YRKESHÖGSKOLAN NOVIA

Environmental Impact of Plastic Used as Packing Material and Protection of Components

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Degree Thesis

Thesis for a Bachelor of Engineering degree

Mechanical and Production Engineering

Vaasa 2023/24

DEGREE THESIS

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Title: Environmental Impact of Plastic Used as Packing Material and Protection of Components

Date: 8.4.2024 Number of pages: 38 Appendices: 5

Abstract

This thesis was conducted on behalf of ABB Oy, Vaasa. The work involved conducting a Material Flow Analysis on plastic used in the packaging of components delivered from subcontractors. The thesis was made based on customer requests about the factory's manufacturing emissions.

The purpose of this work was to determine how much plastic comes from the packaging of components when they are delivered from subcontractors to the factory in 2023. The work also consisted of determining how the components were packed. The work was done by collecting data and measurements from the most used components from four different sizes of electrical motors manufactured by assembly line AL3B.

The result of the work was presented in tables and charts showing how much plastic each component generated for every motor size. By doing a carbon footprint calculation the amount of plastic was converted to show how much greenhouse gas emissions the combustion of plastic generates. Finally, the total amount of plastic and greenhouse gas emissions for the whole assembly line consisting of the total for every motor was presented.

In summary, it was found that this thesis would work as a base for further research on how to lower plastic waste and emissions by improving the packaging methods for the components. By putting requirements for the subcontractors on the packaging method ABB would have lower emissions and smaller costs in waste management.

Language: English
Key Words: Material Flow Analysis, greenhouse gas emissions, plastic, packing method.

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Titel: Miljöpåverkan av plast som används som förpackningsmaterial och skydd för komponenter

Datum: 8.4.2024 Sidantal 38 Bilagor 5

Abstrakt

Detta examensarbete utfördes på uppdrag av ABB Oy i Vasa. Arbetet bestod av att genomföra en materialflödesanalys av den plast som används vid förpackning av komponenter levererade från underleverantörer. Examensarbetet utfördes baserat på kundförfrågningar angående utsläpp från tillverkningen i fabriken.

Syftet med arbetet var att fastställa hur mycket plast som uppkommer från packningen av komponenter som levereras av underleverantörer till fabriken under hela år 2023. Arbetet bestod även av att fastställa hur de olika delarna var packade. Arbetet utfördes genom insamling av data och mätningar av de mest använda komponenterna från fyra olika storlekars elmotorer tillverkade av monteringslinje AL3B.

Arbetets resultat presenteras i form av tabeller och grafer som visar hur mycket plast varje komponent från varje motorstorlek gav upphov till. Genom att utföra en koldioxidavtrycksberäkning omvandlades mängden plast till hur mycket det ger ut i CO_2 -utsläpp vid förbränning av plasten. Slutligen presenteras den totala mängden av plast och växthusgasutsläpp som uppkommit från monteringslinje AL3Bs alla motorer.

Sammanfattningsvis konstaterades att detta arbete kunde fungera som grund för fortsatt forskning inom minskning av plastavfallet och utsläppen genom att förbättra komponenternas packningsmetoder. Genom att lägga krav på underleverantörerna angående förpackningsmetoder kunde ABB uppnå mindre utsläpp och mindre kostnader inom avfallshanteringen.

Språk: engelska
Nyckelord: Materialflödesanalys, växthusgasutsläpp, plast, packningsmetod.

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Päivämäärä 8.4.2024 Sivumäärä 38 Liitteet 5

Tiivistelmä

Tämä opinnäytetyö tehtiin ABB Oy, Vaasassa. Työn tarkoituksena oli suorittaa materiaalivirtojen analyysi muovista, jota käytetään komponenttien pakkaamiseen alihankkijoilta toimitettuna. Työ tehtiin asiakaspyyntöjen perusteella, jotka koskivat päästöjä tehtaan tuotannosta.

Työn tavoitteena oli määrittää, kuinka paljon muovia syntyy komponenttien pakkaamisesta alihankkijoilta tehtaalle koko vuoden 2023 aikana. Työhön kuului myös selvittää, miten eri osat oli pakattu. Työ tehtiin keräämällä tietoja ja mittaamalla neljän eri kokoluokan sähkömoottorin yleisimmin käytettäviä komponentteja AL3B-kokoonpanolinjalla.

Työn tulokset esitettiin taulukoiden ja kaavioiden muodossa, jotka osoittivat, kuinka paljon muovia kukin komponentti kustakin moottorikoosta aiheutti. Hiilidioksidipäästölaskelmien avulla määrä muutettiin muovin polttamisen aiheuttamiksi hiilidioksidipäästöiksi. Lopuksi esitettiin kokonaismäärä muovia ja kasvihuonekaasupäästöjä, jotka syntyivät AL3B-kokoonpanolinjalla valmistetuista moottoreista.

Yhteenvetona todettiin, että tämä työ voisi toimia pohjana jatkotutkimukselle muovijätteen ja päästöjen vähentämisessä parantamalla komponenttien pakkausmenetelmiä. ABB voisi asettamalla vaatimuksia alihankkijoille pakkausmenetelmistä ja materiaaleista saavuttaa vähemmän päästöjä ja pienemmät kustannukset jätehuollossa.

Kieli: Englanti
Avainsanat: Materiaalivirta-analyysi, kasvihuonekaasupäästöt, muovi, pakkausmenetelmä.

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1 Introduction

My thesis work was written during the fall of 2023 and was completed in the spring of 2024. The work was written for ABB Oy, Vaasa, and was the final assignment for graduating in mechanical and production engineering from Novia.

1.1 Background

Since many companies have an interest in becoming greener and more conscious of the environment and how much exhaust they emit from their production, ABB's customers have for a long time wanted to know where their production stands on this question.

During the time I was doing my summer job, I did together with my supervisor some inspections in the factory, looking for areas that could be examined related to the demand from customers.

At the end of the summer, we figured out that a suitable area for the thesis work would be to look at the reception area for components for the production delivered from subcontractors. Most of the components are shipped from China or India and are packed in plastics for damage protection but also as protection against corrosion.

It turned out that there is nothing recorded about how much plastics are coming into the factory from these deliveries, everything is just unpacked and thrown in waste. After this examination, I was put in contact with HSE Manager Ingela Nyman to discuss this subject further. Together we decided that I would analyze how much plastic comes from the subcontractors and the shipping of components needed for the production.

1.2 Purpose

The main purpose of this thesis work was to determine how much plastic is used during the manufacturing of motors in one year, this was done by doing a Material Flow Analysis. A second purpose was also to determine what kind of plastic is used by the subcontractors and how the packing is done.

1.3 Scope

This thesis work's scope was to calculate and present a carbon footprint calculation based on the result of the Material Flow Analysis. The scope was divided into two different groups, both for the whole year of 2023:

- How much plastic in total was used for the packaging of components (kg)?
- How much greenhouse gas does it generate from combustion (kg CO_2/kg)?

1.4 Delimitation

At the beginning of the work, the idea was to examine the amount of all material used during production, wood coming from pallets, cast iron from the components, and so on. After discussion with my supervisors, the conclusion was that it would be too broad an area, therefore the focus shifted to just plastic, but also because it is the biggest waste material in the factory.

When the decision to focus on plastic was made the first idea was to look at the plastic used in the whole factory at all stations, this was also considered too broad. At last, the work was set to focus on plastic coming from the components needed for motor production.

1.5 ABB company presentation

The history of ABB together with its predecessor companies stretches back more than 130 years. ABB was founded in 1988 when the two companies ASEA and BBC merged, in that time ABB had revenues of $17 billion and employed 160,000 people around the world. (ABB, 2023).

In 1891 Charles E. L. Brown and Walter Boveri established Brown, Boveri & Cie (BBC) in Baden Switzerland. BBC was the first company to transmit high-voltage power and in 1893 BBC supplied Europe’s first large-scale combined heat and power plant producing alternating current. (ABB, 2023).

Around the same time as Brown, Boveri & Cie was established the two Swedish companies Elektriska Aktiebolaget and Wenströms & Granströms merged to form Allmänna Svenska

Elektriska Aktiebolaget, ASEA. More precisely this happened in 1890. Elektriska Aktiebolaget was founded in Stockholm by Ludvig Fredholm in 1883, the company was a manufacturer of electrical lighting and generators. Jonas Wenström was the person who invented the three-phase system for generators, transformers, and motors in 1889. (ABB, 2023).

Today ABB employs about 150, 000 people with 491 offices in 86 countries around the world. ABB is considered a technology leader in electrification and automation to make the future more sustainable and resource-efficient. The company consists of four different business areas. (1) Electrification offers a wide-ranging portfolio of products, digital solutions, and services. (2) Motion, which is the largest supplier of drives and motors in the world, provides customers with a complete range of generators and electrical motors. (3) Process Automation offers a broad range of solutions for process and hybrid industries. Process Automation includes industry-specific integrated automation, electrification, and digital solutions, to name a few areas of activity. (4) Robotics and Discrete Automation is the fourth and final business area. They provide value-added solutions in robotics, machine automation, and factory automation. In 2022 these four areas alongside Corporate and Other had a total revenue of $29,4 billion. (ABB, 2023).

Figure 1. ABB Logo.

1.6 Disposition

The following presents a short description of what the chapters in this work will include:

2. Theory, this chapter will present the theoretical work of this thesis. The theory worked as a ground for the whole work. This section is built up from previous research and work done on the same theme.

3. Method, how the work was done practically is presented in this chapter.

4. Result, here is the result from the research presented and how it was done.

5. Discussion, this chapter analyses the result, if it is reliable, and what could have been done differently. My own opinion on the work is mentioned here and what further research could be done based on this thesis.

2 Theory

Material Flow Analysis (MFA) is used to quantify material flow in a factory and how you measure the number of different materials used in a factory. The theory section will describe the benefits of material flow analysis and how it is done. The theory will also mention what plastics are and how the pollution from plastics affects our environment.

2.1 Material Flow Analysis

In today's modern world, the environment has a very central role in many companies. Most companies are trying to reduce their emissions and waste from different kinds of materials. To succeed with this, Material Flow Analysis is a central methodology of industrial ecology. The method quantifies how the materials are used, reused, and lost. To present MFA results Sankey diagrams (figure 2) are often used because they provide a good visual overview. Depending on what method of MFA the study is done with the results can also be presented with tables. Sankey diagrams are often termed the ''visible language of industrial ecology''. MFA are nowadays being linked with environmental input-output assessments, scenario development, and Life Cycle Assessment (LCA). All are to be used as central tools for sustainable development and circular economy. (Graedel, 2019). For the rest of the thesis work, Material Flow analysis will be mentioned just as MFA.

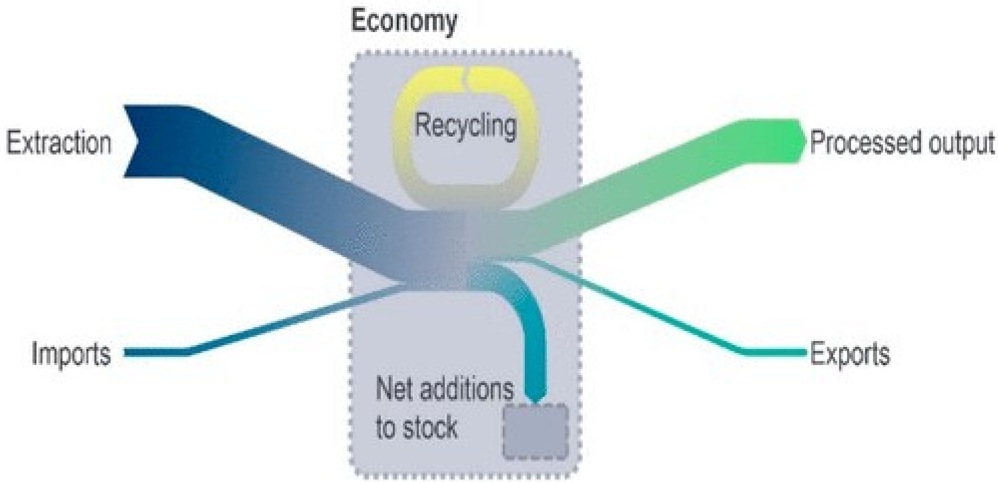

Figure 2. Sankey Diagram. (Graedel, 2019)

2.1.1 Why to use MFA

MFA as a methodology consists of a comprehensive mass balance of a distinct material or substance depicted in a flowchart and defined in a specific space and period. Today MFA is one of the most widely accepted and utilized tools in the industrial ecology field and used to support decision-makers. The results from an MFA can also be used to support company management to help give a better understanding of how to improve its environmental reputation and reduce costs, by reducing waste materials. (Lombardi, Rana, & Fellner, 2021).

Material Flow Analysis is often used to analyze several materials and substances to connect the sources, the pathways, and the intermediate and final sinks of materials. The results from all the connections can be controlled by a simple mass balance comparing all inputs, stocks, and outputs of a process. By doing this the results present a complete and consistent set of information about all flows and stocks in a process or a whole factory over time. (Brunner & Rechberger, 2016).

2.1.2 MFA or SFA

Sometimes an MFA can focus on just one substance and is then referred to as substance flow analysis (SFA) and is considered a special type of MFA. If a SFA is done it is critical to keep in mind that the substance in question is often a component in goods or materials, therefore both goods and materials are a part of MFA and SFA. MFA is classified as a more universal term rather than SFA. (Brunner & Rechberger, 2016).

2.1.3 Circular Economy

The circular economy can be described as a model of production and consumption. Sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products as long as possible are all parts of the circular economy model. By doing this the life cycle of products is extended. (European Parliament, 2023).

In practice, this means that when a product reaches the end of its life the materials are kept within the economy wherever possible thanks to recycling. These materials can be productively used again and again thereby creating further value, it will also imply reducing waste to a minimum. (European Parliament, 2023).

The benefits of a circular economy are for example slowing down the use of natural resources, reducing landscape and habitat distribution, and helping to limit biodiversity loss. A circular economy also provides a reduction in total annual greenhouse gas emissions. Industrial processes and product use are responsible for 9,10% of greenhouse gas emissions in the EU, while the management of waste accounts for 3,32% according to the European Environment Agency. (European Parliament, 2023).

Figure 3. The circular economy model. (European Parliament, 2023)

2.2 Advantages and Disadvantages

Like most of the methods used for measuring, MFA consists of both advantages and disadvantages. Both need to be evaluated before considering doing an MFA.

2.2.1 Advantages

The advantages of MFA are all linked to environment and sustainability where MFA helps to evaluate the environmental soundness of sanitation options. Beyond evaluating MFA also allows having a critical view of the current sanitation management within a company and how to make the company more sustainable. MFA is not only a tool for factories and companies, but MFA can also be used by developing and emerging countries as an ideal technical basis for planning and decision-making. Especially with limited technical and financial resources. Apart from the decision-making, MFA is also a very suitable tool for the detection of environmental problems and the development of appropriate solutions in these countries. (SSWM, 2024).

2.2.2 Disadvantages

Some disadvantages worth mentioning are that an MFA needs a lot of data to be reliable and even work. MFA is very good to use in developing and emerging countries to help them develop, but it can also be very challenging in these countries because of the need for a lot of data. These data can often be hard to get and are often very limited in these countries. Overall, there is a big requirement to deal with uncertainties with MFA. (SSWM, 2024).

2.3 Two Different Approaches of Material Flow Analysis

Material Flow Analysis can be divided into two different approaches of how the method is used, the first one is the traditional one also known as static MFA and the second one is called dMFA (dynamic Material Flow Analysis). Both methods are used for the same purpose but are used in different ways and measure the materials from different angles. (Deng, Zhang, & Fu, 2023).

Since the first method is called static MFA, it means that the study of material flows focuses on static description and analysis of flows and stocks. By using this method, the result provides a snapshot of material flows and stocks. A downside with the static MFA is that it is frequently unable to demonstrate the dynamic transformation relationship between flow and stock over a long time. (Deng, Zhang, & Fu, 2023).

2.3.1 Dynamic material flow analysis (dMFA)

Static material flow analysis has been the main method for a long time but since the 21st century, dMFA has become the more dominant method for accounting material flows and stocks. DMFA was developed to embed the idea of a time-dynamic correlation between flows and stocks, either for materials or substances. Unlike static MFA, dMFA can be used for a long period and account for both flows and stocks during the entire life cycle of a product. (Deng, Zhang, & Fu, 2023).

The process of dynamic material flow accounting involves three main variables, which are inflows, stocks, and outflows. Inflows or stocks are usually used as the input variable, either way, one of these is used as the input variable the two remaining variables are used for assuming the possible average lifetimes and lifetime distributions of inflows. Not only does dMFA involve three variables, but it can also be divided into two different categories, stock-driven and flow-driven approaches (figure 4).

The stock-driven approach is used to predict material stocks and waste flows, this is done by predicting inputs to explore future stock accumulation and waste emissions in different material production and input scenarios.

This provides insight into the recycling and secondary use potential of resources. In this method, stocks are often conceptualized as units of products or services (e.g., vehicles or buildings) that consist of a specific material or substance. Stocks determine flows, and flows are controlled by stock accumulation according to the stock-driven method. Usually, the accounting process starts by calculating the in-use stocks before outflows are estimated over time. The outflows can be estimated by using a product's loss curve or by estimating the stocks that will remain from the so-called survival curve. The survival curve then inverts the inflows related to producing, maintaining, expanding, and renewing the stocks. (Deng, Zhang, & Fu, 2023).

The flow-driven method is used to predict the inflows required to maintain or expand the stock and the waste flows formed by the stock. This predicts the possible secondary resource potential and replacement of stocks by predicting material stocks to explore future resource demand and depletion. With the flow-driven method, the actual inflows will be used as the model's exogenous variable. The outflows will be estimated by keeping track of the actual inflows throughout the model and will therefore be giving the inflows a lifespan function. By subtracting the outflow from the inflow and integrating it you can derive the stock accumulation; the calculation will present three different possibilities:

- Inflow > outflow, the stock will accumulate in the system.
- outflow > inflow, waste flow from the stock will be generated.
- inflow = outflow, there is no stock accumulation, but the stock may be updated and replaced.

The actual inflow can also be converted to mass by identifying end-use sectors in a socio-economic system and combined with material intensity, or they can be directly calculated with materials. (Deng, Zhang, & Fu, 2023).

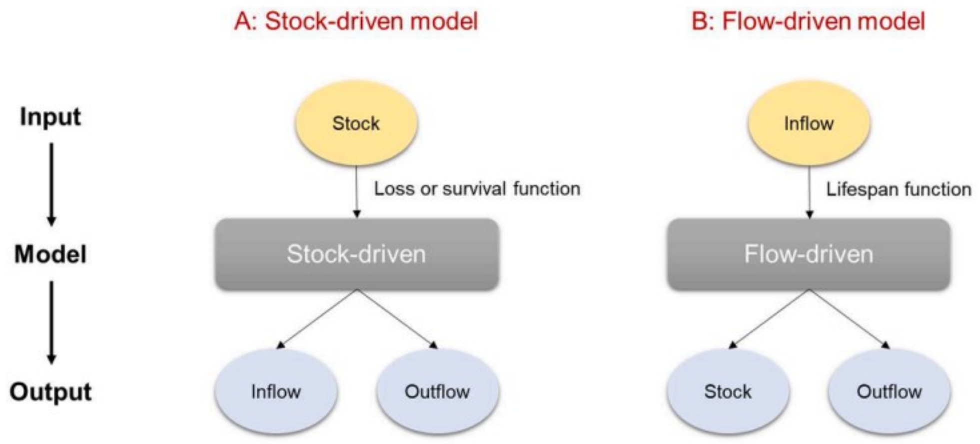

Figure 4. Difference between stock-driven model and flow-driven model. (Deng, Zhang, & Fu, 2023)

2.4 Plastics

Plastics can be described as synthetic organic polymers which means that they are hydrophobic, inert, high-molecular-weight long chains of molecules joined together by covalent bonds. Plastics are a very useful and suitable material for companies due to their good properties that they are modulable, lightweight, strong, malleable, and inexpensive. (Chia, Tang, Khoo, Lup, & Chew, 2020).

Synthetic plastics are traditionally produced using refined petroleum products where synthetic polymers made up of carbon-carbon bonds are derived in a controlled environment. All these kinds of plastics come with challenges and could lead to issues of fossil resource depletion, but they also affect the climate, leading to climate change and greenhouse gas emissions. Even though the plastics are made of heavy crude oil it is not the source used to collect the monomers that define the biodegradability of plastics but on their chemical structure. Depending on the chemical structure plastics are given different names, where each one has its properties and area of use, some commonly used plastics are for example polyethylene terephthalate (PET), polyvinyl chloride (PVC), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polystyrene (PS), polypropylene (PP). All these plastics are so-called non-degradable plastics, even though PE, PP, PVC, and PET all have starting monomers that could be obtained from biological resources. (Chia, Tang, Khoo, Lup, & Chew, 2020).

Degradable plastics can be divided into four different groups: compostable plastics, photodegradable plastics, bio-based plastics, and biodegradable plastics. It is when interacting with water, enzymes, UV, and gradual changes in pH that break down these plastics. Biodegradable plastics can be produced from renewable resources and include components of animals, living plants, and algae as well as micro-organisms. Polyhydroxyalkanoate (PHA) is an example of a completely biodegradable plastic which also has similar properties as conventional plastics. Energy saving, avoiding food waste, and reducing carbon dioxide emissions are some advantages of biodegradable bioplastics. (Chia et al, 2020).

2.4.1 Plastic Pollution

Plastic pollution is a globally urgent problem where traces of plastics have been found in deserts to mountaintops, from deep ocean to Artic snow, plastic debris in the marine environment has been reported for half a century back. According to studies the emission from plastic pollution is increasing and will continue doing so in the most optimistic future scenarios of plastic waste reduction. Global plastic waste in rivers, lakes, and oceans has been estimated to range from 9 to 23 million metric tons per year and in the terrestrial environment from 13 to 25 million metric tons per year as of 2016. By 2025 these estimated emissions rates from 2016 will approximately be doubled if following business-as-usual scenarios. (Macleod, H.Arp, Tekman, & Jahnke, 2021).

The definition of plastic pollution comes from when an accumulation of plastic occurs in the environment at the rate at which plastic pollution enters an area faster than the natural removal process or cleanup actions, the natural removal process of plastics happens at the scale of decades to centuries. Because of the long time plastic stays in the environment together with the fact that emissions cannot be curtailed plastic fits the profile of a “poorly reversible pollutant”. (Macleod et al, 2021).

2.4.2 Plastic Tax

As of June 2021, there are 195 signatories to the Paris Agreement to limit their CO_2 emissions, according to the UN. The Paris Agreement permits countries to set their ambitions within certain parameters, and some jurisdictions and regions have undertaken to cut carbon emissions faster than others. By 2030 the EU has stated that their emissions would be cut by 55 percent in comparison with 1990 levels. (KPMG, 2021).

The commitment to the target of the cut has been made as part of the EU Green Deal, which is a comprehensive package of tax and non-tax measures. One of several tax reforms proposed as part of the Green Deal is the EU's plastics tax. In Figure 5 the taxes made by the EU Green Deal can be seen. (KPMG, 2021).

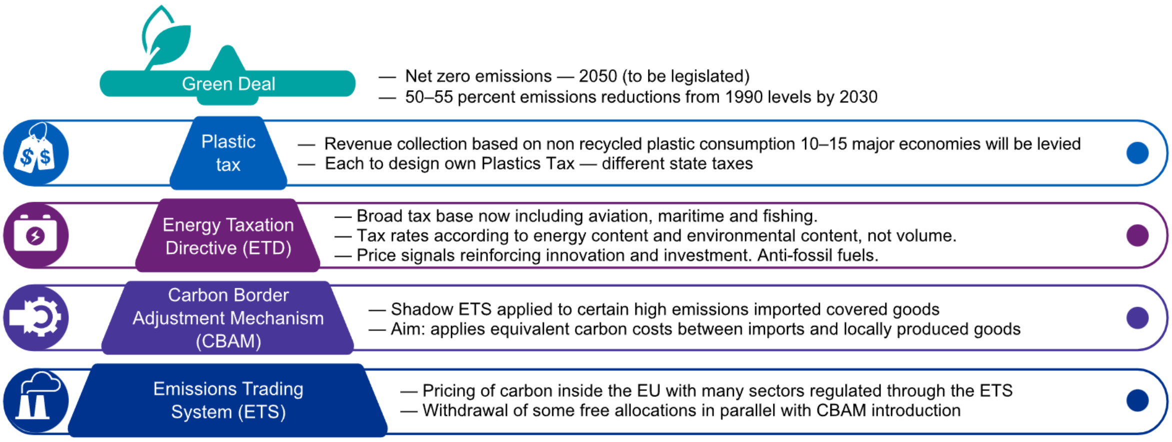

Figure 5. Tax Measures (and other interventions) in the EU Green Deal. (KPMG, 2021)

The plastic tax introduced by the EU is part of the EU recovery package necessitated by EU spending because of Covid 19, the tax is an own resource to the 2021-2027 EU budget. The plastic tax is not a tax but a contribution from the Member States to the EU. The tax is based on the amount of non-recycled plastic packaging waste produced by each member state. What each Member state should contribute is calculated by the weight of non-recycled plastic packaging waste with a uniform rate of 0.80 €/kilogram. (KPMG, 2021).

Italy is one example of a country in the EU that has proposed a plastic tax on the consumption of manufactured single-use items. In Italy the definition of single-use plastic has the function of containing, protecting, handling, or delivering goods or food products. Italy has chosen the following persons obligated to pay the plastic tax:

1. The manufacturer.

2. The seller.

3. The purchaser if the items are brought from other EU countries and sold for business activity.

4. The EU supplier, if the items are bought from other EU countries and sold to a private consumer.

5. The importer. (KPMG, 2021).

2.4.3 Carbon Footprint

Carbon footprint can be explained as the total amount of greenhouse gases generated by our actions, including carbon dioxide and methane. On average the global carbon footprint is about 4 tons, by 2050 this number needs to drop under 2 tons for a chance to avoid 2°C rises in global temperatures. The United States has one of the highest rates in the world with an average carbon footprint of 16 tons per person per year. (The Nature Conservancy, 2024).

In a survey done in 2018, the average Finn had a carbon footprint of 10 300 kg CO_2e/per person/year. (Sitra, 2018). In 2020 Finland as a country had a total carbon footprint of 47.8 million tonnes of CO_2e, which was one of the lowest in the EU, according to Statistics Finland. (Official Statistics of Finland (OSF), 2022).

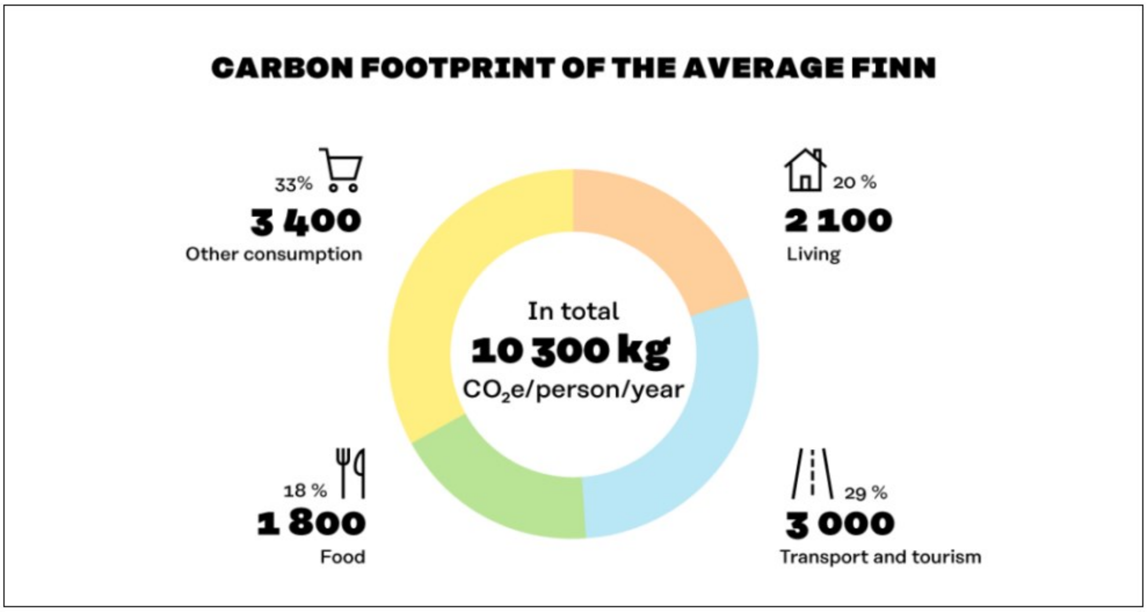

Figure 6. The carbon footprint of the average Finn in 2018. (Sitra, 2018).

When measuring GHG (greenhouse gases) there are essentially three categories, also called scopes, that need to be considered. These three categories are all generated by a company's processes, actions, and employee behaviors. (British Business Bank, 2024).

- Scope 1 – Direct emissions created by the company through heating systems and fueling vehicles.
- Scope 2 – The company's indirect emissions from e.g. energy bought from external sources.
- Scope 3 – Indirect emissions from the company's actions like transportation of office supplies or employees traveling to and from work.

Scope 3 is often the largest category for the company because of its wide range of sources at so many different levels. (British Business Bank, 2024).

2.4.4 Scope 1 & 2 calculation

When calculating scopes 1 and 2 the first thing to be done is to gather records of energy consumption over a specific time, usually a year. The data should consist of all utility bills for water, electricity, and gas, and all travel data for planes and train tickets as well as all fuel receipts for all different kinds of company vehicles. After that the data needs to be put into a carbon footprint calculator or if it is done manually the conversion needs to be done using formula 1. (British Business Bank, 2024).

$$Data \times Emission\ Factor = Greenhouse\ gas\ emissions \quad (1)$$

The emission factor is a so-called conversion factor presented in the in units of "kilograms of carbon dioxide equivalent of Y per X, (kg CO_2e of Y per X), in this situation, Y is the gas emitted and X is the unit activity, where each activity and material has its own factor. Even though GHG consists of seven main gases that contribute to climate change CO_2 is the universal unit of measurement to indicate the global warming potential (GWP). The six other gases contributing to climate change are methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). (British Business Bank, 2024).

2.4.5 Scope 3 Calculation

Because scope 3 is the biggest category for companies it is also the most challenging to calculate, therefore scope 3 is often calculated by a calculation tool. In general scope 3 emissions account for over 70% of a company’s carbon footprint, the Greenhouse Gas Protocol has identified 15 categories of scope 3 emissions:

1. Purchased goods and services
2. Capital goods
3. Fuel- and energy-related activities
4. Upstream transportation and distribution
5. Waste generated in operations
6. Business travel
7. Employee commuting
8. Upstream leased assets
9. Downstream transportation and distribution
10. Processing of sold products
11. Use of sold products
12. End-of-life treatment of sold products
13. Downstream leased assets
14. Franchises
15. Investments

A complete carbon footprint calculation is done when the emissions from all three scopes are summed together. (British Business Bank, 2024).

2.4.6 ABB's CO_2 targets 2024

With the help of Scope 1,2, and 3 ABB has set up its targets to achieve CO_2 emission reduction for 2024. Each scope is used for its target and several scopes can also be used for the same target (figure 7).

Topic	Goal	Meter	Tracking
Actions regarding energy efficiency and climate change	We are reducing greenhouse gas emissions in our operations, a decreasing trend Scope 1,2 (RE 100)	Reduction of greenhouse gas emissions, CO_2 tonnage	Legal entity/ Lead Business and Local Division
Actions regarding energy efficiency and climate change	Improving material efficiency - Gradual reduction in the amount of waste sent from production processes to energy production, a decreasing trend Scope 3	The amount of waste sent to energy production, percentage.	Legal entity/ (Lead Business) and Local Division
Actions regarding energy efficiency and climate change	ABB Ltd; Reduction of transportation carbon dioxide emissions, decreasing trend (identifying changes in quantity: orders, revenue) Scope 3	CO_2 -ton (transport mode x average shipment) and CO_2 -ton/ shipped kg (business activity).	Lead Business and Local Division
Actions regarding energy efficiency and climate change	The decreasing trend of emissions - Our vehicle fleet transitioning to emission-free electric alternatives (EV100). Scope 3.	The decreasing trend of emissions, new fleet consisting of full electric vehicles.	Legal entity and Local Division
Actions regarding energy efficiency and climate change	The decreasing trend of emissions - Our vehicle fleet transitioning to emission-free electric alternatives (EV100) and the use of renewable diesel. Scope 3.	The decreasing trend of emissions, the use of renewable diesel	Legal entity and Local Division

Figure 7. Translation of a picture taken from ABB Finland quality target presentation (original in Finnish).

3 Methods

To achieve a result in this thesis the work needed to be done by using quantitative research and through interviews with people who knew components and the process of components ordering.

Quantitative research is done by analyzing structured data which then are sorted into different categories or with numbers. The data can be collected either with survey studies, registry extracts, or with structured observations. In this thesis, the data was collected by registry extracts and structured observations. (Kvantila, 2024).

As a part of the result in this thesis, registry extracts were used to get information about the motors answering the following three questions:

1. How many of each motor's size were manufactured by assembly line AL3B in 2023?

2. Which components should be examined?

3. Quantity of the components that are going to be examined.

When the registry extracts were done the research continued with structured observations and measuring. The observations consisted of packaging method, plastic-type, and measuring of plastic amount. (Kvantila, 2024).

As a complement to the quantitative research, interviews also needed to be conducted to get a better understanding of the manufacturing of motors. The interviews were done with the supervisor for the assembly line who explained how to read the codes for each motor and what they stand for and explained about the different sizes. Further interviews were done with people who oversee the purchasing of components, he explained how the process is done and where they come from.

In the following chapters, the result of this thesis work will be presented, including more specific explanations of how the three questions for the quantitative research were answered.

4 Result

To be able to determine which motor size and what parts should be included in this work I needed to get a short training in SAP. SAP is used in the whole factory and all necessary information concerning the production of motors is registered in the SAP system.

The biggest challenge at the beginning of the work was to choose which motor size and type I should look at. I knew from my work experience that assembly line AL3B was the one that manufactured most motors in the factory for one year. Apart from AL3B, there are also three other lines in the factory, AL3A, AL3C, and AL3D. AL3C and D assemble aluminum motors and therefore was these two not relevant in this work since we had decided to look at cast iron motors. Compared with AL3B, AL3A manufactured a significantly smaller number of motors during 2023 than AL3B did. So together with the knowledge I had from working in the factory and after discussion with my supervisor, I decided to look at AL3B.

4.1 Assembly line AL3B

AL3B manufactures 4 different sizes of cast iron motors, 160, 180, 200, 225, 250. The numbers refer to the height between the floor and the center of the shaft in millimeters when mounted on the footrest.

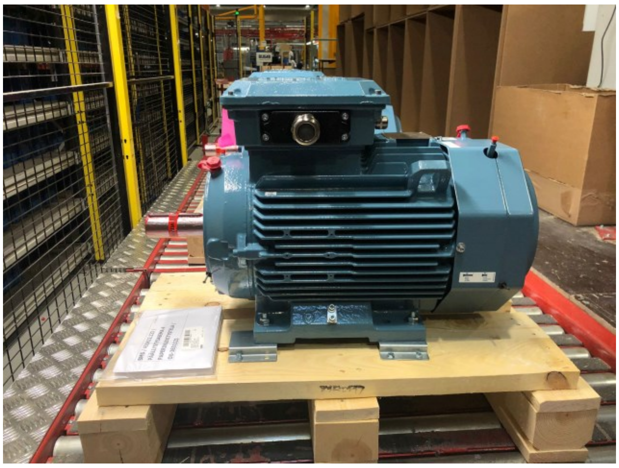

Figure 8. Size 160.

Figure 9. Size 220.

During 2023, AL3B manufactured a total of 19816 motors, *table 1* shows how many of each size were manufactured. The table was done to get a better perspective of the scale of the manufacturing process. Information needed for *Table 1* was taken from an SAP program where every completed motor was listed.

Table 1. Completed motors 2023.

[redacted] Classified

Figure 10 shows a screenshot of the list from SAP, but since the list consisted of nearly 30, 000 rows only a screenshot is shown to give an overview of how it looked.

[redacted]

Classified

Figure 10. Screenshot from SAP.

Other than the number of completed motors, BasicCode and Order were also two important factors needed for the analysis.

4.1.1 BasicCode

BasicCode is an individual code for each motor, telling what materials are used, size, and area of use. Area of use can for example be that the motor is used in maritime, mining, or explosive environments. For this work, BasicCode was used to sort out the type of motor that had been manufactured most for each size.

4.1.2 Order

Each assembly of every motor has its own order number even though multiple motors with the same BasicCode are assembled. In this work, the order number was used to get information about which components were used for one specific motor.

[redacted]

Classified

Figure 11. Screenshot from SAP showing component list for order 106892330.

From the list shown in *Figure 9*, the component code for each component used for the analysis was copied and used in another SAP program. The code for each component was necessary to get information about how many of each component was used during 2023 (figure 12). One component can be used for multiple motor types as long as it's the same size.

[redacted]

Classified

Figure 12. Screenshot from SAP showing the amount of End Shield -D used in 2023.

The following cast iron components are used in each size of motor manufactured by AL3B and were examined in this work.

- Stator Frame
- End Shield -D
- End Shield -N
- Rotor
- Terminal Box Frame
- Flange with holes

4.2 Data Collection

Data collection consisted of figuring out how each component was packed when they arrived at the factory and what type of plastic was used. Components are delivered from subcontractors from both India and China.

A challenge during the data collection was to find the right components on the shelves. Storage locations for each component were found in SAP, but this information wasn't always correct and therefore each shelf needed to be controlled manually.

4.2.1 Method of Packing

For every component, a visual inspection was made to determine how they were packed and what kind of plastic was used. The method of packing varied between two different methods, either with a plastic bag and film or with a plastic bag, film, and layer protection. Appendices 1-5 show what type of method was used for each component for every size.

Explanation of protection method:

- Bag: Component wrapped in closed VCI plastic bag.

- Film: A bigger sheet of VCI plastic is put inside of the pallet covering both the bottom and side.

- Layer protection: Plastic well disc between each layer.

Figure 13 shows how component End Shield -D was packed using all three protection methods.

Figure 13. Packing of End Shield -D.

Figure 14 shows how End Shield -N was packed using only two protection methods, bag, and film with cardboard for separating the parts from each other.

Figure 14. Packing of End Shield -N.

Figure 15 shows an example of how rotors were packed using only film as protection. For the bigger rotors, another method than plastic had been used for transportation and therefore no plastic has been recorded and marked with X (appendix 3,4, and 5).

Figure 15. Packing of smaller rotors.

4.2.2 Plastic measuring

Since the plastic used for the components was so thin and small it wasn't possible to measure the weight of the plastic with a scale, the weight of the plastic needed to be calculated based on equation 2.

$$\rho = \frac{m}{V} \tag{2}$$

To be able to calculate the mass in equation 2, density and volume were the parts in the equation that needed to be sorted out. Density was taken from a VCI manufacturer's website where the thickness of a film was also found. Volume was then calculated with the help of the thickness and by measuring the length and width of a bag, for the films the measures were taken from the manufacturer's website by putting in the length, width, and height of the pallet. For components using only layer protection the density of the plastic well was also taken from the manufacturer's website. When the mass was calculated it was put into equation 1 (2.4.4 Scope 1 &2 calculation).

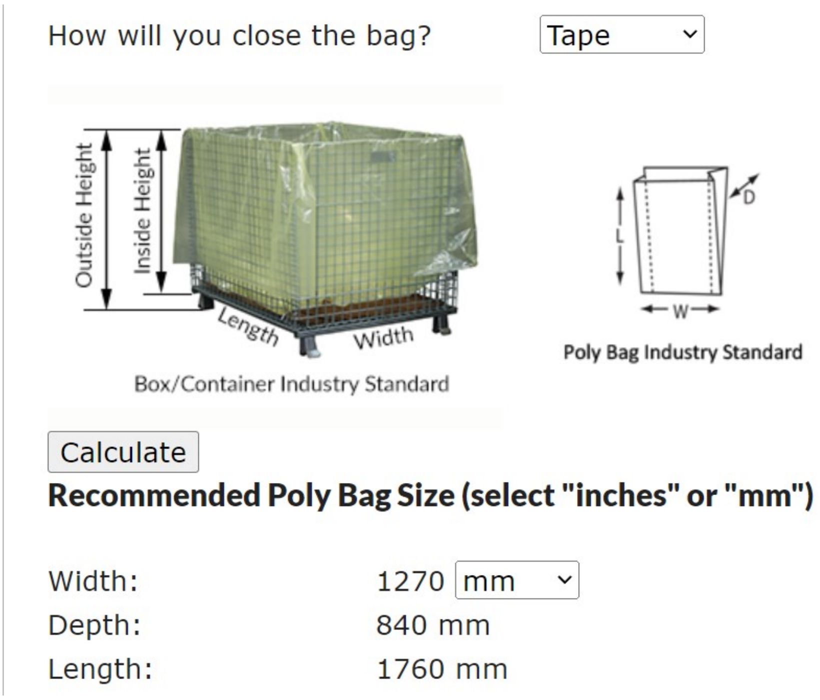

Figure 16. Dimensions of a film based on a euro pallet.

4.3 Carbon Footprint Calculations

The carbon footprint calculations of this work will now be presented. The results consist of graphs and tables showing how much each size and component used plastic and how much greenhouse gas is generated from the combustion of the plastic. For each motor is also presented the packing format. The appendices charts for each motor show all the collected data needed for the result.

At the end of the result a comparison is presented between the entire factory's amount of waste in 2023 and how much plastic from the examined motors is of the total amount.

4.3.1 3GBP161410-ADK result

Table 2 shows how much of each component has been used for size 160 in 2023. From the figure can also be seen that components used for size 160 have the components protected with VCI plastic, and flange with holes is the only component using just layer protection.

Table 2. Size 160 table over component quantity, plastic-type, and packing format.

Component	Stator frame	End Shield -D	End Shield -N	Rotor	Terminal Box Frame	Flange with holes
Quantity	416	2011	3291	189	8256	7703
Plastic type	VCI	VCI	VCI	VCI	VCI	Plastic well
Packing format	Film	Bag+Film x3	Bag+Film x3	Film	Bag+Film	Layer protection x8

In *Figure 17* the components are shown in graphics to show which component used the most amount of plastic and at the same time generated the most GHG. The amount of both plastic and GHG follows with the most used component, for this size Terminal Box Frame was the most used component and used most plastic for its protection. An exception is the Stator frame and Flange with holes. When looking at quantity stator frame was used much less than flange with holes but the way it was packed had a big impact on the result. The stator frame used a much bigger VCI film compared to the Flange with holes that used just layer protection, so in this case, the size of the protection was the difference between these two components.

When looking at two similar components such as End Shield -D, and -N which both used the same packing method, the number of components used during 2023 was the difference between these two. More components generated more plastic and more GHG.

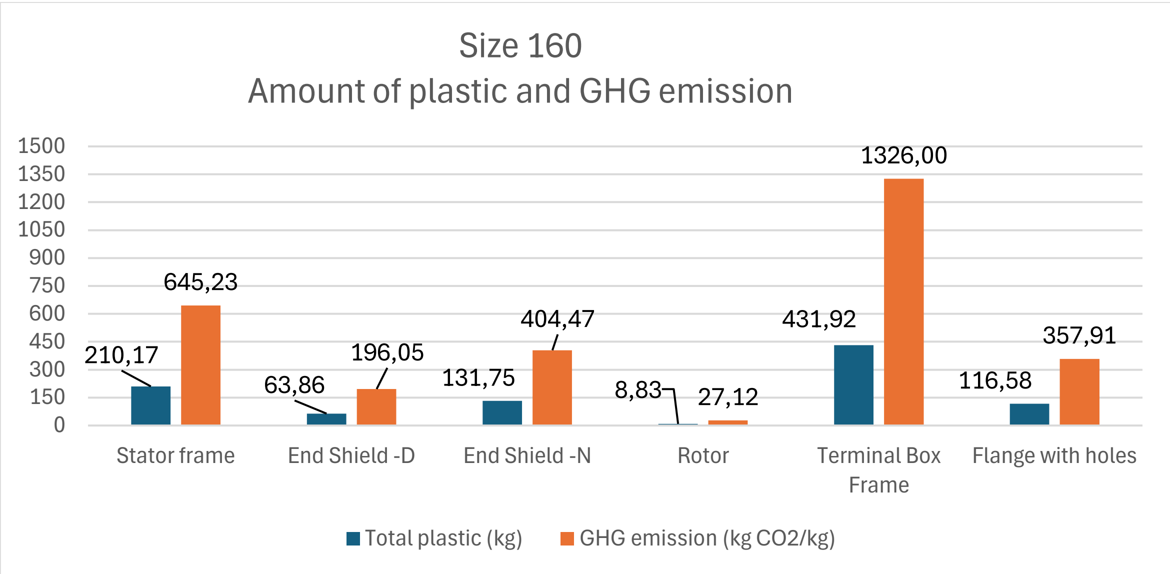

Figure 17. Plastic and GHG emissions from 3GBP161410-ADK.

Table 3 shows how much just one piece of every component used plastic and how GHG emissions just one piece generated from the combustion of the plastic.

Table 3. Plastic and GHG emissions from one piece of each component.

Component	Stator frame	End Shield -D	End Shield -N	Rotor	Terminal Box Frame	Flange with holes
Plastic (kg)	0,51	0,03	0,04	0,05	0,05	0,02
GHG emission (kg CO_2/kg)	1,55	0,10	0,12	0,14	0,16	0,05

4.3.2 3GBP182420-BDK result

As *Table 4* shows, components for size 180 were used significantly less than for size 160. The Flange with holes stayed the same since they both use the same flange with holes component, another difference between 160 and 180 was that rotors were used more in 180 than in 160. A difference in packing method can also be seen between the components from 160 and 180, for End Shield -Flange -N the packing method has a slight difference from 160. Instead of using bag + film like in 160, the End Shields for 180 used bag + layer (protection layer).

Table 4. Size 180 table over component quantity, plastic-type, and packing format.

Component	Stator frame	End Shield -Flange	End Shield -N	Rotor	Terminal Box Frame	Flange with holes
Quantity	643	638	1834	490	7520	7703
Plastic type	VCI	VCI	VCI	VCI	VCI	Plastic well
Packing format	Film	Bag + Layer x5	Bag + Layer x5	Film	Bag +Film	Layer protection x8

The difference between using bag + film or bag + layer can be seen in *Figure 18*. Even though End Shields for 180 were used less than for 160 the amount of plastic was higher for 180 End Shield -N than for 160.

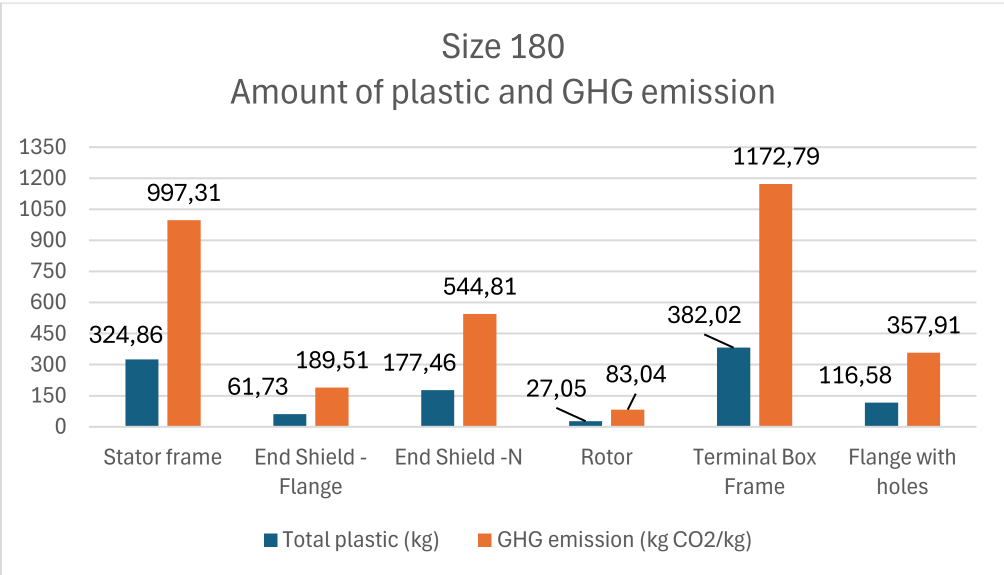

Figure 18. Plastic and GHG emissions from 3GBP182420-BDK.

Table 5 presents the same results as *Table 3* but for size 180. By comparing these two tables the difference between different packing methods is shown better by seeing which method uses less plastic.

Table 5. Size 180 plastic and GHG emissions from one piece of every component.

Component	Stator frame	End Shield -D	End Shield -N	Rotor	Terminal Box Frame	Flange with holes
Plastic (kg)	0,51	0,10	0,10	0,06	0,05	0,02
GHG emission (kg CO_2/kg)	1,55	0,30	0,30	0,17	0,16	0,05

4.3.3 3GBP201430-ADK result

Unlike the two smaller sizes, the stator frame and both End Shields were the most used components for size 200. The method for how the End Shields were packed also differed from size 180 and used the same method as for 160. For this size the rotors didn't use any plastic when they were stored in the factory, therefore Rotor are marked with X in *Table 6*.

Table 6. Size 200 table over component quantity, plastic-type, and packing format.

Component	Stator frame	End Shield -D	End Shield -N	Rotor	Terminal Box Frame	Flange with holes
Quantity	1689	1243	1493	X	6052	5223
Plastic type	VCI	VCI	VCI	X	VCI	Plastic well
Packing format	Film	Bag + Film x2	Bag + Film x2	X	Bag+ Layer x5	Protection Layer x5

The results for size 200 follow the pattern of the number of parts used, increasing the amount of plastic and GHG emissions and packing method. Compared to size 160 and 180 size 200 used a smaller number of Terminals box frames but had a different packing method.

The difference between the two methods can be seen in *Figure 19*. Even though size 200 used fewer Terminal box frames the method *bag + Layer* results in more total plastic than *bag + film*.

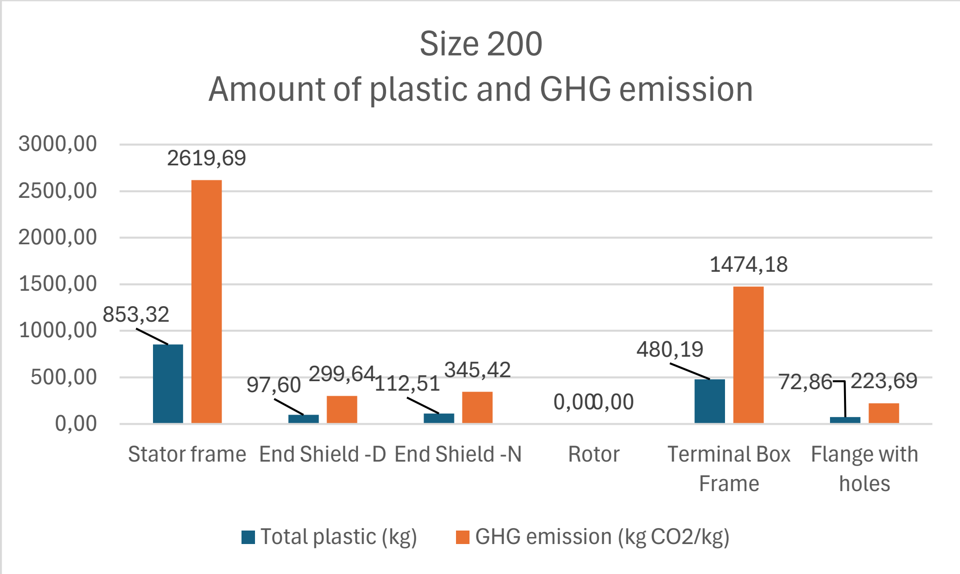

Figure 19. Plastic and GHG emission from 3GBP201430-ADK.

4.3.4 3GBP221210-ADK and 3GBP252210-ADK result

The results from the two biggest motors, 225 and 250, are presented in the same chapter. These two motors used all the same components, and both used the same packing method for each component. It is only the difference between the number of used parts that separates them.

Table 7. Size 225 table over component quantity, plastic-type, and packing format.

Component	Stator frame	End Shield -D	End Shield -N	Rotor	Terminal Box Frame	Flange with holes
Quantity	1261	1163	1469	X	6052	5223
Plastic type	VCI	VCI	VCI	X	VCI	Plastic well
Packing format	Film	Bag + Film x2	Bag + Film x2	X	Bag+ Layer x5	Protection Layer x5

Table 8. Size 250 table over component quantity, plastic-type, and packing format.

Component	Stator frame	End Shield -D	End Shield -N	Rotor	Terminal Box Frame	Flange with holes
Quantity	70	81	134	X	6052	5223
Plastic type	VCI	VCI	VCI	X	VCI	Plastic well
Packing format	Film	Bag + Film x2	Bag + Film x2	X	Bag+ Layer x5	Protection Layer x5

As can be seen from *Table 7* and *Table 8* and compared to *Table 6* sizes 225 and 250 used the same number of both Terminal box frame and Flange with holes as for size 200 and therefore also generated the same amount of plastics and GHG emissions. Since 225 and 250 both used the same packing methods this gives a good example of the increased number of components used also increased GHG emissions and plastics.

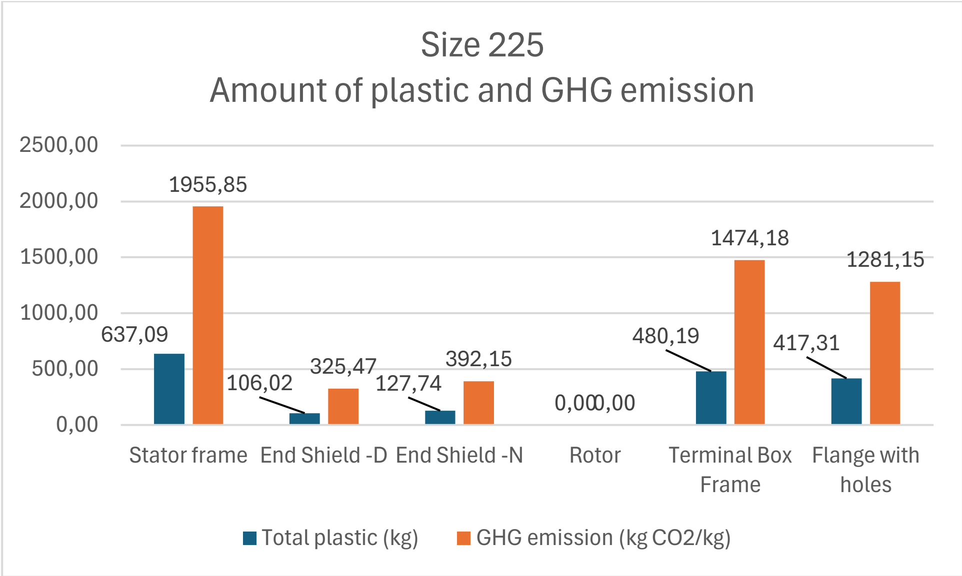

Figure 20. Plastic and GHG emissions from 3GBP221210-ADK.

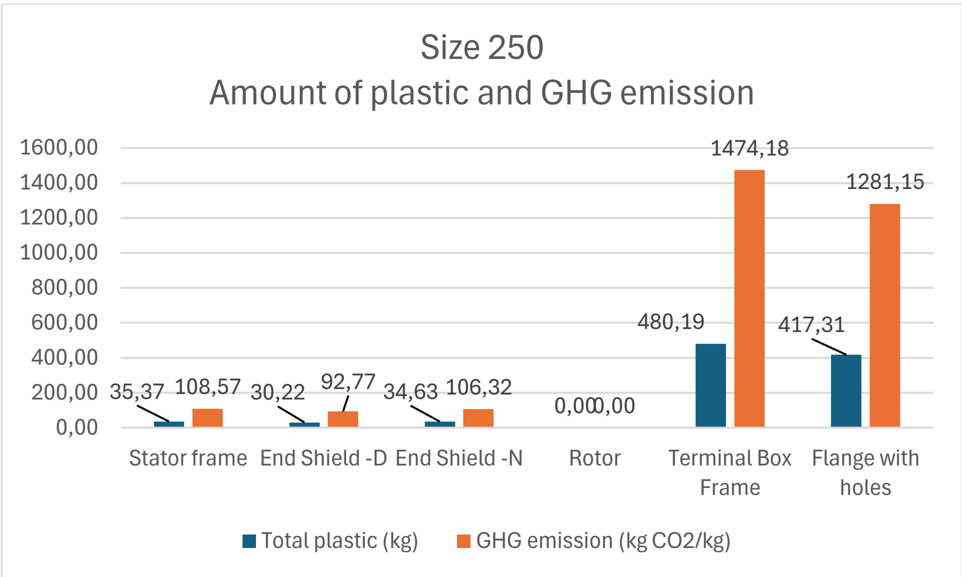

Figure 21. Plastic and GHG emissions from 3GBP252210-ADK.

4.4 AL3B plastic and Greenhouse gas emissions for 2023

In *Table 9* the total amount of both plastic and greenhouse gas emissions are listed to show a comparison between the four sizes. For each motor, the total amount of plastic and GHG emissions from every component are added together to get a total number.

Table 9. Table over AL3B total plastic and GHG emissions.

Motor size	160	180	200	225	250	Total
Plastic (kg)	963,12	1089,70	1616,49	1768,34	997,72	6435,37
GHG emissions (kg CO_2/kg)	2956,77	3345,39	4962,63	5428,80	3062,99	19756,58

Size 225 was the motor that generated the most plastic from its packaging of components with 1768,34 kg, which also leads to a total amount of GHG emissions of 5428,80 kg CO_2/kg. The least plastic and GHG emissions came from size 160 with a total of 963,12 kg plastic and 2956,77 kg CO_2/kg GHG emissions. Even though 160 used more components during 2023 than what 225 did, 160 still had lower total plastic and GHG emissions, this can be explained by two things. Firstly, the difference between the sizes of the End Shields, 225 uses bigger End Shields than 160 and that automatically leads to a bigger plastic bag, which then leads to more GHG emissions. Secondly, the difference between the packing method of the Terminal Box frame, both motors use the same Terminal Box Frame, but they come from different subcontractors. 160 used more Terminal Box Frames than 225 did but still had lower GHG emissions, for 160 the packing method was *bag + Film* while 225 used *bag + protection layer*.

For the three remaining sizes, 180, 200, and 250, both plastic and GHG emissions were on quite similar levels of waste. All components for every motor combined generated a total of 6435,37 kg of plastic which led to GHG emissions of 19756,58 kg CO_2/kg during 2023.

Based on an assigned report from ABB's global report containing waste amount for 2023, which I had access to, ABB had a total amount of energy waste for 2023 amounting to 154,424 tons. This means that the total plastic amount derived from the examined components in this work accounted for 4,17% of the total energy waste in 2023.

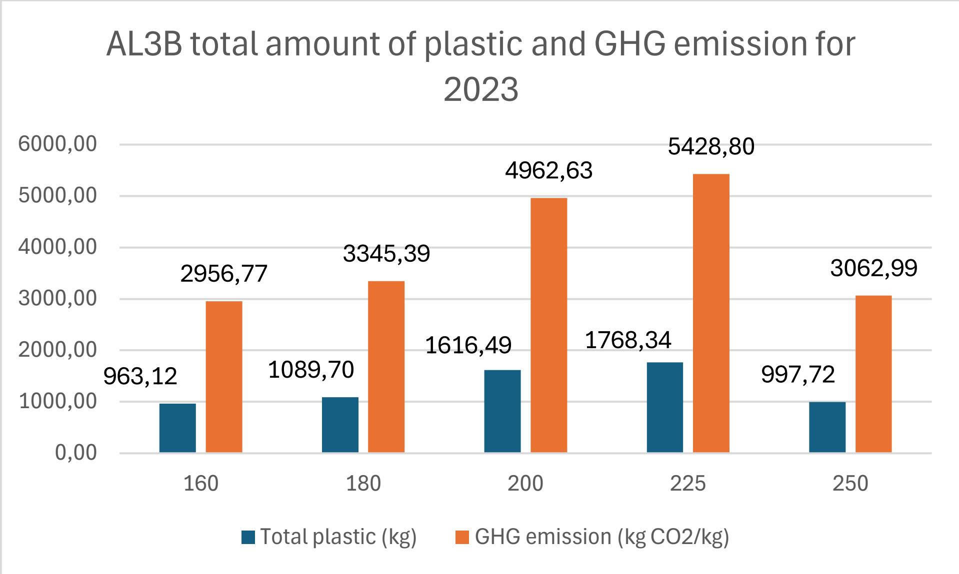

Figure 22. Chart of AL3B total plastic and GHG emissions for 2023.

4.4.1 Definition of plastic-type

Part of the scope of this work was to determine what plastic-type is used for the protection of components during transport and storage. During the examination and measurement phase of the work the plastic used in the packaging was noticed, the result was mainly two different types. Both types are found in the tables for each motor's result, the two types are *Vapor Corrosion Inhibitor* (VCI) and *Plastic well*.

At the beginning of this work, neither myself nor the company had any knowledge or information about what type of plastic the subcontractors used for protection. This was something that came up during the work and the examination of the packaging, therefore plastic-type is mentioned in the result part of this work and not in the theory.

4.4.2 Vapor Corrosion Inhibitor (VCI)

Vapor Corrosion Inhibitor packaging is made from poly packaging film which has been manufactured with added VCI chemistry. Mainly VCI films are made of polyethylene, and polypropylene, which means that all types of VCI packaging can be recycled at facilities for PE/PP processing or incinerated. The use of VCI chemistry added to poly packaging gives a protection function for metal products by forming a thin, invisible layer on the surface. The layer protects the product from corrosion caused by oxygen, water, and contaminants. (Zerust, 2024).

The process of how the layer works is that the VCI molecules from the added chemistry are emitted and settled on the metal surfaces, which then forms the invisible layer and protects it from corrosion. By interrupting the electrochemical corrosion process caused by moisture, oxygen, and contaminants in the atmosphere the component is then protected. VCI packaging can be made in different sizes, weights, and inhibitor types. In addition, it can be ordered in rolls, bags, and with custom printing. (Zerust, 2024).

4.4.3 Plastic well

Plastic well is known for being flexible, tough, impact-resistant, and clean material, thereto it also resists water and most acids and oils. The plastic well is made of coextruded polypropylene plastic (PP) which makes it completely recyclable, to the shape plastic well resembles corrugated cardboard. (eqpack, 2024).

For products with sensitive surfaces or delicate products, plastic well is an excellent choice. In environments where the standards of cleanliness and hygiene are high plastic well is also a very good fit. Compared to corrugated cardboard, plastic well does not leave dust or fibers. (eqpack, 2024).

Some typical characteristics of plastic well are that it can be machined, punched, and screen printed. Further, it can be glued, heat or ultrasonic welded, taped, or stapled together. It comes in a variety of colors and can be laminated with PP woven fabric, PP foam, metalized PP film, and PP film with print. Plastic well can be made in two variations, either two-layer or three-layer. (eqpack, 2024).

Examples of applications for plastic well are protection during strapping, spacers, protection of coils or tubes in steel, boxes, and advertising (eqpack, 2024). In this work plastic well was noticed to be used as spacers between layers of components, it is a good choice for spacers since the components have sensitive surfaces and cannot be scratched. In *Figure 13* plastic well can be seen as the grey material between the levels preventing the End Shields from scratching each other.

4.5 Conclusion

After analyzing the results for each motor and comparing them with each other I have concluded that there are mainly two factors that affected the result. Firstly, the number of components used had a big impact on the amount of plastics, especially in the cases where components were packed in bags. The more components that came into the factory, the more bags also had to be used. Combined with this the size of the components also had a big impact on the plastic amount, bigger components needed bigger bags, which then led to more plastic. Secondly, is the packaging method. Depending on the method some components generated more plastic than others even though they had similar numbers of components, this is showed well when comparing 160 and 180. *Bag + layer* was used by size 180 and even though it used fewer numbers of End Shields it had nearly the same amount of plastic and even more, so to get a lower emission the packing method should change to *bag + film*.

4.6 Proposal for further research

Since a big impact on the result was the difference in packing method this work could function as a base for further research in packing methods and how to improve them. In this work, there was no focus on the subcontractors and how they chose to do the packaging, but during the work, I was told the components were delivered from both India and China. The same component can be ordered from both countries and the only reason for that is to use it as a backup if something happens in one country, they can still get the same component from the other country.

The only difference between the countries was that they used different packaging methods. By using this work as a base to find out which method generates less GHG emissions, further work would then be to examine every component and determine which method is better for the environment. This would then be applied in the component ordering phase and be sat as a requirement for the subcontractors to pack components based on the requirement. By doing that ABB would get lower GHG emissions from plastics and less costs within waste management since they have less plastic.

A suggestion for improvement for this work should be to do a bigger examination and include more components and motors. To get a more complete picture of the whole factory’s plastic use and how much GHG emissions it generates, all assembly lines should be included but also every single component should be examined to see how much the total would be. As mentioned in the theory section, the MFA needs a lot of data to be a reliable method, for this work, the collected data was enough to get a result for a small part of the factory. To do a complete MFA more data would be needed, which should include all variations of every motor size from every assembly line and all materials, not only plastic. By doing that the result would be complete to show the whole factory’s GHG emissions coming from the production apart from Scope 1 and 2.

5 Discussion

During this work, I have been able to analyze how much plastic and GHG emissions are generated from the manufacturing of four different sizes of electrical motors. The result consisted of tables and charts showing how much each component and motor generated during the year 2023. Included in the result was also a calculation of the total amount of plastic waste and what the total GHG emissions were for assembly line AL3B in 2023.

What went well during the work was that I was able to determine the difference between different packing methods and how they affect the environment in terms of emissions. Sorting out which components were necessary to examine for this work to avoid that it got too broad worked well, I managed to sort out the components that are used in every motor to be able to present a reliable result.

If I were to redo this work, I would include all assembly lines in the factory and examine a bigger variation of motors. This would broaden the result and give a better overview of the factory’s emission amount.

By doing this thesis work I have gained more knowledge about the electrical motors ABB is manufacturing and given me a better understanding of emissions, plastics, and how to do a Material Flow Analysis. It has also given me an eye-opener for how much waste comes from motor manufacturing and how it affects the environment.

I would like to thank Mikko Ristimäki who gave me the opportunity to write my thesis work for ABB Oy, and who put me in touch with my supervisor Ingela Nyman.

I would like to thank my supervisor Ingela Nyman at ABB Oy, who helped me with this work by brainstorming ideas about the topic and how to approach the work. Ingela also gave me helpful information about ABB's quality targets regarding emissions and how the HSE department has worked with similar topics to my own.

I would like to thank Leif Backlund at Novia University of Applied Sciences for good constructive feedback on how to improve this thesis work. The help with delimitation for the work was very helpful, otherwise this work would have been too broad to complete.

Finally, I would like to thank all the colleagues in the factory at ABB Oy, who have given their opinions on my thesis work and helped me with SAP and explanations about the motors, components, and the ordering of components.

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Appendices

Appendix 1. Table with measurement values and calculations for size 160.

Motor size 160 **BasicCode: 3GBP161410-ADK**						
Component	Stator frame	End Shield -D	End Shield -N	Rotor	Terminal Box Frame	Flange with holes
Quantity	416	2011	3291	189	8256	7703
Plastic type	VCI	VCI	VCI	VCI	VCI	Plastic well
Packing format	Film	Bag+Film x3	Bag+Film x3	Film	Bag+Film	Layer protection x8
VCI Film thickness (m)	0,000212	0,000212	0,000212	0,000212	0,000212	0,000212
Plastic well thickness (m)	0,003	0,003	0,003	0,003	0,003	0,003
Bag Width (m)	X	0,40	0,44	X	0,50	X
Bag Lenght (m)	X	0,40	0,46	X	0,50	X
Layer Width (m)	1,25	0,80	0,80	1,00	0,80	0,8
Layer Lenght (m)	2,05	1,20	1,20	1,40	1,20	1,2
VCI Density (kg/m^3)	930	930	930	930	930	930
Plastic well density (kg/m^3)	230	230	230	230	230	230
Packing volume Bag (m^3)	X	0,00003392	0,00004291	X	0,000053	X
Bag plastic (kg)	X	63,4382016	131,32796054	X	406,93824	X
Packing volume Layer (m^3)	0,00054325	0,000452323	0,000452323	0,0002968	0,00040704	0,02304
Total Packing volume (m^3)	0,00054325	0,000486243	0,00049523	0,0002968	0,00046004	0,50688
Layer plastic (kg)	210,17256	0,420660576	0,42066058	8,833	24,9841152	116,5824
Total Plastic (kg)	210,17	63,86	131,75	8,83	431,92	116,58
Emission factor	3,07	3,07	3,07	3,07	3,07	3,07
GHG emission (kg CO_2/kg)	645,23	196,05	404,47	27,12	1326,00	357,91

Appendix 2. Table with measurement values and calculations for size 180.

Motor size 180 **BasicCode: 3GBP182420-BDK**						
Component	Stator frame	End Shield -Flange	End Shield -N	Rotor	Terminal Box Frame	Flange with holes
Quantity	643	638	1834	490	7520	7703
Plastic type	VCI	VCI	VCI	VCI	VCI	Plastic well
Packing format	Film	Bag + Layer x5	Bag + Layer x5	Film	Bag +Film	Layer protection x8
VCI Film thickness (m)	0,000212	0,000212	0,000212	0,000212	0,000212	0,000212
Plastic well thickness (m)	0,003	0,003	0,003	0,003	0,003	0,003
Bag Width (m)	X	0,50	0,50	X	0,50	X
Bag Lenght (m)	X	0,50	0,50	X	0,50	X
Layer Width (m)	1,25	0,80	0,80	1,00	0,80	0,8
Layer Lenght (m)	2,05	1,20	1,20	1,40	1,20	1,2
VCI Density (kg/m^3)	930	930	930	930	930	930
Plastic well density (kg/m^3)	230	230	230	230	230	230
Packing volume Bag (m^3)	X	0,000053	0,000053	X	0,000053	X
Bag plastic (kg)	X	31,447	90,39786	X	370,6608	X
Packing volume Layer (m^3)	0,00054325	0,0010176	0,0010176	0,0002968	0,00020352	0,02304
Total Packing volume (m^3)	0,00054325	0,0010706	0,0010706	0,0002968	0,00025652	0,50688
Layer plastic (kg)	324,858	30,284	87,066	27,050	11,356	116,582
Total Plastic (kg)	324,86	61,73	177,46	27,05	382,02	116,58
Emission factor	3,07	3,07	3,07	3,07	3,07	3,07
GHG emission (kg CO_2/kg)	997,31	189,51	544,81	83,04	1172,79	357,91

Appendix 3. Table with measurement values and calculations for size 200.

Motor size 200 BasicCode: 3GBP201430-ADK						
Component	Stator frame	End Shield -D	End Shield -N	Rotor	Terminal Box Frame	Flange with holes
Quantity	1689	1243	1493	X	6052	5223
Plastic type	VCI	VCI	VCI	X	VCI	Plastic well
Packing format	Film	Bag + Film x2	Bag + Film x2	X	Bag+ Layer x5	Protection Layer x5
VCI Film thickness (m)	0,000212	0,000212	0,000212	X	0,000212	0,000212
Plastic well thickness (m)	0,003	0,003	0,003	X	0,003	0,003
Bag Width (m)	X	0,55	0,55	X	0,55	X
Bag Lenght (m)	X	0,55	0,55	X	0,55	X
Layer Width (m)	1,25	0,80	0,80	X	0,80	0,80
Layer Lenght (m)	2,05	1,20	1,20	X	1,20	1,20
VCI Density (kg/m^3)	930	930	930	X	930	930
Plastic well density (kg/m^3)	230	230	230	X	230	230
Packing volume Bag (m^3)	X	0,00006413	0,00006413	X	0,00006413	X
Bag plastic (kg)	X	74,1336387	89,0438637	X	360,9467268	X
Packing volume Layer (m^3)	0,00054325	0,00040704	0,00040704	X	0,0010176	0,0144
Total Packing volume (m^3)	0,00054325	0,00047117	0,00047117	X	0,00108173	0,3168
Layer plastic (kg)	853,321	23,4699264	23,4699264	X	119,242368	72,864
Total Plastic (kg)	853,32	97,60	112,51	X	480,19	72,86
Emission factor	3,07	3,07	3,07	X	3,07	3,07
GHG emission (kg CO_2/kg)	2619,69	299,64	345,42	X	1474,18	223,69

Appendix 4. Table with measurement values and calculations for size 225.

Motor size 225 BasicCode: 3GBP221210-ADK						
Component	Stator frame	End Shield -D	End Shield -N	Rotor	Terminal Box Frame	Flange with holes
Quantity	1261	1163	1469	X	6052	5223
Plastic type	VCI	VCI	VCI	X	VCI	Plastic well
Packing format	Film	Bag + Film x2	Bag + Film x2	X	Bag+ Layer x5	Protection Layer x5
VCI Film thickness (m)	0,000212	0,000212	0,000212	X	0,000212	0,000212
Plastic well thickness (m)	0,003	0,003	0,003	X	0,003	0,003
Bag Width (m)	X	0,60	0,60	X	0,55	X
Bag Lenght (m)	X	0,60	0,60	X	0,55	X
Layer Width (m)	1,25	0,80	0,80	X	0,80	0,80
Layer Lenght (m)	2,05	1,20	1,20	X	1,20	1,20
VCI Density (kg/m^3)	930	930	930	X	930	930
Plastic well density (kg/m^3)	230	230	230	X	230	230
Packing volume Bag (m^3)	X	0,00007632	0,00007632	X	0,00006413	X
Bag plastic (kg)	X	82,5469488	104,2660944	X	360,9467268	X
Packing volume Layer (m^3)	0,00054325	0,00040704	0,00040704	X	0,0010176	0,00288
Total Packing volume (m^3)	0,00054325	0,00048336	0,00048336	X	0,00108173	0,0144
Layer plastic (kg)	637,086	23,4699264	23,4699264	X	119,242368	417,312
Total Plastic (kg)	637,09	106,02	127,74	X	480,19	417,31
Emission factor	3,07	3,07	3,07	X	3,07	3,07
GHG emission (kg CO_2/kg)	1955,85	325,47	392,15	X	1474,18	1281,15

Appendix 5. Table with measurement values and calculations for size 250.

Motor size 250 BasicCode: 3GBP252210-ADK						
Component	Stator frame	End Shield -D	End Shield -N	Rotor	Terminal Box Frame	Flange with holes
Quantity	70	81	134	X	6052	5223
Plastic type	VCI	VCI	VCI	X	VCI	Plastic well
Packing format	Film	Bag + Film x2	Bag + Film x2	X	Bag+ Layer x5	Protection Layer x5
VCI Film thickness (m)	0,000212	0,000212	0,000212	X	0,000212	0,000212
Plastic well thickness (m)	0,003	0,003	0,003	X	0,003	0,003
Bag Width (m)	X	0,65	0,65	X	0,55	X
Bag Lenght (m)	X	0,65	0,65	X	0,55	X
Layer Width (m)	1,25	0,80	0,80	X	0,80	0,80
Layer Lenght (m)	2,05	1,20	1,20	X	1,20	1,20
VCI Density (kg/m^3)	930	930	930	X	930	930
Plastic well density (kg/m^3)	230	230	230	X	230	230
Packing volume Bag (m^3)	X	0,00008957	0,00008957	X	0,00006413	X
Bag plastic (kg)	X	6,7473081	11,1622134	X	360,9467268	X
Packing volume Layer (m^3)	0,00054325	0,00040704	0,00040704	X	0,0010176	0,00288
Total Packing volume (m^3)	0,00054325	0,00049661	0,00049661	X	0,00108173	0,0144
Layer plastic (kg)	35,366	23,4699264	23,4699264	X	119,242368	417,312
Total Plastic (kg)	35,37	30,22	34,63	X	480,19	417,31
Emission factor	3,07	3,07	3,07	X	3,07	3,07
GHG emission (kg CO_2/kg)	108,57	92,77	106,32	X	1474,18	1281,15