tension.
2) The bending work.
3) The friction work.

In the first stage consisting of internal work, during the deep drawing process, the metal is directed towards the center. This causes strain in the following way:

- Compression strain
- Tension strain

The bending stage also produces tension, as well as compression in the material. Tension causes the outer side of the sheet to stretch and lengthen, whereas compression causes the inside to shorten.

The neutral axis is the border line in the blank being bent, where the tension and compression are not performed. Therefore, it has a constant length. The sheet material bends when the punch exceeds the bending moment.

The study shows that the difference between the theoretical energy consumption and the results received during the experiments fluctuates between nearly 7% and 9.64%. The actual values were between nearly 7 kJ and 8.5 kJ. (Gao et al., 2018.)

5.3 Laser cutting

Laser cutting, as evident from the name, is a technology that cuts material with the help of a laser. Figure 9 provides an example of how a laser cutting machine looks.

Figure 9. Laser cutting machine (The Fabricator, 2014)

The process of laser cutting has a long history and it comes as no surprise that its impact on the environment has been a subject of interest for a long time. For example, a study from 1991 by Dawn Tharr examines two cases of CO_2 laser cutting as a source of airborne emissions. In the first case the main contaminants were fused silica up to 2.2 mg/m^3, which was much higher than the allowed limit of 0.1 mg/m^3, when cutting fused quartz, barely detectable quantities of chromium, copper, iron, nickel, and zinc, when performing metal cutting. When cutting plastics, the significant emissions were those of ethyl acrylate, which is a known carcinogen and may cause nausea and other effects. The second case considered Kevlar material. Among potentially hazardous emissions detected were nitrogen oxides, however, the limits were set to a relatively high number, so other emissions may not have been detected. Therefore, the authors of the study concluded, that more observations were needed. (Tharr, 1991)

Since the study was conducted a long time ago, the laser in question was a CO_2 laser, which is a 1st generation laser. Currently, according to Kellens, the most modern 3rd generation lasers use direct diodes as their power source, which, however, still have not replaced CO_2 lasers that are widely used. Fiber and disk lasers are known as 2nd generation lasers and are also more energy efficient than CO_2 lasers, however, this technology has its limitations, and such lasers cannot be utilized for materials as thick as 4 mm and above providing the same cutting quality. (Kellens et al., 2014, p. 855)

According to the study, in the production of the nesting energy consumption is the biggest contributor to the total environmental impact. Cutting energy corresponds to over 44%, air movement energy accounts for 13,13% of the total and other kinds of energy, such as additional energy, production ready energy and table changing energy, account for 9.48%. This results in energy consumption contributing over two thirds of the overall environmental impact. Other factors include the assist gas, whose contribution is over 11% of the total, and about 20% of the entire impact is attributed to material waste. Also, during the production process, direct emissions are released, such as aerosols, nitrogen oxides and ozone, however, the amounts released have little significance and their contribution to the overall environmental impact is close to 0%. (Kellens et al., 2014, pp. 856-859)

The authors of the study suggest several areas for improvement.

- Process/machine tool selection
  Even when considering the same technology, namely CO_2 lasers, the selection of the right cutting tools can save up to 3 kW. Naturally, more advanced lasers result in even more significant energy savings. The energy demand for a CO_2 laser compared to a disk laser could be more than twice as high.
- More efficient tool components
  As the study indicates, different tool improvements could result in a 1-2% increase in efficiency.
- Change of technology
  As the study indicates, switching from a CO_2 laser to a disk or a diode one, could boost the efficiency of the operations from 5-10% to
- Reduction of standby energy
  Improvement in technology allows for saving modes, resulting in significant reduction of energy used, since standby time accounts for 15% of the machine's use.
- Integrated versus central peripherals
  The idea is for CO_2 lasers to generate the assist gas used locally, which could reduce the environmental impact by one third, compared to the cylinder-based supply.
- Optimized process parameters
  Environmentally, the most optimal conditions for a laser to function is at its highest output power and cutting speed, which minimizes the time it takes to finish a piece. The cutting quality is also to be upheld.

- Selective actuation of sub-units
  Helps save the energy on the units currently not being used. This can result in an annual saving of 3.2MWh for a one-shift regime.
- Energy recovery / cascading
  The measure is more effective for CO_2 lasers, because of huge energy losses that could amount to 90-95%. The use of more modern lasers would already provide better energy efficiency, which makes the savings from energy recovery less significant.

(Kellens et al., 2014)

5.4 Grinding

By its own nature, grinding does not release any emissions into the atmosphere, since it is a process of removing excess material from an object's surface that uses a grinding wheel. No part of this process leads to greenhouse gases being released. However, the direct emissions are not the only ones that should be considered. As it was described above, scope 2 emissions, namely the emissions associated with the energy consumption happening on-site, are a big contributor to the total amount released in the production process. Therefore, this theoretical segment is focused on the energy consumed in the process of grinding.

In a paper by Li, grinding is considered in terms of its eco-efficiency, which is defined as the relation of value of a product to its ecological impact. The study authors use the term "unit process" to describe a service creating value and consuming energy. The idea behind using this concept is that if the correlation considered is the one between the energy consumption and the process parameters, the matters become complicated, since the product resulting from the changes will differ. Thus, it becomes more difficult to compare the systems. (Li et al., 2012, p. 59)

An experiment was conducted to research the energy consumption of a grinding machine. Upon the results receipt, the specific energy consumption (SEC), which is the energy needed for grinding 1 cm^3 of the material, was calculated using the following equation.

$$SEC = \frac{\int_{t_1}^{t_2} p_i \, dt}{Q}$$

where Q stands for the total material removed, p_i is the energy consumed during the process of grinding starting at t_1 and ending at t_2. This and other models arrive at the conclusion, that the material removal rate (MRR) is a crucial factor in terms of energy consumption. (Li et al., 2012, p. 60)

However, the factors influencing grinding's eco-efficiency are not limited to amount of energy consumed during the process itself. Other factors include the use of a coolant and dressing. In the case of the grinding machine the authors used, Studer S120, dressing required around 5 kW. The coolant pump consumed around 2 kW during the entire process. Since the authors assume the production to take place in Europe, 1 kJ of electricity is estimated to result in 0.000168 kg CO_2. The study used a cubic boron nitride (CBN) and an aluminium oxide (Al_2O_3) grinding wheels. The results show higher eco-efficiency for the CBN grinding wheel, due to its lower wear. (Li et al., 2012)

Another study which examines both the energy usage and the environmental impact reflected in CO_2 emissions, that result in the grinding process by Ding (2014) has conducted experiments with the following results. Since the study considers energy consumption, the usage of grinding fluid, a grinding wheel and lubricant as the equivalent to the resulting CO_2 emissions, the biggest contributors are the energy consumption and the grinding wheel usage.

5.5 Electricity

Since many of the described above processes' main environmental contribution is that related to their energy consumption, in this section Finland's energy consumption will be considered.

According to the information provided by Statistics Finland (2021), which provides information on Finland's energy use since 1970. In the year 1970 the share of fossil fuels of the total energy consumed was over 70% with the rest coming from renewable energy sources. By the year 2020, 50 years later, the amount of fossil fuels used had only insignificantly decreased from 141251 GWh to 129570 GWh, however, fossil fuels' share had dropped by a big margin. The total energy use amounted to 354814 GWh which made the share of fossil fuels 36.5%. The change is evident in the diagram presented below in figure 10. Given the existing tendencies, it is unlikely that fossil fuels will go out of use soon, however, the increase in production volumes will likely be covered by renewable energy sources.

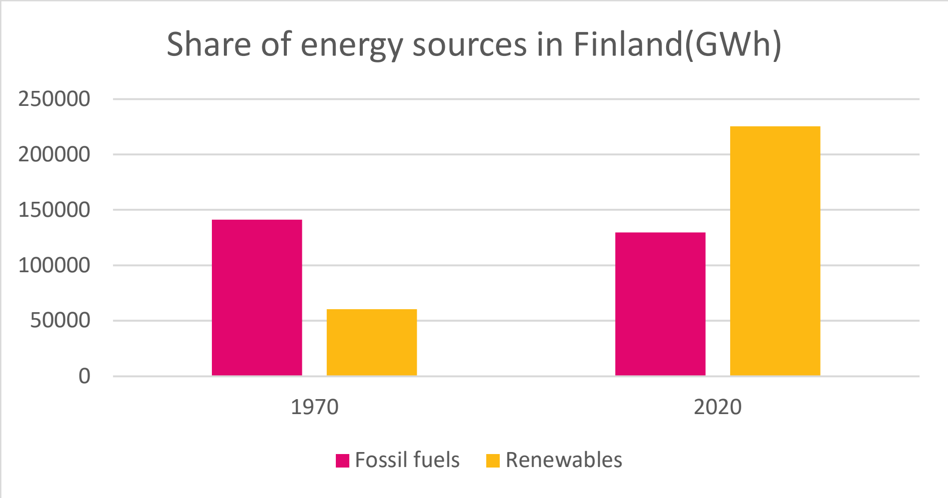

Figure 10. Energy consumption in Finland

Another source on energy consumption in Finland provides a chart of various energy sources in Finland in 2021. The chart is presented in figure 11.

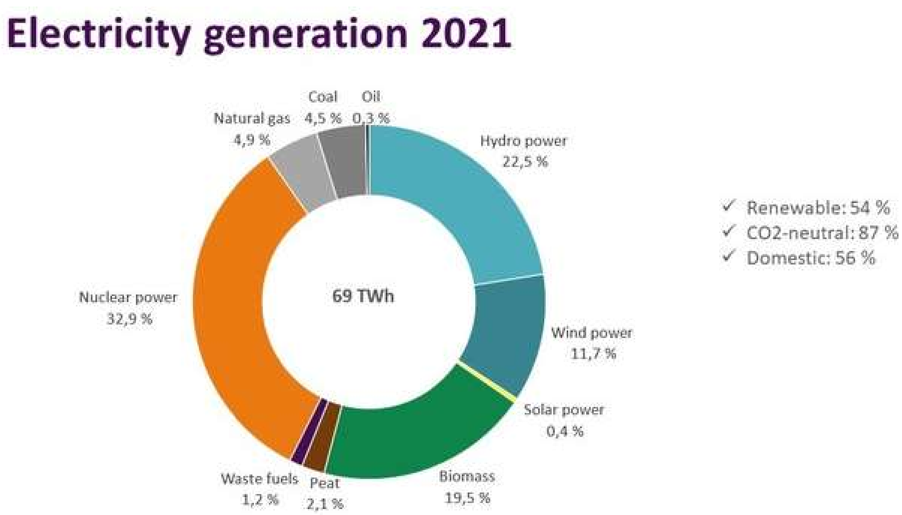

Figure 11. Sources of electricity generation in Finland (Finnish energy, 2022)

The environmental impact of energy production in terms of CO_2 emissions varies by country. For example, according to RTE, which is the French electricity transmission operator, coal-fired power plants produce 0,986 tons of CO_2 per MWh, the plants that use oil are responsible for 0,777 tons of CO_2 per MWh, the plants that work on biomass produce 0,494 tons of CO_2 per MWh, gas-fired plants' output is equal to 0,429 tons of CO_2 per MWh and all the other possible power plants do not contribute to CO_2 emissions. (RTE, 2022)

As stated by Motiva (2022) in their analysis of CO_2 emissions factors based on the data provided by Statistics Finland, the average emissions factor for electricity production based on the years 2018-2020 is 89 kg CO_2/MWh. District heating accounts for 177 kg CO_2/MWh and margin-based electricity production accounts for 600 kg CO_2/MWh.

6 Research implementation

6.1 Research methods

Research is a way to expand one's knowledge of a certain topic and it may be conducted in various ways, depending on what the topic is and how the researcher wants to approach it. These ways of conducting research are called research methods. Research methods are generally categorized as qualitative, quantitative or mixed, when both of the approaches are utilized. (Shorten & Smith 2017)

Research methods are described in detail by Mildred L. Patten and Michelle Newhart. The empirical approach to research is based on experience and observation and it incorporates both qualitative and quantitative research methods. Quantitative research usually means numbers. When data has been gathered in numerical form, its subsequent analysis is quantitative research. Some data can be initially obtained without using numbers, but if it is then transformed into numbers and analyzed this way, it still falls into the category of quantitative research. Scientific findings that are not translated into numbers are spoken of as qualitative research. (Patten & Newhart, 2018)

The ways in which data is obtained also depend on the goals of the researchers and the research methods used. Quantitative research most commonly involves highly organized questionnaires or interviews designed to receive a numerical answer. Qualitative research, on the other hand, aims for a more narrative-based response from interviewees to create a complete picture of a phenomenon full of details that are not presented as numbers. There is an important difference in research planning between the two methods. Quantitative research usually implies deductive planning when current knowledge or hypotheses are applied to a new situation to understand if existing theories are fully applicable or if some changes are necessary. Qualitative research generally means inductive planning, since it is usually used when little has been established about the topic at hand. (Patten & Newhart, 2018)

6.2 Research process

Based on the research questions identified in chapter 2, the research process followed this scenario:

1) Understanding the whole production process requires knowledge of how an item is produced. The only people who certainly have the correct information are the ones working for this company. Therefore, an interview with the company representatives had to be conducted, where this question was answered in detail and the limitations of this research were discussed.
2) Calculating the total amount of CO_2 emitted in the process, as well understanding the entire climate impact in its complexity, requires theoretical knowledge of the manufacturing processes that comprise the production process of the item and of the climate impact of transportation with the help of which parts and raw materials are delivered. To achieve that, books and research papers on the topic had to be studied. When the processes' environmental impact was known, more data had to be gathered from the company to receive the exact data needed for further calculations.
3) The next step was analysis and discussion of what could be done to decrease the environmental impact of the operations. This also involved study of previous research, as well as own considerations on the topic.

6.3 Collected data

During the data gathering stage, multiple interviews were conducted and much of data was received by email. The data included the bill of materials for the target product, the amounts of raw materials and other items purchased for the production of the final product, the machines utilized in the production, the weight of each item and the package used to transport it, as well as the transportation routes and the production processes involved with their process times and characteristics in terms of power consumption. The breakdown of the means to receive data can be found in Table 2.

Table 2. Data inventory

Data type	**Quantity**	**Original data source**
Interviews	4	Company personnel
Documents	5	Company personnel
Observational data	1	Researcher

In terms of transportation, two important points were found. There were two suppliers, one was based 263 km away from the factory and the other one was based 266 km away from the factory. The former delivered items out of which company X manufactured its final product and the latter was responsible for delivering steel sheets.

As to the manufacturing process, the details are presented in Table 3.

Table 3. Processes inside the factory

Process	Time (seconds)	Maximum power	Other information
Process 1	44	0.67 kW	
Process 2	65	4 kW	
Process 3	711	1.05 kW	
Process 4	340	0.23 kW	
Process 5	400	1.2 kW	10 pcs at a time
Process 6	50	0.09 kW	10 pcs at a time
Process 7	162	1.35 kW	10 pcs at a time
Process 8	47	0.01 kW	10 pcs at a time

6.4 Emissions calculations

6.4.1 Transportation

As mentioned in the CO_2 emissions in transportation chapter, transportation carbon footprint can be calculated by using different methods, including the EDF handbook, as well as the calculators provided by Commercial Fleet, Comcar industries, SunEarthTools and CarbonCare. The exact way to calculate it would depend on the known parameters.

The EDF calculator is provided by a well-known organisation and it includes different calculation methods which a company can utilize depending on its circumstances. One is able to calculate a truck's emissions knowing its route's distance only or having both the distance and the load available. Comcar industries provides data on how much CO_2 is emitted per one liter of petrol used for different vehicles, however the Comcar table contains a limited number of cars which are not used for freight transportation, therefore, this method of calculation was left out. Commercial Fleet's calculation tool requires the amount of fuel used, the amount of money spent on fuel or the distance travelled and fuel consumption of the vehicle. SunEarthTools provides a variety of calculation methods based on fuel consumption data. It also provides a way to calculate the CO_2 emissions from electricity and heat, however, the data is rather old. CarbonCare is a ready-made tool for CO_2 emissions calculations according to the EN16258 standard. It requires the transportation mode, the weight of the load and the route travelled. Given the data above, EDF and CarbonCare provide the most easily accessible and up-to-date tools, therefore, the two calculation methods were selected.

In the case of the EDF calculator, If the distance travelled and the weight of the shipment are known figures, the equation would be as follows

GHG Emissions = D*W*EF,

where D is the distance, W is the weight and EF is emissions factor.

The values provided by EDF use the imperial system, so they are to be transferred into the metric system. In the event of both the distance and the weight of the shipment known, the unit for the emissions factor is grams per short ton-mile. A short ton-mile equals 2000lb, which is 907.1847 kg. A mile is 1.609344 km. In order to transfer the unit into the metrics system, the following equation can be used

1 short ton-mile = 907.1847 kg * 1.609344 km = 1460 kilogram-kilometers = 1.46 ton-kilometers

The emissions factor is 161.8 g CO_2/short ton-mile, which is 161.8 g CO_2/1.46 ton-km = 110,822 g CO_2/ton-km. This value can be used for all further calculations involving weight-based emissions factor for truck shipments. It indicates how much CO_2 is released into the atmosphere by a truck carrying a ton of weight after travelling a distance of one kilometer.

In order to conduct calculations, it was important to note that deliveries varied in their size, so a 0.8-coefficient was chosen to determine an average delivery. The usual numbers were 500 pieces of items and 12000 kg worth of metal sheets. Thus, an average delivery was as follows

500 * 0,8 = 400 pieces,

12000 * 0,8 = 9600 kg.

One blank weighed 25,92 kg, so the total number of blanks and, thus, items produced was

9600 / 25,92 = 370.

To find out the number of deliveries required in each case to be able to produce the same number of the final product, the least common multiplier had to be found. For numbers 370 and 400, the least common multiplier is 14800.

14800/400 = 37,
14800/370 = 40.

Hence, 37 deliveries were required for the items and 40 deliveries were required for the metal sheets in order to produce 14800 pieces of the final product. Thus, to calculate the impact of one item's manufacturing, the amount of CO_2 emitted by the deliveries must be added to the amount caused by the production of the 14800 pieces and the sum must then be divided by that number.

In the case at hand, transportation by road is done using two routes: from the components supplier and from the steel sheets supplier to the production plant. The distances to the plant are 266km and 263km respectively. With a batch of 1347.8 kg transported from the components supplier, by following the formula provided above, the emissions are equal 266km * 1347.8 kg * 110.822 g CO_2/ton*km = 39731.33 grams of CO_2 ≈ 39.73 kg CO_2. With a batch of 12160 kg transported from the steel sheets supplier, the emissions are equal 263 km * 12160 kg * 110.822 g CO_2/ton*km = 354417.6 grams of CO_2 ≈ 354.44 kg CO_2. The total amount of emissions is 394.15 kg CO_2.

The adjusted calculations using the 0.8-coefficient are as follows. The batch transported from the components supplier is responsible for 266 km * 1347.8 kg * 0.8 * 110.822 g CO_2/ton*km ≈ 31.76 kg CO_2 per delivery, thus, 37 deliveries account for 31.76 kg CO_2 * 37 ≈ 1176 kg CO_2. The batch transported from the steel sheets supplier accounts for 263 km * 12160 kg * 0.8 * 110.822 g CO_2/ton*km ≈ 283.5 kg CO_2. Thus, 40 such deliveries account for 283.5 kg CO_2 * 40 ≈ 11341 kg CO_2. The total amount of emissions is 12517 kg CO_2.

The same calculations can be done using CarbonCare's calculator. It is a tool that takes in the data on the cargo weight, the mode of transport, as well as the starting point and the end point of the delivery. In this case the results for transportation emissions from the parts supplier and the steel supplier are in tables 4, 6 and 5, 7 respectively. Tables 6 and 7 present more accurate values, since they account for a more realistic transportation model and are, therefore, used for further calculations and conclusions.

Table 4. Transportation emissions from the components supplier

Emission units	Emission values	Clarification
CO_2e	36.50 kg	TTW
CO_2	35.85 kg	TTW
CO_2e	44.31 kg	WTW

Table 5. Transportation emissions from the steel supplier

Emission units	Emission values	Clarification
CO_2e	150.23 kg	TTW
CO_2	147.68 kg	TTW
CO_2e	182.55 kg	WTW

Table 6. Transportation emissions from the components supplier (adjusted)

Emission units	Emission values	Clarification
CO_2e	18.13 kg	TTW
CO_2	17.82 kg	TTW
CO_2e	22.02 kg	WTW

Table 7. Transportation emissions from the steel supplier (adjusted)

Emission units	Emission values	Clarification
CO_2e	117.64 kg	TTW
CO_2	115.35 kg	TTW
CO_2e	142.75 kg	WTW

TTW (Tank-To-Wheel) emission value is the direct result of a delivery. WTW (Well-To-Wheel) also accounts for the CO_2 emissions and their equivalent required for the fuel production and transportation. The combined TTW value is 186.73 kg CO_2e. The combined value for WTW is 226.86 kg CO_2e. The difference between the values produced by the two calculation tools is rather significant.

The results for adjusted cargo values are also presented in tables 6 and 7. The WTW value for the parts delivery is 22.02 kg CO_2e and the total for 37 deliveries is 22.02 kg CO_2e * 37 = 814.74 kg CO_2e. The WTW value for the steel delivery is 142.75 kg CO_2e and the total for 40 deliveries is 142.75 kg CO_2e * 40 = 5710 kg CO_2e. The combined value is 6524.74 kg CO_2e.

6.4.2 Production

In order to calculate the environmental impact of the production processes, it is required to calculate the amount of energy consumed and then calculate how much CO_2 or CO_2 equivalent is emitted during the process.

Based on the data from table 2, the total amount of energy consumed in the process of producing one item is calculated by multiplying the time in hours by maximum power of the process stage and divided by the number of parts processed at a time. To transform seconds into hours the number of seconds must be divided by 3600. Hence, the calculation is as follows

(44 * 0.67 + 65 * 4 + 711 * 1.05 + 340 * 0.23 + (400 * 1.2 + 50 * 0.09 + 162 * 1.35 + 47 * 0.01)/10)/3600 = 0.3291 (kWh)

The energy consumption for one item produced is thus 0.3291 kWh and the energy required to produce 14800 items is 4870.01 kWh. These same calculations can be found in Figure 12.

Manufacturing Phases	**Time for one part (seconds)**	**Time in hours**	**Max.Power**	**Max Power (kW)**	**Energy**
Process 1	44	0,012	0,67 kWh/piece	0,67	time*max power
Process 2	65	0,018	4 kW	4	time*max power
Manufacturing Phases	**Time for one part (seconds)**	**Time in hours**	**Max.Power**	**Max Power (kW)**	**Energy**
Process 3	711	0,1975	1,05 kW	1,05	time*max power
Process 4	340	0,094	0,23 kW	0,23	time*max power
Process 5	400	0,111	1,2 kW	1,2	time*max power
Process 6	50	0,014	0,09 kW	0,09	time*max power
Process 7	162	0,045	1,35 kW	1,35	time*max power
Process 8	47	0,013	0,01 kW	0,01	time*max power
	Manufacturing batch	Maximum delivery batch (pieces)	Adjusted delivery batch	Least common multiplier	Least common multiplyer (max)
Raw materials 1	250	500	400	14800	115500
Raw materials 2	12000 kg	462,96	370	14800	115500
K-factor	0,8				
	Energy consumed per piece (kWh)	**Parts processed at a time**	**Electricity emissions factor (kg CO2/MWh)**		
Process 1	0,0082	1	89		
Process 2	0,0722	1			
Process 3	0,2074	1			
Process 4	0,0217	1			
Process 5	0,0133	10			
Process 6	0,0001	10			
Process 7	0,0061	10			
Process 8	0,0000	10			
Total per piece	0,3291				
Total for adjusted delivery	4870,0099				
CO2 per piece (kg)	0,0293				
Total CO2 emitted (kg)	433,4308801				

Figure 12. Energy consumption calculations

Given the coefficient of 89 kg CO_2/MWh for electricity consumption in Finland (Motiva, 2022), the environmental effect of the production of 14800 items is (4870.01 kWh * 89 kg CO_2)/(1000 kWh) ≈ 433.44 kg CO_2. The emissions value for one item is (0.3291 kWh * 89 kg CO_2)/(1000 kWh) ≈ 29.3 g CO_2.

6.4.3 Total emissions

In order to calculate the environmental impact in terms of CO_2 emissions for one item produced, the transportation emissions should be added to the emissions or their equivalent needed to process the entire delivery batch. In the case of one delivery batch being enough to produce 500 items, the transportation CO_2 emissions are added to the ones emitted during the process of producing the 500 items.

Calculation using the EDF model:

(0.3291 kWh * 500) * 89 kg CO_2/ (1000 kWh) + 394.15 kg CO_2 = 408.8 kg CO_2.
408.8 kg CO_2 / 500 items = 0.818 kg CO_2 / item

Calculation using the CarbonCare model:

(0.3291 kWh * 500) * 89 kg CO_2/ (1000 kWh) + 226.86 kg CO_2 = 241.5 kg CO_2.
241.5 kg CO_2/500 items = 0.483 kg CO_2 / item.

Using the adjusted values, calculations with the EDF model and the CarbonCare model respectively are as follows:

0.3291 kWh * 14800 * 89 kg CO_2/1000 kWh + 12517 kg CO_2 = 12950.5 kg CO_2.
12950.5 kg CO_2 / 14800 items ≈ 0.875 kg CO_2/item, out of which 0.844 kg CO_2 are emitted in the transportation stage.

0.3291 kWh * 14800 * 89 kg CO_2/1000 kWh + 6524.74 kg CO_2 ≈ 6958.23 kg CO_2.
6958.23 kg CO_2/14800 items ≈ 0.47 kg CO_2/item, out of which 0.444 kg CO_2 are emitted in the transportation stage.

7 Results and Conclusions

7.1 Results

The objective of this thesis was to answer the following questions:

1) What does the entire production process look like in terms of the chosen product?
2) How much carbon dioxide is emitted in each stage of the supply chain and in total?
3) How can such calculations be automated for other products?

Based on the interviews with the company personnel and company documents, an analysis of the supply chain and the production process was conducted. Thus, the answer to the first research question was found during the interviews and the production process examination and the results are as follows:

1) Transportation of sheet metal to the production plant. The routes considered start at the sheet metal supplier and the components supplier, both located in Finland, even though the ultimate supplier of raw materials is further away. This is done in order to optimize the scope of work, as well as account for other parties also being responsible for the shipments.
2) Process 1.
3) Process 2.
4) Processes 5-8.
5) Process 3.
6) Process 4.
7) Parts sent to the painting contractor. This was limited out of the scope of the current work.

Based on the data received from the company on the processes involved in the manufacturing of their product, the energy consumption of each individual stage and its duration, the transportation distances and amounts, as well as the information on the energy sources in Finland, calculation was performed on how much CO_2 or CO_2 equivalent is emitted in both stages over a long period of time and how that translates into emissions per one item produced. Different tools and methods for transportation emissions were discovered in the process. Depending on the calculation method, the environmental impact was either 0.875 kg CO_2/per item or 0.47 kg CO_2/item. The manufacturing stage was responsible for 29.3 g CO_2/item. This means that the biggest environmental impact was caused by transportation, accounting for around 94-97% of the CO_2 released into the atmosphere during the production process of one item, depending on the calculation method. This is presented visually in Figure 13 below.

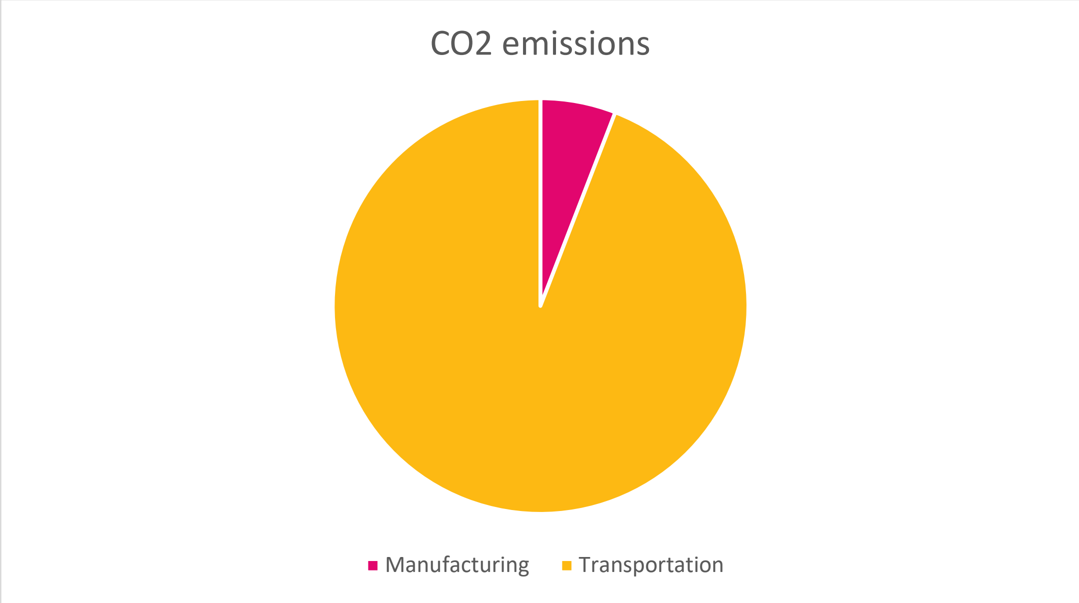

Figure 13. Emissions distribution

The data gathered during the research process, such as the manufacturing phases, their takt times and energy consumption, as well as the transportation data on components and raw materials delivery, was entered into a Microsoft Excel document which served as a calculation tool. As a result of the calculations, not only was the environmental impact of company X discovered, but the company also received calculation tool which can be applied to further calculations for other products in the future. The tool requires manual data entry and one of the transportation emissions calculators must be used outside the said tool, but with the formulas in place, the calculation process got significantly simpler as a result.

7.2 Conclusions

Since transportation emissions comprise the biggest part of the emissions in the process, the primary focus should be on transportation optimization and only then on production. In terms of production, the biggest contributors were welding and laser cutting. Therefore, if the focus is to be put on the production processes, these stages ought to be considered first.

There were stages in the process, whose impact was limited out of this work, such as intralogistics energy expenses and the usage of gas in the process 3 stage. It should be noted, however, that even in the event of the gas making up as much as a half of the emissions released during the process 3 stage, the overall environmental impact of transportation would still stay above 90% of the total.

8 Discussion

8.1 Significance

The work will now enable company X to measure their environmental impact and conduct further research into it. This is the first step on the company's way to being completely aware of their impact on the climate and reducing it. Further calculations were simplified as a result of this work and the future research could, in turn, be conducted in a faster pace. Additionally, this work can facilitate higher quality work to avoid scrapped material and, hence, unnecessary CO_2 emissions.

On a bigger scale, this work has a potential of attracting more attention to the topic at hand and increasing its visibility. This will lead to other companies following in their footsteps and thus building towards a sustainable future. The calculation tool can be reused by other companies and adjusted to their particular needs.

8.2 Reliability and validity

Reliability of a research means one's ability to reproduce the same results under the same conditions (Middleton, 2019). The research's results were received using mathematical calculations and can be repeated using the same entry data with the same results.

Validity of a research can be categorized into different types which are defined by the research's ability to measure the exact values it was intended to measure, inclusion of every relevant aspect of the concept measured and exclusion of every irrelevant one and its comparability to a known valid method of research (Middleton, 2022). This research was set to measure the environmental impact of the company in terms of CO_2 released and it did exactly that. The downside there were the two methods used to calculate the transportation emissions which produced different results. Both of the tools are provided by respected organisations and could be used in calculations, however, the method provided by CarbonCare uses the European standard EN16258 and should be preferred over the one provided by EDF, that primarily uses the imperial system of units and its main focus must be on the US.

The work was limited in terms of the input data, since it did not consider the entire supply chain and can thus be contested. However, there were good justifications to leave out parts of the supply chain, as mentioned in chapter 2. The data gathered and used in the calculation directly contributed to the total amount of emissions and thus making the research valid on this account.

8.3 Possibilities for further research

This work can be used as a stepping stone for the company to investigate its entire impact on the climate. The next logical step would be to examine every other product using the methodology of this thesis work. When every product has been looked at, it becomes possible to add such factors as general heating and lighting into consideration, which will then be divided by each product to receive the final result.

Another important issue that arose from this thesis work was the discrepancy found between different emission calculation methods. As a result, the yearly emissions figures received by one of the methods can be almost two times higher than those received using the alternative tool. Studying such discrepancy and its possible causes, as well as which tool could be more appropriate under what circumstances, can be a topic of an entirely new research work.

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