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Digitization and Avoided Emissions

A Case Study of Product Information at SEMCON

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Abstract

The environmental threat of our time puts pressure on all areas to reduce the climate impact. The Paris Agreement set by the United Nations has set an aspiring goal of limiting the global warming by 1.5°(United Nations, 2021). This goal has started the work towards developing accounting standards for greenhouse gas emissions. The latest accounting framework presented by the organisation GHG Protocol is the calculation of avoided emissions. The framework aims to be able to measure the effects of companies emission reducing activities. This thesis examines how the digitization of product information can reduce a company's CO_2 footprint. The examination will be carried through as a case study of digitization projects implemented by the company Semcon. The thesis purpose is to create an initial understanding how calculations can be carried through and what environmental effects digitization can have. It also aims to inspire further investigation within the area. Information about the cases was collected through qualitative interviews with people involved in the cases at hand. This information was then compared to established calculating methods, identifying both carbon saving mechanisms and primary avoided emissions. The main findings was the understanding of the complications of the difference in the cases. Every specific case required a substantial amount of collected data, both regarding before and after the implementation of digitization. Results showed that digitization of product information reduced the emissions of greenhouse gases in both cases, to a limited extent.

Keywords: Avoided Emissions, Product Information, Digitization, Digitalization, CO_2 Footprint, Scope 3 Emissions, GHG Protocol

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Elucidations

BAU (Business as Usual) - The actions and methods used and implemented before an implementation of an emission reducing decision.

Greenhouse Gases (GHG) - All gases that contributes to global warming.

CO2 Equivalent (CO_2e) - All GHG are compiled and scaled after their global warming potential (GWP) and summarize into the unit CO_2e. For instance the GWP of methane is 25, which means that burning 1 unit of methane is equivalent to burning 25 units of CO_2.

Carbon Abatement Factor - A factor that measures the amount of reduced CO_2e emission per unit. For example: CO_2e/kg and CO_2e/km

Carbon Emission Factor - A factor used to convert materials or processes into CO_2e, is found in various databases.

CO2 Footprint - All the GHG emissions a product or service is responsible for during its lifecyle. CO_2 footprint is specified in CO_2e.

Carbon Saving Mechanism - Activities or change in methods that lead to a reduction in CO_2e emissions.

Digitalization - Transforming business processes by leveraging digital technologies. The aim is to use digitalization in order to reach higher levels of efficiency and revenue.

Digitization - Converting data or information into a digital representation. The data itself does not change, it is just encoded in a different format.

GHG Protocol - Organisation working towards developing standardized accounting methods for emissions from greenhouse gases.

Product Information - Details or description connected to a specific product. For example: user manuals, safety- and repair instructions.

Solution - An activity or a change in a process that reduces the emission of greenhouse gases

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1 Introduction

This chapter offers relevant background information on the present subject and presents arguments for the implementation of the thesis.

1.1 Background

The Paris Agreement entered in force in November 2016, setting an aspiring goal of limiting global warming to well below 2°C and pursuing efforts down to 1.5°C (United Nations, 2021). To meet this ambitious goal, companies all over the world need to drastically cut their greenhouse gas (GHG) emission and find new technologies, allowing them to continue operating without contributing to global warming in the future. Companies are forced to come up with new disruptive and innovative solutions in order to survive. Digitization has, over the past couple of years, completely changed how we communicate, work and absorbs information. This new era, by many called the digital age, has great potential for creating a sustainable society. Smart homes could reduce the energy consumption and car sharing apps make it easier for us to commute together and eliminate the need of owning a car. The list goes on for examples of where digitization contributes to a more sustainable future (Fuchs, 2019).

The rapid growth of accessibility to data, information and computational power for sure opens up possibilities that were unthinkable of only a few years ago. Ten years ago statistics shows that there where 2 billions active users on the world wide web and today that number has doubled up to 4 billions. More shockingly is that in 1995 only one percent of the worlds population had access to the internet and between 1999 and 2013 the numbers of internet users had increased ten times (Statista, 2021). The accessibility is growing fast and is forecasted to do so for the next decade. This, of course works as a driving force for digitalization. Often today there is the economic incentives that decides whether a business chooses to implement a digital solution or not. Many times the transitions implies lowering operating expenses and increasing efficiency (Ylander, personal communication, November 16, 2021).

Moving into the digital world is a transition which takes time and often means that huge investments are required. This is especially true for big mature companies that do not possess the agile abilities that smaller companies do. A relatively new and undiscovered path in the world of industries is using digitalization in order to present the product information. The traditional way of presenting it is in paper form in brochures or blueprints. Today most product information is paper-based and often thrown away before or directly after it is used. At large multinational corporations like Ikea, the product information is also provided in multiple languages which results in unnecessarily large brochures where only a few pages in the brochure are used (Sondén, personal communication, October 18, 2021). A solution to the problem which already a number of companies have been assimilating is to make the product information more digitized. By making it digital you can for an example get rid of the excessive use of paper and consequently decrease the carbon emissions a company is responsible for.

Other areas where carbon emissions can be lowered is in the area of improved instructions for machines and repair. The highly technological machines and industries of today create big challenges for machine operators and repairers to localize and fully understand breakdowns in the machines. This problem can result in two unfavorable situations that can be improved through digital information and resulting in lowered carbon emissions. These two situations, or problems, are that the repairer chooses to replace a whole subsystem instead of a single component or that the repairer does not have the correct knowledge or information about the machine, and consequently orders the wrong spare part (Sondén, personal communication, October 18, 2021). Both of these scenarios lead to economic losses, but also to carbon emissions due to extra transport or wastefulness of material in components. This is just one scenario where an effective product information contributes to a more sustainable society.

As mentioned before companies have to think of themselves as solutions provider which come up with innovative ideas in order to make climate change come to a halt. When presenting new solutions there is also a need to present how much less GHG they are emitting by choosing the new solutions. Here the need of the concept ”Avoided emissions”, also known as scope 4 could play an important and meaningful role in the future.

The consulting firm Semcon AB helps firms to improve their product information through digitalization, and thereby limits the problems presented above. The thesis will be done in collaboration with the Product Information department at Semcon. Today, the incentive for digitalization is to reduce monetary costs. But in the future it may also be a sustainability incentive amongst companies where they inquire for the amount of GHG that is being emitting when introducing new solutions. This thesis aims to develop a method for calculate the gains in forms of avoided carbon emissions.

1.2 The Concept of Avoided emissions

The general concept of avoided emissions is the comparison between different solutions. A solution could be a product or a service, the purpose of the solution should be in the nature that it implies a reduction of GHG emissions, in order to result in avoided emissions. The avoided emissions can therefore be defined as the difference in GHG emissions between the business as usual (BAU) scenario and the solution in question (Stephens & Thieme, 2020). In the current situation there is no general or well established method of calculating the avoided emissions. The reasoning for this is partly based on the fact that the avoided emissions depend on a lot of different factors, depending on the situation, and partly on the fact that there at the moment does not exists an economic incentive. The later is expected to change, since the sustainability requirements will increase over the coming years. The Paris agreement and COP26 have increased the pressure on firms to decrease their emissions, and work towards net-zero (Bowcott, Pacthod & Pinner, 2021). A method for measuring the avoided emission will be necessary for companies to make the right decisions for sustainability, a gross margin for the environment. This thesis will apply the concept of avoided emissions in order to explain the impact of different levels of maturity in the product information.

1.3 Problem Discussion

In order to make businesses willing to improve and be innovative in terms of finding new solutions there is a need to find a way of assessing the avoided emissions that come with it (Stephens & Thieme, 2020). A proper way of quantifying the avoided emissions could lead to an incentive for the company to implement the new solutions. It could also work as a tool for investors and customers in order to compare the impact of the different solutions. A company working on for an example a new way of heating up buildings and as a consequence can drastically reduce their CO_2 footprint with that particular solution, must have a way of showing it in order to be noticed for their work, otherwise companies will not be willing to improve in this area. The focus has always been on the worst polluters and reporting the GHG emissions they are responsible for, here avoided emissions give the opportunity to see companies as solutions provider instead of the sources of emissions (Stephens & Thieme, 2020). The focus shifts from trying to pinpoint the worst ones to highlight the real solution providers. The tool of the concept avoided emissions will be a way for companies to demonstrate the positive impacts their new solutions have on society. Therefore the ultimate goal for the concept of avoided emissions is that it becomes a mandatory part of a companies financial reporting (Stephens & Thieme, 2020). Of course this will not be necessarily for all companies and products or services. For heavy polluter companies, such as steel companies or companies in the oil and energy sector, the main goal is to just reduce their own emissions. There is an obvious risk of greenwashing if these kind of companies would start accounting for their avoided emissions. A more innovative company, such as the car sharing pool company, could benefit from the avoided emissions accounting where they could report how much their solution contributes to the avoided emissions category.

Today there is an established system for how you monitor companie's greenhouse gas emissions. According to the GHG Protocol the emissions can be divided into three different scopes, called scope 1, scope 2 and scope 3 (Bernoville, 2020). Where scope 1 is the GHG emissions a company is directly responsible for. It can be described as the emissions released to the atmosphere as a direct consequence of the company's operation. Scope 2 is the indirect emissions, this scope accountants for all the emissions created by the purchased power. The purchased power is all power used to create steam and heat, but also electricity and the power used for cooling. Examples of emissions accounted for in scope 2 could be the emissions created by extracting and burning natural gas to generate electricity and heating for a factory. Apart from scope 1 and 2 the emissions in scope 3 are not controlled directly by the reporting company. Scope 3 is all the emissions created in the value chain of the company. Because the emissions are not owned by the company they are not accounted for in scope 2. Because of the vast complexity of the emissions created in scope 3 corporations usually do not have to report these emissions (Bernoville, 2020).

As discussed in chapter 1.2, is there no established standard for calculating and reporting the category including avoided emissions. The vast complexity of how much emissions a certain solution is responsible for makes it hard to find reliable data, one has to remember that the calculations and the results are never better than the provided data. The problem that occurs if companies would be enforced to report avoided emissions is that the data that the calculation would be based on would, in most cases, have a low degree of credibility. To obtain reliable data for the new solution is a very costly and resource intensive process. The biggest challenge is that it takes a lot of time to track how the new solution performs. It could be hard to know beforehand how much GHG emissions the new solution is responsible for, therefore it is going to take time before reliable data for the new solution could be determined.

It is important to keep in mind that the concept of avoided emissions is not the main problem. It is a relatively easy concept to grasp and it does not imply any deep complexity. The main problem is to make justified delimitations and gather data with a sufficient reliability.

Just to digitilaize the product information is a big step for many companies. As seen in the product maturity staircase (section 4.1), many companies are still at the level where the product information are printed in paper form. The digital product information would also have a huge impact on how the consumers are using the product information (Sondén, personal communication, October 18, 2021). Instead of searching through the pages of a thick brochure trying to find a certain spare part it would be way easier just searching for it on your Ipad or on a computer. But a higher level of product information could also contribute with even more benefits, often benefits that we would not think of in the first place. Increasing the intelligence of the product information could mean such things as a longer life time of the product. Which consequently means that more products can be used for longer and there is a decreased demand to produce as much products, which in the end contributes to a more environmentally sustainable society. The product information will also help the user to find better and more efficient ways of repairing the products. In the longer run this will not only be beneficial for the company but also for the climate (Sondén, personal communication, October 18, 2021). But the big question is how you can assess this so called avoided emissions that comes as consequence of the more intelligent product information. The ideal would be if an established framework was published and companies all around the world could use this framework as a guideline in order to report their avoided emissions.

1.3.1 Contribution to Literature and Practitioners

The aim of this thesis is to bring understanding and further knowledge about the complexity of GHG emissions and and how it could be quantified in a fair way and finally presented in terms of avoided emissions. It could be seen as an example of how the concept of avoided emissions could be used on real cases. It also aims to investigate how much of an impact digitalization have and was therefore chosen by the researchers to act as an example for the concrete calculations. The studied company, Semcon, was chosen because of its work in the field of digitalization in order to improve the user friendliness of today's tech. They could offer hands on cases where they had advised companies in using digitalization in order to get more efficient and intelligent product information, resulting in costs savings. Semcons Product Information department are therefore deemed to be a good case for the study and could deliver reliant results. The findings of this thesis are primarily most valuable for Semcon since it is their real cases that are being examined. Hopefully the findings will also be valuable for other organizations or companies, of similar characteristics, that are interested in the subject. It could for instance be companies that are thinking of doing the same digital transition regarding product information and want to find out the decrease in GHG emissions. Conclusively the thesis aims to make a contribution to the still very fresh and unexplored research field of Avoided Emissions.

1.4 Purpose and Research Question

The purpose of the study is to quantify the avoided carbon emissions connected to digitalization of product information. The end goal of the study is to be able to develop a method of calculating the avoided CO_2e emissions. Semcon is later going to use the study as a foundation for their further work on the subject. It also important that the study is also general, so its results can be applicable to various scenarios.

The research questions that the study aims to answer is:

- **How is product information used in order to reduce the CO2 footprint?**
- **How can we measure the climate benefit of digitalized product information in terms of avoided emissions?**

1.5 Delimitations

In order to make the study relevant for Semcon and within the frame of the course the following delimitations have been decided.

- In order to manage to quantify the avoided emissions connected to product information, assumptions have to be made. The amount of data required would be too big otherwise. This will create problems with making the work applicable. Therefore the range of emissions associated with the solution in question will be limited to how much data is available.

- The environmental impact will only be measured in terms of Carbon dioxide equivalents (CO_2e). The main reason why only CO_2e is included is to reduce the complexity of the result to make it more comprehensible. The databases used for the study utilize the unit CO_2e.

2 Theoretical Framework

This section provides the theoretical framework for the thesis. The theoretical framework will build the foundation of the analysis of the empirical data.

2.1 GHG Protocol

Greenhouse Gas Protocol (GHG Protocol) is an organisation working with establishing of standardized frameworks to measure and manage greenhouse gas emissions from organisations, operations and value chains (GHG Protocol, 2021). The organisation is partnering with World Resource Institure (WRI) and the World Business Council for Sustainable Development (WBCSD), and works with several governments, industry associations, NGOs and other business.

GHG protocol has since its first corporate standard in 2001 developed several methods, frameworks and technical guidance's in order to provide organisations with reliable tools to understand and measure their carbon footprint at several levels and sections (GHG Protocol, 2021). The following frameworks and guidances are all created by the GHG Protocol and will work as tools to answer the research question at hand.

2.2 The Avoided Emissions Framework (AEF)

The Avoided Emissions Framework is the second out of three modules in the 1.5 °C compatible Solution Framework. The module is written by the main authors Andie Stephens and Veronika Thieme. The document strives to define a framework of avoided emissions and provides examples for how avoided emissions can be calculated. The goal is that relevant companies routinely publish their avoided emission, alongside their financial report. This will help investors and customers to evaluate a company's exposure to climate change related risks as well as their potential to be successful under different reduction scenarios (Stephens & Thieme, 2020). The companies will also gain on evaluation of avoided emissions. It allows the company to compare different product's sustainability and can set goals for the future that does not just focus on lowering the emissions, but also shows how their actions limits emissions that could have been.

The framework presents a methodology that provides a comparison between the emissions of GHG of business as usual with those from an improved solution. This gives a demonstration of the benefits of the solution compared to the baseline. To calculate the avoided emissions, the emissions of the following categories must be calculated (Stephens & Thieme, 2020):

- Business-as-usual system: The emissions without the introduction of the emission enabling solution.
- Enabling effects: Avoided emissions due to the avoided activities as a result of the enabling solution. These can be divided into primary enabling effects or secondary enabling effects.
- Direct solution emissions: The life cycle emissions caused by the enabling solution.
- Rebound Effects: The increased business-as-usual emissions occurring as a result of the enabling solution.

The net avoided emissions are then calculated as:

$$Net\ avoided\ emissions = Enabling\ avoided\ emissions - Direct\ solution\ emissions - Rebound\ emissions \tag{1}$$

It can also be defined as a relation to the business-as-usual emissions:

$$Net\ avoided\ emissions = BAU\ baseline\ emissions - Emissions\ of\ the\ solution\ enabled\ scenario \tag{2}$$

In order to quantify the total carbon abatement, the framework presents the utilization of a carbon abatement factor. This factor represents the avoided emissions of a single unit or action. The factor is then scaled up with a volume to give the total carbon abatement. The factor makes it possible to compare different actions to each other, and can act as a basis for the choice of strategy. In a broader perspective, the calculation can be broadened with the likelihood of success and adaption. This is presented in equation (3).

$$\begin{aligned} \sum(Probability\ of\ success \times Probability\ of\ adaption \times \\ Volume \times Carbon\ abatement\ factor) = Total\ Carbon\ Abatement \end{aligned} \tag{3}$$

The framework further provides general steps for quantifying avoided emissions. The steps are as follows:

1. Identify solution

2. Establish boundary and baseline
3. Document methodology and identify data
4. Test mechanism and methodology
5. Identify studies. Determine carbon abatement factor
6. Collect data
7. Calculate carbon abatement
8. Final documentation and validation

2.3 Corporate Value Chain (Scope 3) Accounting and Reporting Standard

The Corporate Value Chain (Scope 3) Accounting and Reporting Standard is a supplementary report to the GHG Protocol Corporate Accounting and Reporting Standard, which was published in 2004. The report is written by six authors within the GHG Protocol Team. The report aims to establish a standard for businesses to account and report emissions from their products or services. The report presents a new boundary for which the company is responsible for, scope 3. This is an addition to the already established scopes 1 and 2. Scope 3 applies to emissions connected to activities up- or downstream from the firm's direct operation. Examples of this are emissions connected to production of purchased goods and services, transportation of raw material, use of sold products, and end-of-life treatment of sold products. The three scopes combined intends to represent the complete sum of emissions connected to a company's activities, thereby representing a company's business-as-usual emissions (GHG Protocol, 2011).

The report presents a series of steps in scope 3 accounting and reporting:

1. Define business goals
2. Review accounting reporting principles
3. Identify scope 3 activities
4. Set the scope 3 boundary
5. Collect data
6. Allocate emissions
7. Set a target & track emissions over time

8. Assure emissions
9. Report emissions

These steps allows companies to standardize their emissions report, and gives the opportunity to compare both products and whole businesses.

Further, the report presents a couple of concepts and definitions. The authors claims that the accounting should follow five key principles in order to obtain consistency and legitimacy. These principles are: Relevance, completeness, consistency, transparency, and accuracy. The authors further presents the concept pairs: direct- and indirect emissions, and upstream- and downstream emissions. These definitions are then used to define the scope 3 boundaries and to identify and allocate the emissions (GHG Protocol, 2011).

Although these definitions and setup activities are necessary to gain legitimacy and a standardization, it is the data collection part that require both the most time and the most engagement. In this thesis, the framework was used to find guidance on how the value chain of different products or services seemed. It was also useful when it came to data management and how different methods in *Technical Guidance for Calculating Scope 3 Emissions* could be applied when only a certain amount of data was available.

2.4 Technical Guidance for Calculating Scope 3 Emissions

Technical Guidance for Calculating Scope 3 Emissions is another supplementary report to the GHG Protocol Corporate Accounting and Reporting Standard. The report is written by nine authors from the GHG Protocol and Carbon Trust team, and provides applicable tools and methods for firms to calculate their scope 3 emissions. The report divides different emitting activities into different categories and presents specialized methods for calculating the emissions, and also provides examples. The categories are as follows:

1. **Purchased Goods and Services**
2. **Capital Goods**
3. Fuel- and Energy-Related Activities not Included in Scope 1 or Scope 2
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

Categories associated with the topic at hand are category number: 1, 2, 4, 5 and 6. Detailed decision- and calculation methods are presented in appendix A.

Beyond just presenting calculation formulas and decision trees, the report focuses on the fact that the data collection is a vital part of deciding on the emission calculations and where to focus the enabling solutions (GHG Protocol, 2013). The report claims that a screening over the different categories should be made in order to find out where the enabling activities have the biggest effects. This will also help with deciding on how the data collection should be carried through. More accurate data and calculations should be applied to large emission contributors, and less accurate to smaller contributors (GHG Protocol, 2013).

The report continues to describe different kinds of data, and what data that is necessary for different category of emissions. GHG Protocol also believes that proxy data should be used to fill in the data gaps in order to minimize the risk of missing emissions. This thesis will use the framework in order to find relevant equations that could be applied to the two cases. The framework was used to answer the second research question regarding how the climate benefit can be quantified and measured.

3 Methodology

The following section explains the decision process of developing and selecting a suitable method for the research questions at hand. The section also presents relevant tools used for the assessment of avoided emissions.

3.1 Choice of Method

Bryman and Bell (2017) divides the research approach into two categories: inductive research and deductive research. The difference between the two categories can be summed up as follows: the deductive method is controlled by theories, and the inductive method creates new theories (Bryman & Bell, 2017). This thesis will apply a deductive approach, which means that the data collection, results and analysis will be based on already established theories and concepts. The challenge associated with the deductive method is the activity to connect methods and research to the concept at hand, digitization.

The research question was answered using both a qualitative and quantitative method. The first question: *How is product information used in order to reduce the CO2 footprint?* will be answered through a qualitative method. Patel and Davidson (2011) describes a qualitative method as a collection of "soft data". This aims to enhance understating and to identify new solutions and conclusions. The qualitative method was utilized, since the project required detailed and extensive information about the problems at hand. This information will be collected through qualitative interviews with the aim to gain understanding about both digitization and how its implemented.

The second question, *How can we measure the climate benefit in terms of avoided emissions?*, will be answered using a qualitative method with support from a quantitative method. The reasoning for this is the need to acquire environmental data for different activities and materials, and apply this data to methods acquired from analysis of literature. Rennstam and Wästerfors (2015) explains that the aim of a qualitative method is not to measure how much and how many, but rather to give an understanding about processes, decisions and qualities. This thesis end goal is to measure avoided emissions, therefore is a quantitative method implemented, but the construction of the calculation will utilize a qualitative methodology. Noted is that the quantitative method won't be carried through first hand, but rather be based on research by others. This increases the focus on reliability and legitimacy of the data.

3.2 Case Study

The report was conducted as a case study of the company Semcon, and how their implementation of digitization can result in avoided emissions. The analysis will be based on a number of different cases, where digitization has been implemented in different ways. The aim is the attain an overall picture of how digitization is used today, and analyze how it can provide sustainable benefits. Säfsten and Gustavsson (2019) recommends a case study when a deeper understanding is sought for a specific occurrence or activity. A case study is also useful when answering the questions *why* and *how*, but also *what*-questions can be answered. A case study will also offer the opportunity to investigate less explored situations and makes it possible to look into the case in its natural setting and thereby get valid and reliable results (Säfsten & Gustavsson, 2019). The case study will, in contrast to real time, be carried through in a retrospective way. The studied cases have all, already, been implemented and the case study will be based on the results and effects from the cases.

The information in this project will be based on both primary and secondary data. Primary data will be acquired through interviews and the secondary data from a literature study and already existing data bases. Säfsten and Gustavsson (2019) describes primary data as data collected with the focus to answer the topic at hand, while secondary data is based in primary data not collected for the topic at hand (Säfsten & Gustavsson, 2019). The project will follow a deductive methodology and base all conclusions on already established research and facts. The collected primary data through interviews will merge with the secondary data from literature in order to try to answer the research questions.

The data collection will be based on two different cases. Information form these cases will be acquired through interviews with people involved in the cases. The cases are already, by Semcon, implemented digitization projects and will be used as foundation and examples of where calculation of avoided emissions could be applied. The two selected cases: ESAB and Arcam, are selected because they represent cases often implemented by Semcon. The biggest challenges with the two cases is to identify and quantify activities that reduces emissions, and also activities that increases the emissions. Measurement of changes in behavior is also a big challenge, since these often are complicated to identify and often are unplanned and unwanted. Detailed information about the cases are presented in section 4.

3.3 Interviews

The purpose with the interviews is to collect information and data about Semcons operation and how they use digitization. The interviews will also give a better insight in the different cases, their purpose, their extent and the expected results. The interviewees are provided by Semcon and the intention of the interviews is to provide a greater understanding and to acquire data about the different cases. The interviewees are:

- David Sondén - General Manager Sweden, Semcon (18 October 16:00-17:00 Lindholmsallén)
- Håkan Andersson - Team Manager, Semcon (10 November 14:15-14:45, 4 January 9:30-9:45 Microsoft Teams)
- Teresa Berndtsson - Information Architect, Semcon (12 November 15:15-15:45 Microsoft Teams)
- Andreas Säwström - Team Manager with focus on spare part engineering, Semcon (16 November 9:00-9:45 Microsoft Teams)
- Pär Ylander - Manager Customer Developer, Semcon (16 November 15:00-15:45 Microsoft Teams)

The interview with David Sondén was carried through with the intention to provide the project with initial information about digitization, and to decide which cases that would be investigated. The interviews with Teresa Berndtsson and Håkan Andersson was directly connected with the two cases at hand: ESAB (T. Berndtsson) and Arcam (H. Andersson). Andreas Säwström and Pär Ylander were interviewed with the focus on getting further understanding and knowledge about how digitization is utilized and how avoided emissions can be used as a future incentive for digitization. All the interviews have taken place digitally on Microsoft Teams and notes were taken throughout the whole interview.

Since the interview's purpose is to provide initial information about the cases and the project as a whole, semi-structured interviews were utilized. This allowed the interviewee to freely describe the cases (Patel & Davidson, 2021). This was desirable since the interviewer lacked in knowledge about the cases, and lowered the risk in missing something important. If the interviewer in a later stage realised that they needed more information about the cases, they had the opportunity to reach out to the interviewee to get additional details.

Säfsten and Gustavsson (2019) presents weaknesses with only using interviews as a collecting method for a case study. To limit this weakness triangulation is recommended to be used. By complementing interviews with other methods, the weaknesses with interviews can be reduced. Though, this is limited by the availability of both time and additional data.

3.4 Life Cycle Analysis

In order to get a grasp of the environmental impact of a service or product, its necessary to apply an established and inclusive methodology. This project will utilize the Life Cycle Analysis to achieve a complete view of every product or service.

The idea of a Life Cycle Analysis (LCA) is to evaluate the environmental impact of a product through its entire lifespan (Golsteijn, 2020). This includes every step from raw material extraction, to manufacturing, to usage, and the disposal and recycling. This method gives a much more nuanced view of a product, and exposes environmental impacts that easily can be overlooked at a first glance. The absolute biggest advantage of using LCA is that all the emissions are accounted for, consequently all emissions in the three different scoopes are included when LCA is utilized. LCA forces companies to expand their view of their product to outside their own walls. Another huge advantage is that there are different kinds of LCA and you can choose how complex you want it. In general it becomes more complex the further away from the product or service in question you move (Golsteijn, 2020). According to Golsteijn (2020) a rule of thumb is that the more detailed you want your LCA to be, the more data you need to have. Since it wont be possible to gather enough data to perform a comprehensive LCA for this particular study, the idea is still used, to the extent where reliable data is available when calculating emissions associated with events.

3.5 Granta EduPack

A big part of the avoided emissions in this project will come from reduced usage of materials. In order to calculate the avoided emissions of the reduced material, information about the material is necessary. This project aims to use Ansys database called Granta EduPack to get the necessary information and data about the materials.

Granta EduPack is a data software used to handle material selection (Ansys, 2021). EduPack includes a database of materials and processes. It also has a software that calculates materials, and products, carbon footprint based on type of material and what manufacturing process is used to create the material or the finished product. The software is also capable of taking into consideration which country the materials are being manufactured in. Also the transportation emissions associated with the material could be taken into account. Granta is widely used amongst students at Chalmers University of Technology and are a crucial tool for performing LCA and finding material parameters. Therefore Granta was chosen as the main source for data regarding the emissions throughout the whole thesis.

3.6 Literature Review

Literature and information in the research field at hand was evaluated with a critical eye. The selection resultet in two established physical books about research, Säfsten and Gustavsson (2019) and Patel and Davidson (2017). Initially, an overall research was conducted in order to get an understanding of the different basic concepts and methods, for example digitization, greenhouse gases and product information. This information was gained through scientific articles, physical books and initial discussions with employees at Semcon. When an initial understanding was created, a more extensive information search was carried through. The search was limited to reports and research conducted by established organisations and researchers in order to secure the quality. Keywords were used to achieve an accurate search. Examples of keywords are: "avoided emissions", "greenhouse gases", "CO2 accounting", and later "scope 1", "scope 2" and "scope 3". To evaluate the quality of the literature, all authors and originators were checked, and it was made trustworthy organisations were used.

3.7 Reliability and Validity of Calculations

It is of utmost importance to keep in mind that when GHG emissions calculations are applied delimitation's have to made. The LCA approach where all GHG emissions are accounted for is a perfect world scenario and it is almost impossible to achieve such a complete LCA. In reality it is impossible to reach a perfect result when it comes to calculating emissions, because of all the different error factors included. In the *Avoided Emissions Framework* the terms "primary avoided emissions" and "secondary avoided emissions" are used (Stephens & Thieme, 2020). By working further away from the solution the complexity rapidly increases (GHG Protocol, 2011). Further away means working with both upstream and downstream emissions in scope 3 (GHG Protocol, 2013). For instance, you should go back to the mining process when you are assessing GHG emissions on a smartphone. The answer depends on the reliability of the data that is available, is it known which mining company is responsible and which transportation and mining methods that are being used? If there are unambiguous answers to these kind of question it could justified to include those upstream scope 3 emissions, otherwise they should be excluded. Along the whole process the data constantly needs to be evaluated and critically reviewed (Greenhouse Gas Protocol, 2021). As discussed before, the calculations have to possess a certain degree of reliability in order to be relevant, both for the case company Semcon, but also for other practitioners that may want to take part of the thesis. Therefore it is preferred to have a lower degree of complexity and make use of the direct emissions caused by the solution rather then trying to include all the emissions and as a result have a much lower reliability. When the complexity behind the calculations increases the requirements of data increases exponentially (GHG Protocol, 2013). Hencefort, the calculations performed on the cases were made with great caution when selecting data and how far away from the product emissions were accounted for.

4 Results from the Interview Study

This section provides the interviews on the cases made at the product information department at Semcon. It also provides additional information retrieved at Semcon.

4.1 Semcon and Product Information

In Semcon's work they have developed a product information ladder, showing where different companies are positioned in terms of how far they have gotten with their product information. The ladder is called the "product information maturity" staircase and consist of five steps. In the lower end of the staircase, product information is seen as a cost and the only incentive for a company to provide the information is because of legislation. In the higher end of the staircase there is a different perspective on product information. Here it is seen as a valuable asset for the company. By interviewing customers, Semcon is mapping out where in the staircase they are positioned. In this study the ladder will be used in order to explain which kind of climate benefit product information will give if a company would enter a new level.

Level 0 - The first step in the staircase is called "compliance focused". At this level of maturity the product information is not providing any value to the business and is just made in order to fulfill legal requirements, industry standards or environmental regulations. The product information is not reused and is solely in printed paper form.

Level 1 - Further up in the staircase the company are more production focused regarding their product information. The aspect of lowering costs are taken into account and the product information is also distributed in a more cost efficient way. The information also has a high level of reuse and efficient translation management.

Level 2 - Moving one step up means that the information is product focused and easy to update. It is also often topic based and not as general as it could be in the lower levels. Here the information is also completely consumed and distributed digitally. Most of the big international manufacturing companies are today located at this level in staircase (Sondén, personal communication, October 18, 2021).

Level 3 - The next step is to make the information more end user focused. This means that the product information should be available at a variety of digital channels making it easy to find. It is also always topic based which makes it more specific. The aim of the product information is not just to inform the end user about the different components in the product, but also how you can increase the uptime and efficiency of the product. The main goal at this level is therefore to satisfy the end user with the provided product information.

Level 4 - At this level the information is event and context driven. Which means that it becomes more dynamic and is triggered by different factors such as time, place, role and product or system status. An example of this level of product information is that you get a notification in your phone as soon as there is something wrong in your car. Then the product information is driven by different events and lets you know right away when there is something wrong.

Level 5 - The final step in the staircase is the intelligent product information. The product information is machine readable and then processed by an AI algorithm. Such complicated and complex system is rarely used by any usual customer and Semcon has only had one customer requesting this high level of product information.

4.2 Theresa Berndtsson - ESAB-Case

This case is a still ongoing digitization project and treats the welding company ESAB. The company is specialized in different welding solutions and manufactures and sells welding machines. The company was founded in 1904 and has manufacturing sites on four different continents (ESAB, 2021). The welder machine in this case was an Aristo 500ix, the technical specifications are used in the calculations section, see section 5.1.5. The project Semcon was working on at ESAB is to replace an existing instruction manual with a digital system. Originally, the company ESAB, which produces industrial welding machines, used two different versions of instruction manuals (Berntdsson, personal communication, November 12, 2021). One for the North-American market, and one for the European market. Due to the great variation of languages across Europe, the European manuals included a great variation of languages, thereby forcing the manual to include pages that doesn't provide any useful information to the average user. These manuals are ordered and printed in big batches with every new serial number. When the serial number of the products changes, the remaining manuals is thrown away (Berntdsson, personal communication, November 12, 2021).

Due to different laws and regulations, some information needs to be in physical, printed, form. For instance, the safety manual needs to be printed in physical form. ESAB has to this day two versions of this safety manual, one European and one North-American. This is explained by the fact that the European version is compatible in the whole world, except North-America (Berndtsson, personal communication, November 12, 2021). The safety manual is printed in A4 format and consists of seven pages. Another physical information needed is a short quick start manual, which helps experienced users to easily start the welding machines in a few steps. The quick start manual is printed in A5 format. The manuals could have 30 different languages. Both of these two types of printed information are not sensitive to changes in serial number (Berndtsson, personal communication, November 12, 2021).

The digitization project does not only focuses on splitting up the manuals into different languages, but also makes the documentation more versatile, accessible and user friendly. The new documentation is structured as a website with a structure similar to Wikipedia, where different subjects and instructions are linked to each other. The structure is designed to be more accessible for the user, and to avoid the struggle and time consuming activity of flipping or scrolling through a document. The digital documentation is easily implemented, since smartphones and iPads already exists within a welder's tools. The digital documentation also allows improvements and updates to be made easily when new serial numbers are added (Berndtsson, personal communication, November 12, 2021).

The main positive environmental result is the reduction of printed paper. According to Berndtsson, 1300 sheets of paper will be saved on each product sold. This is also the aspect that this case study will focus on. The calculation of reduced amounts of paper is relatively easily done, but the challenge in calculating the avoided emissions lies in the emissions associated with the production, usage and waste management of the paper as well as the emissions associated with the replacing solution.

4.3 Andreas Säwström - Documentation of Spare Parts

Andreas Säwström is working with the implementation of digitization within spare parts and maintenance. The aim is to concentrate all information to one place. Often today the product information could be stored at different databases and in different formats. This means that different systems had to be used in order to use the product information. This is creating inefficiency and makes it complicated for service technicians to repair products and order spare parts, which increases the likelihood of ordering wrong spare parts or not being able to repair the products properly (Säwström, personal communication, November 16, 2021). According to Säwström the main incentive to invest in the area of product information is to make it easier to repair and build the products.

To gather all information in one place, a service bill of material (SBOM) was created. The SBOM is a database that presents all spare parts, and how they are connected and how to be mounted to each other. This is a complement to the already established Manufacturing Bill of Materials (MBOM), which is directed to the manufacturing activities (Säwström, personal communication, November 16, 2021). The main focus with the SBOM is to eliminate paper copies and to minimize mistakes. The digital documentation involves interactive computer generated 3D-models, where the software program Catia V5 is used. The 3D-models isn't necessary in 90% of the situations, where simple drawings are sufficient, but can help a lot in for example a wrecked car (Säwström, personal communication, November 16, 2021). The cloud storage of the documentation also allows the information to be updated periodically, without extensive costs.

Säwström says that the sustainable usefulness is hard to measure, since its benefits vary over different cases. The gains are also a lot bigger in a newly established organisation, where the SBOM can be implemented in a more extensive way. In an old and established organisation, the new documentation does not immediately replace the old printed documentation. But rather it is slowly phased in with new products (Säwström, personal communication, November 16, 2021).

4.4 Håkan Andersson - Arcam

Arcam is manufacturing and selling 3D-printed products. They own tens of thousands of 3D-printers and are operating all over the world. Some of the products Arcam is 3D-printing are dental implants and various components for the aircraft industry. This means that the customers places high demands on the quality of the produced goods (Andersson, personal communication, November 10, 2021). Arcam had problems with their 3D-printers often breaking down and they reached out to Semcon in order to solve the problem for them. The break downs were described as a small explosion which aroused and then the printer stopped. It was hard to find the source of error and every time the presence of a service technician was required. Every factory did not have their own technician so typically it took a few hours until a service technician was on site. After a breakdown the printer was taken out of production for 4-5 days, which meant that the production would come to a halt and result in losses for Arcam (Andersson, personal communication, November 10, 2021). It was not uncommon that the same problem occurred again and service technicians had to come to the site again. For instance technicians would have to fly to Luleå from Stockholm in order to fix the problem (Andersson, personal communication, November 10, 2021). Since the 3D-printers are very complex and advanced they are also sensible to failure. They are also very expensive and therefore Arcam was not interested in replacing them. The actual problem lay in the fact that Arcam was so dependent on service technicians, which is why they wanted to find a solution that enable the operators to fix the breakdown by themselves. The solution would be applicable to all of Arcam's printers (Andersson, personal communication, 10 November, 2021).

Andersson and his team of several diagnostic engineers started their work by trying to find out the cause of the breakdowns. Interviews were kept with service technicians and operators where they told how the printers broke down. Andersson was also reading documentations of how the breakdowns had occurred earlier. After doing the research Andersson and the team could conclude that the breakdowns often was caused by dirt in the printers or wrong torque on a screw-nut or any other minor inaccuracies. By collecting all of the information regarding the printers and the breakdowns a solution was provided. The solution was an HTML file which worked like a tree structure. As soon as a printer broke down you opened the file and it asked you a bunch of questions and in return suggested what could be done in order to make the printer work again. A tree structure means that you work your way down the file until the problem is solved (Andersson, personal communication, November 10, 2021). One of big advantage of the solution was that it enabled a more precis error search. Before, service technicians had been changing entire subsystems hoping to solve the problem. This new solution guided the user down to the very faulty component. To only change a component rather than an entire subsystem is far more economically beneficial. It was also found that the components not always were broken but only needed cleaning in order to start working again. Andersson estimated that on average you could avoid changing up to ten components when using the file, the components mainly consisted of copper and plastic. Cabling was about 50 % copper and 50 % plastic and was an example of the components discussed. The operational time of the printers would increase by 75-80 % (Andersson, personal communication, November 10, 2021).

The project took five months to complete, which was longer than usual according to Andersson. The complexity of the problem was much larger than first anticipated. The error searching file fulfilled its purpose in eliminating service technicians and the break downs could be fixed directly by the operators on site. The file could also be used on all of Arcam's printers which was very beneficial for the company since they have around ten to fifteen thousand of the printers (Andersson, personal communication, November 10, 2021). The cost of the project was estimated to half a million Swedish kronor. According to Andersson, Arcam lost that kind of money on only one of the breakdowns and the project could therefore be seen as a huge success for both Arcam and Semcon. Worth mentioning is that the sustainability aspect of the project was not directly discussed in the interview (Andersson, personal communication, November 10, 2021).

4.5 Pär Ylander

The purpose of the interview with Pär was to discuss if customers of Semcon did see any incentives, other than economical, to invest in more sustainable solutions. The core of Ylander's work was to see the customers need and pinpoint what was important for the customers. He was highlighting the characteristics for deliberate Product Information. And it was the fact that the right knowledge must be applied at the right time. Ylander meant that the information about the product should be presented to the customer at the time when it was needed. For instance shouldn't the tire pressure of your car be highlighted if you do not have a flat tire (Ylander, personal communication, November 16, 2021).

Further it was discussed how avoided emissions could be assessed. Ylander meant that it was important to have access to robust data, both before the solution and after the solution has been introduced. The data should be coming from the company that utilized the solution in order to be valid. It could be hard to estimate the avoided emissions in advance and therefore different kinds of measurement should be made on site and constitute the data for the calculations. Maybe the solution did not enable such decrease in emissions that first was anticipated. Ylander also said it was important to have something to measure against when doing comparisons (Ylander, personal communication, November 16, 2021).

5 Calculating Avoided Emissions

This section will provide the analysis performed on the two cases and subsequently the result in terms of the avoided emissions. The section will first address the ESAB-case, presented under subsection 4.2 and thereafter the Arcam-case, presented under subsection 4.4.

5.1 ESAB-case

The first step in calculating the avoided emissions is to identify the solution that constitutes the foundation of the concept. By analysing the information given by the interview it could be concluded that the main solution in this case was simply the substitution of paper. The equation used to find the Net Avoided Emissions consists of three different parts that have to been identified see equation 1 at section 2.2.

5.1.1 Carbon Saving Mechanisms

After analysing the case it could be concluded that the chosen solution enabled carbon saving mechanisms. The carbon saving mechanism is what makes up the basis for enabling avoided emissions. In this particular case two carbon saving mechanisms where identified and are presented below.

1. **Reducing the use of paper**

2. **Reducing number of incorrect usage**

In this calculation it was decided to establish a primary and a secondary avoided emissions that was connected to the carbon saving mechanism in question. This was to decrease the complexity and as argued in section 3.7 increase the reliability by not taking emissions too far away from the product into consideration. The solution that replaces the BAU scenario also comes with emissions that have to be identified. The basis of calculations are shown in table 1 where the different emissions connected to the carbon saving mechanism are listed.

Table 1: Identification of emissions in the ESAB case.

Carbon Saving Mechanism	**Description**	**Primary Avoided Emissions**	**Secondary Avoided Emissions**	**Direct Solution emissions**	**Rebound Emissions**
Reducing paper	Less paper will be used	GHG emissions from paper manufacturing	Transportation of paper	More usage of iPads, phones or computers. (excluded)	No rebound effects
Reducing incorrect usages	A more user friendly and accessible documentation that helps the user to a better extent	Increased lifetime (excluded)	Reducing the need for educated personnel (excluded)	Emissions associated with the digital solution (excluded)	Increasing operation time

5.1.2 Business as Usual Scenario

The business as usual (BAU) scenario is the amount of paper printed per product. If ESAB had not chosen to implement the solution, this is how they would have operated. Equations are needed to describe the scenario and the calculated values for the BAU scenario will constitute the foundation of the comparison.

Primary Avoided Emissions

From the the framework *Technical Guidance for Calculating Scope 3 Emissions* category one was used and the average-data method was applied. This produced the following equation that was used to find the total GHG emissions for the BAU scenario associated with the first carbon saving mechanism see section 5.1.1.

$$BAU\ baseline\ emissions\ (kgCO_2e) = Use\ of\ paper\ (kg) \times Embodied\ Emissons\ paper\ (CO_2e) \tag{4}$$

Furthermore, an increased lifetime of the product would probably result in less GHG emissions over time. But to make these measurements it would have been necessary to measure over longer time. Since this was an ongoing project there is no available data for how much longer lifetime the welding apparatus will have with the new product information. It was therefore concluded that the primary avoided emissions associated with longer life time was excluded from the calculations.

Secondary Avoided Emissions

The secondary avoided emissions refers to the mileage the paper have to travel in order to reach the end customer and is used in order to find the total avoided emissions. From the technical guidance for calculating emissions the distance-based method for transportation is used (GHG Protocol, 2013).

$$\begin{aligned} \sum Transportation\ Emissions\ (kgCO_2e) &= \sum Mass\ of\ goods\ purchased\ (kg) \\ &\times Distance\ (km)\ \times\ Emission\ factor\ of\ transportation\ (kgCO_2e/kg/km) \end{aligned} \tag{5}$$

Regarding the second carbon saving mechanism it was concluded that the lack of data would not make it possible to perform reliable calculations. It was not known how much educated personnel was on site and the task of finding the GHG emissions associated with the personnel was seen as too complex for the time frame of the thesis.

5.1.3 Direct Solution Emissions

Phones and iPads are already established tools for welders and did not had to be produced or transported in order to enable the solution. Although the increased use of internet could contribute to increased GHG emissions since the data centers powering the internet are consuming vast amounts of electricity (Danfoss, 2021). But since just storing very small amounts of data as in this case, this will have an incredibly small impact. Further it could be found that the CO_2e footprint of using electricity in Sweden is 0,42 $kgCO_2e/MJ$ this is amongst the absolute lowest in terms of carbon footprint when it comes to using energy there is in the world (GrantaEdu, 2021). The combination of the low environmental impact of consuming electricity in Sweden and the small amounts of data that was stored in the data center led to the conclusion that the emissions associated with the solution was negligible in comparison to the footprint of manufacturing paper. Therefore the solutions emissions will not be accounted for in the calculations.

5.1.4 Rebound Emissions

One possible rebound emission associated with the first carbon saving mechanism could be the fact that the documentation would be used more frequently when it is digital then in printed form. From the interview with Berntdsson it did not appeared how much more the documentation could have been used. To make that estimation it would have been necessary to visit ESAB which was outside the framework of the thesis. One could imagine that it would have been a negligible impact since the environmental impact of using electricity is minor as discussed under section 5.1.3. Because of the lack of knowledge, the rebound emissions will not be accounted for in the calculations. The main reason for this is to strengthen the validity and reliability of the result by decreasing the number of assumptions conducted along the process.

For the second carbon saving mechanism it was reasonable to think that the operation time of the welding apparatus would increase, it would be used more as a consequence of the digitized product information. This would result in GHG emissions and has to been taken into account, although it was not known for the exact increase in operation time and assumptions had to be made. The equation below was used to assess the GHG emissions.

$$\begin{aligned} Rebound\ Emissions\ (kgCO_2e) = Increased\ operation\ time\ (hours) \\ \times Power\ consumption\ (kW) \times Carbon\ emission\ factor\ (kgCO_2e/MJ) \end{aligned} \tag{6}$$

5.1.5 Input Data

As discussed before a crucial part of performing emissions calculations is the data enabled. In order to find the required emission factor and the $kgCO_2e\ footprint$, Granta EduPack was used. The units are the same as they are when presented in the equations in section 5.1.2.

- **Emission factor paper**: 1,17 $kgCO_2e/kg\ paper$ (GrantaEdu, 2021)
- **Emission factor of transportation**: 0,06768 $kgCO_2e/(tonne\ paper \times km)$ (GrantaEdu, 2021)
- **Use of paper**: 1300 sheets, of which 1090 A5-size and 210 A4-size (Berndtsson, 2021)
- **Weight of A4-paper**: 5 grams (Papersize, 2021)
- **Weight of A5-paper**: 2,5 grams Ppapersize, 2021)
- **Increased operation time**: 10 minutes (Assumption)
- **Carbon footprint of Sweden's electricity production mix**: 0,42 $kgCO_2e/MJ$ (GrantaEdu, 2021)

- **Power consumption of welder apparatus (Aristo 500ix)**: Assumed that the welder is working on average with 150 Ampere. To obtain the power consumption in kW the ampere had to be divided with 30 (Maskinklippet, 2021).
  $\longrightarrow$150/30 = 5 kw

5.1.6 Assumptions Regarding Input Data

Average data method is used in the reducing paper part, see Appendix A. Since another method would drastically increase the need for data collection and thereby obstruct the generic use of the method. Same goes for the utilization of the distance-based method. For the transportation of paper the data is for a 32 tonne, 4 axle truck was used that was traveling 1000 km.

5.2 Arcam-case

The same methodology was applied as in the ESAB case, see section 5.1 and is outlined below. The carbon saving mechanisms were identified and the BAU scenario, and lastly the associated primary and secondary avoided emissions and the absence of potential rebound emissions. The information is mainly from the interview performed with Håkan Andersson, see section 4.4.

5.2.1 Carbon Saving Mechanism

Two carbon saving mechanisms where identified by analysing the material from the interview with Håkan Andersson, see section 4.4. The complexity of the case opened up the possibility of more carbon saving mechanisms, the ones that are analyzed further, are the ones that where thought to make the biggest impact in terms of GHG emissions.

1. **Eliminating the need of service technicians**
2. **Replacing smaller components rather than whole subsystems**

5.2.2 Business as Usual Scenario

Primary Avoided Emissions

Calculation of the primary avoided emissions is connected to category 6, business travel in the technical guidance for calculating scope 3 emissions. In order to give an opportunity to easily apply the calculations to different cases, the distance-based method was utilized which is presented in the framework *Technical Guidance for Calculating Scope 3 Emissions*, see figure 19 in the appendix.

Table 2: Identification of emissions in the ARCAM case.

Carbon Saving Mechanism	**Description**	**Primary Avoided Emissions**	**Secondary Avoided Emissions**	**Direct Solution emissions**	**Rebound Emissions**
Eliminating need of service technicians	Less use of transportation of service technicians	GHG emissions from means of transport	Less wear and tear on infrastructure and reduced maintenance (excluded)	Increased need for computing power (excluded)	None
Replacing smaller components rather than whole subsystems	The solution enabled more precise error search which made it possible to identify the faulty component	Reducing use of material	Reducing transportation	The emissions associated with components	Increased operational time of the 3D printers

$$BAU\ baseline\ emissions\ (kgCO_2e) = \sum(Distance\ traveled\ by\ the\ service\ technicians\ (km) \times Vehicle\ specific\ emissions\ factor\ (kgCO_2e/vehicle - km)) \tag{7}$$

Regarding the second carbon saving mechanism it had to be determined which material the subsystems consisted of and how much mass that was saved by only changing components rather than subsystems. The BAU scenario will therefore be the emissions associated with the subsystem which is how they would have been continue to operate if the solution was not introduced. For this particular calculating example it is assumed that both the subsystem and components only exists of cabling. This assumption was made to simplify the calculations, since data regarding the subsystems and components where missing. The subsystem was also assumed to only consist of copper and plastic.

$$Subsystem\ Emissions\ (kgCO_2e) = Cabling_{copper}\ (kg) \times Emission\ Factor\ Copper\ (kgCO_2e/kg) + Cabling_{plastic}\ (kg) \times Emission\ Factor\ Plastic\ (kgCO_2e/kg) \tag{8}$$

Secondary Avoided Emissions

Only the secondary emissions associated with the second carbon saving mechanism will be treated in this case. Since it was no available data for how the maintenance would reduce it was not possible to set up equations for this particular category. The transportation of the components would be decreased and can be calculated as.

$$\begin{aligned} \sum Transportation\ Emissions\ (kgCO_2e) = \sum Mass\ of\ goods\ purchased\ (kg) \\ \times\ Distance\ (km)\ \times\ Emission\ factor\ of\ transportation\ (kgCO_2e/kg/km) \end{aligned} \tag{9}$$

5.2.3 Direct Solution Emissions

No considerable direct solution emissions could be identified for the first carbon saving mechanism. Possible emissions could be from the storage and utilization of added computing power, but since the project lack information about both the amount of data and where the data is stored, is this excluded. The same argument as presented in the previous case at section 5.1.3 regarding the power consumption could also be applied for the direct solution emissions regarding this case. Ipads and computers that where necessary to process the product information where already established at the company and there was no need to buy new ones, therefore it wasn't relevant to include the CO_2 footprint of the devices that the product information was displayed on. The direct solution emissions for the second carbon saving mechanism is the emissions associated with the components. In this thesis cabling will be used as a component in the calculations. The CO_2 footprint of cabling are expressed by the following equation.

$$\begin{aligned} Component\ Emissions\ (kgCO_2e) = Cabling_{copper}\ (kg) \times Emission\ Factor\ Copper\ (kgCO_2e/kg) + \\ Cabling_{plastic}\ (kg) \times Emission\ Factor\ Plastic\ (kgCO_2e/kg) \end{aligned} \tag{10}$$

5.2.4 Rebound Emissions

In this particular case, the occurrence of rebound emissions could not be neglected. The enhanced product information implied that the operating time of the 3D-printers was increased by 75-80 % (Andersson,personal communication, November 10, 2021). The overall energy consumption will therefore increase which results in higher emissions. In the calculations it was assumed that the printers broke down two times for on average 4,5 days each time and with the solution the break down time was decreased by 75 % (Andersson, personal communication, November 10, 2021).

$$Rebound\ Emissions(kgCO_2e) = \sum(Operating\ time(hours)\times Energy\ Consumption(kW) \times Emission\ Factor\ Electricity(kgCO_2e/kWh) \tag{11}$$

The emission factor for the electricity is the carbon footprint of the Swedish energy mix and is the same as used in the previous case, see section 5.1.5.

5.2.5 Input Data

The data is largely dependent on different situations. In order to get a legitimate and relevant result, there is a need for correct data collection for the specific case. For example, the specific distance, means of transportation and type of fuel used. The calculation gets more complex when different means of transportation is used in a single trip.

- **Emission factor copper**: 4,05 $kgCO_2e/kgcopper$ (GrantaEdu, 2021)
- **Emission factor plastic**: 1,86 $kgCO_2e/kgplastic$ (GrantaEdu, 2021)
- **Emission factor electricity**: 0,42 $kgCO_2e/MJ$ (GrantaEdu, 2021)
- **Cabling (subsystem)**: 5 kg (Assumption)
- **Energy Consumption**: 7 kW (Arcam, 2021)
- **Emission factor of transportation**: 0,06768 $kgCO_2e/(tonne\ cabling \times km)$ (GrantaEdu, 2021)
- **Distance, Gothenburg to Luleå**: 1250 km
- **Emission factor flying**: 0,12 $kgCO_2e/(passenger \times km)$ (Larsson & Kamb, 2019)
- **Operational time per day**: 5 hours (Assumption)

5.2.6 Assumption

The same distance and transportation vehicle was assumed as in section 5.1.6. The increased operational time and mass of cabling was also assumed since the data could not be provided.

6 Results

This section will provide the results from the calculations in terms of Avoided Emissions. First of the ESAB-case will be presented followed by the Arcam-case

6.1 Total Avoided Emissions - ESAB

Regarding the first carbon saving mechanism the following equations are outlined below. The BAU scenario is calculated first for the primary avoided emissions. Equation 4 was applied.

$$Use\ of\ paper\ (kg) = 1090 \times 2,5\ grams + 210 \times 5\ grams = 3775\ grams = 3,775\ kg$$
$$BAU\ (kgCO_2e) = 3,775\ kg \times 1.17\ kgCO_2e/kg = 4,42\ kgCO_2e$$

Further equation 1 was applied to calculate the *Net Avoided Emissions* regarding the first carbon saving mechanism.

$$Net\ Avoided\ Emissions(kgCO_2e) = BAU - Direct\ Solution\ Emissions + Rebound\ Emissions$$
$$= 4,42kg/CO_2e - 0(Excluded) - 0(Excluded) = 4,42kg/CO_2e$$

The results of the secondary avoided emissions associated with the transportation of the paper is presented below. Equation 5 was applied.

$$BAU\ (kgCO_2e) = 3,775\ kg \times 0,06768\ kgCO_2e/kg = 0,256\ kgCO_2e$$

Finally the rebound emissions identified under section 5.1.4 was calculated using equation 6.

$$Rebound\ Emissions\ (kgCO_2e) = 600\ (seconds) \times 5000\ (watts) \times 10^{-6} \times 0,42\ (kgCO_2e/MJ)$$
$$= 1,26\ kgCO_2e$$

Table 3: Avoided emissions in the ESAB case.

Carbon Saving Mechanism	**Primary Avoided Emissions**	**Secondary Avoided Emissions**	**Direct Solution emissions**	**Rebound Emissions**
Reducing paper	4,42 $kgCO_2e/$ product	0,256 $kgCO_2e/$ product	Excluded	Excluded
Reducing incorrect usages	Excluded	Excluded	Excluded	1,26 $kgCO_2e/$ product

$$\textbf{Total avoided emissions} = 4,42 + 0,256 - 1,26 = \underline{\textbf{3,416}}\ kgCO_{2e}/product$$

6.2 Total Avoided Emissions - Arcam

First off the avoided emissions associated with the first carbon saving mechanism will be calculated. These are the emissions associated with flying in service technicians in order to repair the 3D printers, equation 7 was applied. The distanced traveled was here assumed to be the back an forth distance from Luleå to Gothenburg times two since it was common for the printers two break down twice.

$$BAU\ emissions\ from\ flying\ (kgCO_2e) = 1250\ km \times 4 \times 0,12 kgCO_2e/km = 600\ kgCO_2e$$

The BAU emissions for the second carbon saving mechanism, was the emissions from the subsystem that consisted of plastic and copper. Equation 8 was used.

$$BAU\ emission\ from\ subsystems\ (kgCO_2e) = 2,5kg \times 4,05(kgCO_2e/kg)$$
$$+2,5kg \times 1,86(kgCO_2e/kg) = 14,775\ kgCO_2e$$

Regarding the secondary avoided emissions, it was stated in section 5.2.2 that they where excluded for the first carbon saving mechanism. For the second carbon saving mechanism they where the emissions associated with the transportation. See equation 9.

$$BAU\ transportation\ emissions\ (kgCO_2e) = 0,005\ tonnes \times 0,06867 kgCO_2e/(tonne \times km)$$
$$\times 1000\ km = 0,3434\ kgCO_2e$$

The direct solution emissions for the first carbon saving mechanism was neglected and therefore set to zero. The solution emissions regarding the second carbon saving mechanism is the emissions for the components that was changed. It is here assumed that the subsystem and components was of the exact same material and only the decrease in mass was the actual difference by a factor 10. Equation 10 was used. The direct solution emissions are here equal to the emissions of the components.

$$Emissions\ from\ components\ (kgCO_2e) = 0,25kg \times 4,05\ (kgCO_2e/kg)$$
$$+\ 0,25\ kg \times 1,86\ (kgCO_2e/kg) = 1,478\ kgCO_2e$$

As a consequence of lowering the mass the transportation emissions are also lowered. And the secondary avoided emissions is the difference in transportation emissions when the mass are decreased and the distance stays the same.

$$Transportation\ emissions\ associated\ with\ the\ components =$$
$$0,0005\ tonnes \times 0,06867\ kgCO_2e/(tonne \times km) \times 1000\ km = 0,03434\ kgCO_2e$$

The difference between the transportation emissions constitutes the secondary emissions and was calculated accordingly.

$$Secondary\ Avoided\ Emissions = 0,3434 - 0,0343 = 0,3091\ kgCO_2e$$

The rebound emissions used in the calculations were the ones associated with the increased operational time. Equation 11 was used.

$$Increased\ operational\ time = 4,5\ days\ \times 5\ hours \times 2 \times 0,75 = 33,75\ hours$$

$$Rebound\ emissions = 33,75 \times 3600 \times 7000\ W \times 10^{-6} \times 0,42 kgCO_2e/MJ = 357,21\ kgCO_2e$$

Table 4: Avoided emissions in the Arcam case.

Carbon Saving Mechanism	**Primary Avoided Emissions**	**Secondary Avoided Emissions**	**Direct Solution emissions**	**Rebound Emissions**
Eliminating the need of service technicians	600 $kgCO_2e/$ break down	Excluded	Negligible	None
Replacing smaller components rather than whole subsystems	14,775 $kgCO_2e/$ break down	0,3091 $kgCO_2e/$ break down	1,478 $kgCO_2e/$ break down	357,21 $kgCO_2e/$ break down

The total avoided emissions was lastly calculated using equation 1.

Total Avoided Emissions $= 600 + 14,775 + 0,3091 - 1,478 - 357,21 =$ **256,396** $kgCO_2e$

7 Discussion

This section discusses the results from section 6 with regards to presented theories and information collected from the interviews. The discussion will both handle the two cases one by one, as well as an overall discussion about reliability and implementation.

7.1 Discussion of Results

The primary discussion of the results at hand are the fact that the majority of the calculations are based on assumptions. Since the interviews did not provide any qualitative data about the cases, a precise result was impossible to achieve. The result from interview study pinpointed that the product information should be based on the needs of a specific customer, and that in order to acquire the correct information, information should be measured for each individual customer. In order to attain precise results, a real time case study could be implemented. This would more clearly present the changes in behavior and simplify the collection of data, both for the BAU situation and after the enabling solution is implemented (Säfsten & Gustavsson, 2019).

When assessing the results of the digitization or digitalization the situation must be placed in its context. The avoided emissions are heavily depending in the BAU situation. A company with high BAU-emissions can achieve a high level of avoided emissions, but still have substantial amount of greenhouse gas emissions. Another aspect is how well the solution is implemented. As Andreas Säwström mentions in section 4.3, a newly established organisation can implement the new product information in a better way, while old organisations are used to the old ways, and need a longer time to adjust and fully utilize the new documentation. This connects to the discussion of probability to success in the Avoided Emissions Framework, presented in section 2.2. When an organisation is not used to a documentation, this decreases both the possibility for utilization and for success. In order to attain this statistic, once again, more detailed data must be collected for each specific case.

7.1.1 ESAB

The calculations of avoided emissions shows that the implementation of the digitization project is reducing the emitted greenhouse gases, compared to the BAU-case. Further analysis of the result shows that the main proportion of the avoided emissions is a result of the reduction of used material (paper). Another important aspect to consider is the effects of the rebound emissions. The rebound emissions reduces the avoided emissions with around 25% compared to the primary and secondary avoided emissions. Noted is that the calculation is based on assumption. A higher increase in operating time could result in a negative avoided emissions, depending on the energy consumption of the welding machine and the BAU situation.

The ESAB-case is a great example of entering a new level in the product information ladder presented in section 4.1. The digitalization project moves ESAB up to Level 2. Even though the results are limited to per product, this methodology is easy and relatively cheap to implement in large scales. Since the infrastructure of computers, iPads and smartphones exists in most cases. The strength in a case like the ESAB-case is the simplicity and that is is easy too understand the benefits, which creates the opportunity for large scale implementation.

7.1.2 Arcam

As presented in section 6.2, the implementation of digitization will result in avoided emissions. The majority of the avoided emissions in this case is associated with the transportation of service technicians. Though, this value is heavily based on assumptions, both regarding the means of transportation and the distance traveled. Half the distance will result in a negative avoided emissions, thereby eliminating the incentive from an environmental perspective. The value of the rebound emissions is also based on assumptions, an increased operating time would also result in negative avoided emissions.

In contrast to the ESAB-case, the Arcam-case represents a higher level in the product information ladder. The implementation of the digitization project places Arcam at level 3 in the ladder. The product information is focused on the user and presents the relevant information to the user. Implementation and development of this type of product information is more complicated and expensive compared to the ESAB-case.

7.2 Rebound Emissions

The calculations showed a notable impact from the rebound emission factor. Emissions that could be missed at a first glance. The Rebound emissions were, in both cases, connected to the electricity consumption. These calculations were based on the data of Swedish energy mix, consisting of several different energy production methods. As named in section 5.1.3, the Swedish energy mix one of the most sustainable in the world. Implementation abroad would likely increase the rebound emissions in the cases at hand (GrantaEdu, 2021).

Notable is that both cases at hand are based on big industrial machines, consuming a high amount of electricity. The rebound emissions would have a different impact if implemented on, for example, instructions for furniture assembling. The effects of the increased energy consumption in a broader scale can be debate. In order to produce the market demand the company will, in the BAU scenario, produce the demand later, or the current situation is based to match the demand. A decrease in the down time will either reduce the total production time, eliminating the rebound emissions, or producing more products, increasing their market share. In the second case, the emissions per product are reduced. Depending on the market situation, the decision will change, thereby eliminating a universal result. However, the total emissions connected to energy consumption will always increase or be the same as in the BAU scenario. The utilization of completely renewable energy sources will however eliminate the CO_2e emissions.

7.3 Greenwashing

When calculating environmental impact, there is always a risk for greenwashing. When assessing the effects, the input data must be reviewed. Depending on the assumption made, different results will arise. Conservative assumptions could show a "better" result than the reality. The discussions in section 7.2 are examples of this situation. Utilization of these results could be a great tool when marketing solutions and services to potential customers, but can be harmful in the real world. With this in mind the purpose of accounting avoided emissions must only act as support for decision making, and not as a marketing tool.

8 Conclusion

This thesis has examined the potential of limiting GHG emissions through the implementation of digitization of product information. The increased focus on environmental sustainability has shed light on all business areas within a company. Today is digitization projects carried through with an economic incentive, but in the future will the environmental benefits play an equally important role. One of the future measurements of environmental benefits from digitization is the concept of avoided emissions. This thesis has studied how digital product information can be used to reduce CO_2 emissions and how these eventual climate benefits can be measured in terms of avoided emissions. The thesis has taken an qualitative approach and has been carried through as a retrospective case study of product information at Semcon. Qualitative interviews provided information and understanding about the cases in question. Analysis of the cases and comparison with literature showed that emission reducing activities were connected with the implementation of digitization. In the two cases, both reductions in transportation and use of materials could be identified. However, occurring rebound effects limited the reduction of emissions. Clear examples of this is the increased operating time for machines, increasing the energy consumption.

The thesis realised that in order to get an accurate result that represented the reality to the highest extent, a much more detailed study needs to be carried out. Since the project only examined the cases with a retrospective, comparisons with before and after was complicated to realize. A study in real time would identify changes in behaviour and the occurrence of failures to a higher extent. The utilization of qualitative interviews proved to be a suitable method in order to provide a sufficient understanding to the thesis. Although, in order to provide trustworthy results would quantitative data about the changes in behaviors be useful. The qualitative interviews was enough to construct the equations, but insufficient for providing data.

Results from the study revealed the challenges with constructing a generalized method for calculating avoided emissions. Every digitization project is carried through with different goals and ambitions. The different circumstances and potential effects result in a situation that is hard to generalize. In order to create a valid result applicable to a large number of cases, several factors must be excluded in order for the calculations to be surmountable.

8.1 Further Research

Further research could analyse if there is a correlation between the product information ladder presented in section 4.1 and the avoided emissions associated with moving in the ladder. A correlation could further motivate companies to take the steps towards a higher level of product information. Research connected to economic incentives could also be of interest.

The thesis has shown the vast complexity of emissions and difficulties collecting it. Therefore, the development of a user friendly calculation tool for avoided emissions could be helpful for companies. For example a software acting as a calculator. This could decrease the need for specific data collection and increase the opportunities for generalizability.

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Appendix

Appendix A: Technical Guidance for Calculating Scope 3 Emissions

Technical Guidance for Calculating Scope 3 Emissions is a supplementary report to the GHG Protocol Corporate Accounting and Reporting Standard. The report is written by nine authors from the GHG Protocol and Carbon Trust team, and provides applicable tools and methods for firms to calculate their scope 3 emissions. The report divides different emitting activities into different categories and presents specialized methods for calculating the emissions, and also provides examples.

The categories are as follows:

1. **Purchased Goods and Services**
2. **Capital Goods**
3. Fuel- and Energy-Related Activities not included in Scope 1 or Scope 2
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

Categories associated with the topic at hand is category number: 1, 2, 4, 5 and 6.

Categories 1 & 2 - Purchased Goods and Services, and Capital Goods

For calculating emissions from categories 1 & 2, the same calculation method is utilized. The calculation is divided into 4 different methods. The methods are: *Supplier-specific method, Hybrid method, Average-data method and Spend-based method.* Depending on the situation at hand, the optimal method varies. The main factor is the data availability. For an explanation of the different methods, see figure 1.

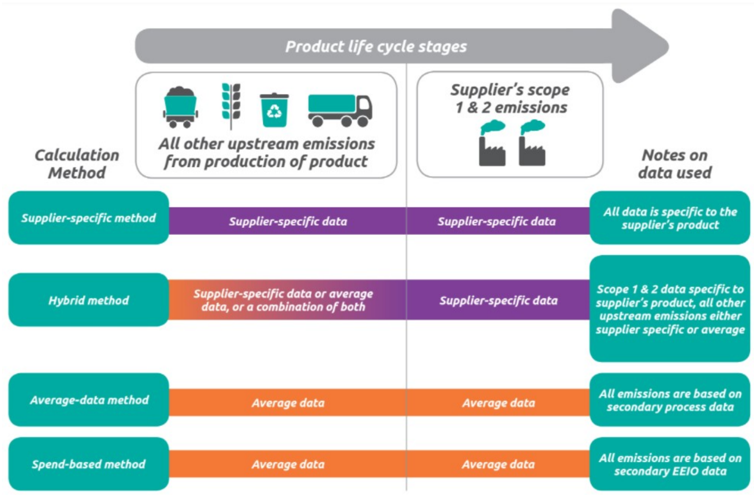

Figure 1: Explanation of the different methods for calculating emissions

The document presents different ways of handling the different methods for the different categories, as well as a scheme for making the decision on what method to use. The decision-tree for category 1 & 2 are presented in figure 2

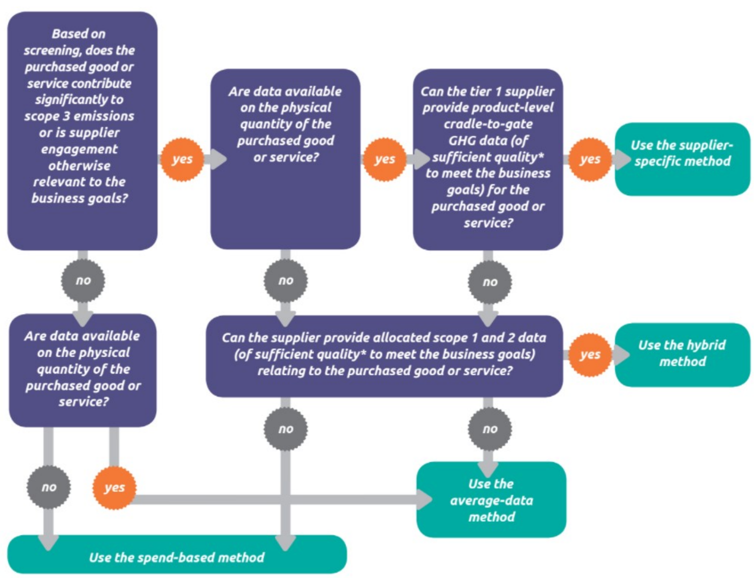

Figure 2: Decision tree for selection a calculation method from purchased goods, services and captial goods.

Depending on the selected method, a different calculation and data-collection is needed. The calculations are presented in figure 3, 4 , 5 & 6:

Supplier Specific Method

CO_2e emissions for purchased goods or services =

sum across purchased goods or services:
∑ (quantities of good purchased (e.g., kg)
× supplier-specific product emission factor of purchased good or service (e.g., kg CO_2e/kg))

Figure 3: Calculation formula for the supplier specific method.

Hybrid Method

CO_2e emissions for purchased goods and services =

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

Figure 4: Calculation formula for the Hybrid Method.

Average-Data Method

CO_2e emissions for purchased goods or services =

sum across purchased goods or services:
∑ (mass of purchased good or service (kg)
× emission factor of purchased good or service per unit of mass (kg CO_2e/kg))
or
∑ (unit of purchased good or service (e.g., piece)
× emission factor of purchased good or service per reference unit (e.g., kg CO_2e/piece))

Figure 5: Calculation formula for the average-data Method.

Spend-Based Method

CO_2e emissions for purchased goods or services =

sum across purchased goods or services:
∑ (value of purchased good or service ($)
× emission factor of purchased good or service per unit of economic value (kg CO_2e/$))

Figure 6: Calculation formula for the Spend-based method.

Category 4 - Upstream Transportation and Distribution

Category 4 has different calculation approaches corresponding to transportation of raw materials or distribution of finished products or services. Category 4 can,Just like category 1 and 2, be divided into different calculation methods. These methods are: *fuel-based method, distance-based method and spend-based method.* The decision tree for transportation and distribution are presented in figure 7 and 8.

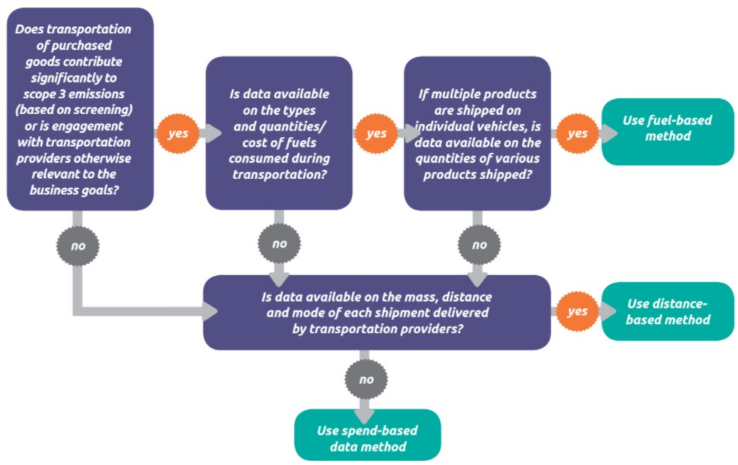

Figure 7: Decision tree for selecting a calculation method for downstream transportation

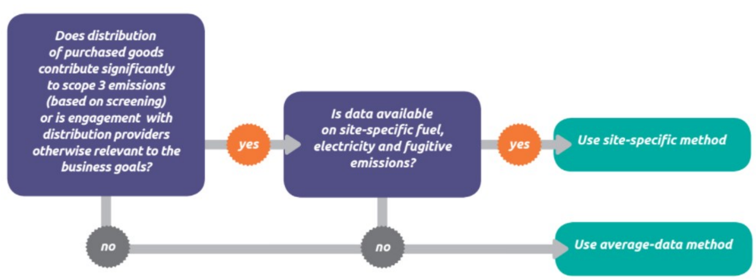

Figure 8: Decision tree for selecting a calculation method for upstream distribution

Upstream Transportation

The different calculation methods for upstream transportation methods, *fuel-based method, distance-based method and spend-based data method* is presented below in figure 9, 10 & 11:

Fuel-Based Method

CO_2e emissions from transportation =

sum across fuel types:
Σ (quantity of fuel consumed (liters) × emission factor for the fuel (e.g., kg CO_2e/liter))
+
sum across grid regions:
Σ (quantity of electricity consumed (kWh) × emission factor for electricity grid (e.g., kg CO_2e/kWh))
+
sum across refrigerant and air-conditioning types:
Σ (quantity of refrigerant leakage × global warming potential for the refrigerant (e.g., kg CO_2e))

Figure 9: Calculation formula for the fuel-based method (transportation)

Distance-Based Method

CO_2e emissions from transportation =

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

Figure 10: Calculation formula for the distance-based method (transportation

Spend-Based Method

CO_2e emissions from transportation =

sum across transport modes and/or vehicle types:
Σ (amount spent on transportation by type ($)
× relevant EEIO emission factors per unit of economic value (kg CO_2e/$))

Figure 11: Calculation formula for the spend-based method (transportation

Distribution

In the case of distribution, there is only two different calculation methods, as shown in figure 8. These methods are: *Site-specific method* and *average-data method*. The corresponding calculation methods are presented in figure 12 & 13

Site-Specific Method

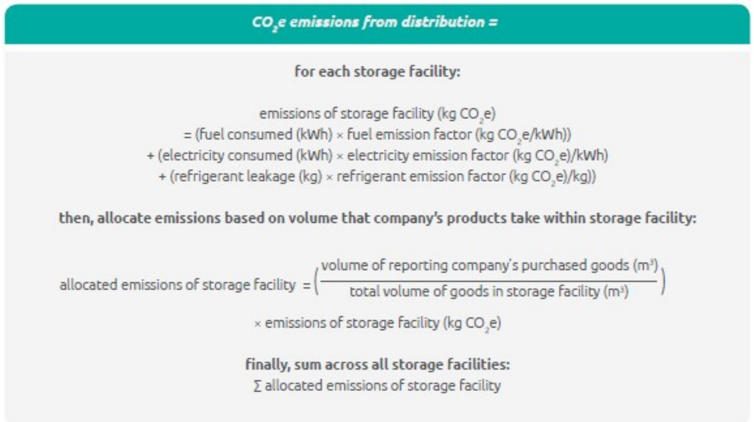

Figure 12: Calculation formula for the site-specific method (distribution)

Average-Data Method

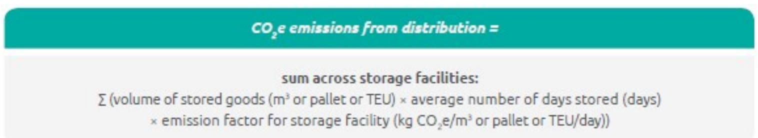

Figure 13: Calculation formula for the average-date method (distribution)

Category 5 - Waste Generated in Operations

Category 5 contains emissions associated with third-party disposal and the treatment of waste. Only waste generated or owned by third-parties is included in this scope 3 calculations. Wastes directly connected to the company at hand is mainly focused in scope 1 and scope 2, thereby not calculated within this calculations.

Just like the other categories, is category 5 divided into different calculation methods, depending on the situation at hand. The decision tree for these methods is presented in figure 14

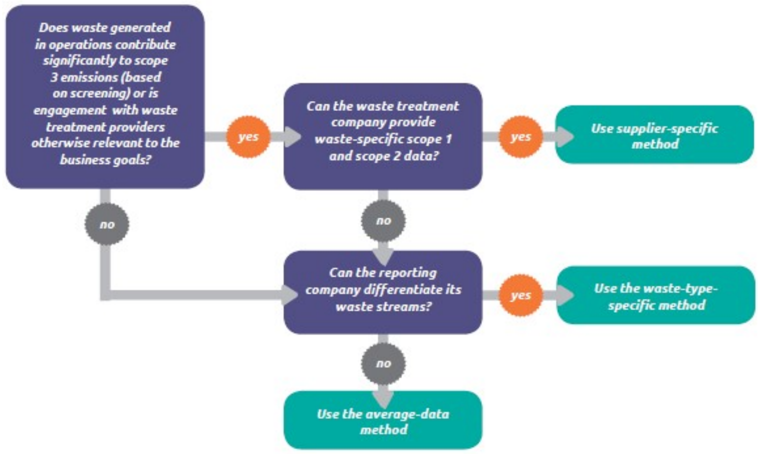

Figure 14: Decision tree for selecting a calculation method for emissions from waste generated in operations

As presented in figure 14, the tree different calculation methods are: *supplier-specific method*, *waste-type-specific method* and *average-data method*. The calculation formulas are presneted in figure 15, 16 & 17.

Supplier-Specific Method

Figure 15: Calculation formula for the supplier-specific method.

Waste-type-Specific Method

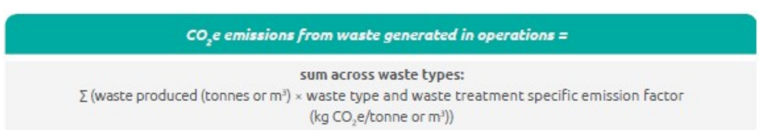

Figure 16: Calculation formula for the waste-type-specific method.

Average-Data Method

Figure 17: Calculation formula for the average-data method.

Category 6 - Business Travel

Category 6, emissions from business travel, has a lot in common with category 4. The three calculation methods has the same names, but includes different factors and data. The decision tree for calculation methods for category 6 is presented in figure 18

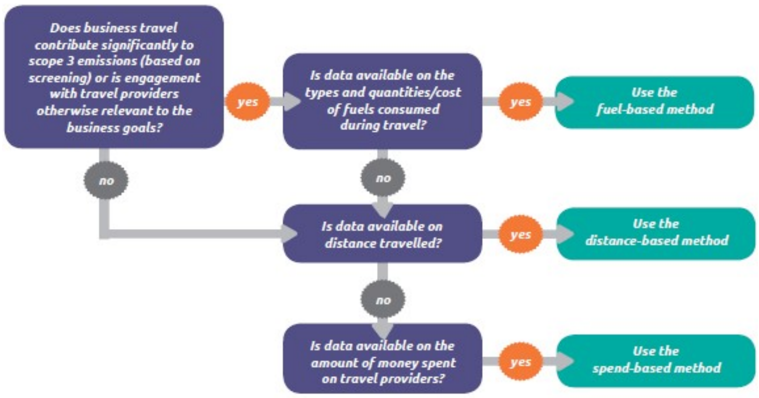

Figure 18: Decision tree for selecting a calculation method for emissions from business travel

The calculation methods presented in figure 18 are: *fuel-based method*, *distance-based method* and *spend-based method*.

Fuel-Based Method & Spend-Based Method

The fuel-based method and the spend-based method is identical with the one presented in category 4, see figure 9 & 11.

Distance-Based Method

CO_2e emissions from business travel =

sum across vehicle types:
Σ (distance travelled by vehicle type (vehicle-km or passenger-km)
× vehicle specific emission factor (kg CO_2e/vehicle-km or kg CO_2e/passenger-km))
+
(optional)
Σ (annual number of hotel nights (nights) × hotel emission factor (kg CO_2e/night))

Figure 19: Calculation formula for the distance-based method (Business travel)