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GREENHOUSE GAS EMISSION CALCULATION MODEL DEVELOPMENT FOR GLOBAL INDUSTRIAL INVESTMENT PROJECTS

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ABSTRACT

Lappeenranta–Lahti University of Technology LUT
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This paper focuses on development of model for calculation greenhouse gas emissions from global industrial investment projects. Model development utilized old investment project as a base project and model was developed in co-operation with an intended user. The theory focuses on defining supply chain and challenges during data collection, aspects affecting to GHG emissions from supply chain stages, and defines principles for model development. The empirical part consisted of a model development process for six systems delivered during base project utilizing life cycle thinking.

Calculations and sensitivity analysis with the developed model indicated that production of materials and transportation of systems to customer are the most important emission sources during investment projects. The model followed principles defined earlier and proved to be suitable for intended use. Model's actual functionality will be seen later, when it is applied broader for different projects and systems by other users.

TIIVISTELMÄ

Lappeenrannan-Lahden teknillinen yliopisto LUT
LUT School of Energy Systems
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Jemina Oksala

Laskentamallin kehittäminen globaalien teollisuuden investointiprojektien kasvihuonekaasupäästöjen laskentaan

Diplomityö
2019
101 sivua, 29 kuvaa, 7 taulukkoa ja 1 liite
Työn tarkastajat: Professori, TkT Risto Soukka
Tutkijatohtori, TkT Kaisa Grönman
Hakusanat: elinkaarimallinnus, arvoketju, tason 3 päästöt, hiilidioksidipäästöt, laskentamallin kehitys

Tässä työssä kehitettiin laskentamalli globaaleista teollisuuden investointiprojekteista syntyvien kasvihuonekaasupäästöjen laskentaan. Malli kehitettiin aiemmin toteutetun investointiprojektin pohjalta yhteistyössä mallin käyttäjän kanssa. Teoriaosuudessa keskitytään toimitusketjun määrittelyyn ja tiedon keräämisen haasteisiin, toimitusketjun eri vaiheista aiheutuviin päästöihin sekä määritellään periaatteet mallin kehitykselle. Empiirisessä osassa luotiin laskentamalli kuudelle aiemmassa projektissa toimitetulle tuotantolaitteelle elinkaariajattelua hyödyntäen.

Mallilla toteutettujen laskelmien sekä herkkyysanalyysin perusteella suurimmat päästölähteet investointiprojekteissa ovat materiaalien tuotanto sekä tuotantolaitteiden kuljetus asiakkaalle. Malli noudatti aiemmin määriteltyjä periaatteita ja osoittautui soveltuvaksi aiottuun käyttötarkoitukseen. Laskentamallin todellinen toimivuus nähdään tulevaisuudessa, kun sitä päästään soveltamaan laajemmin muiden käyttäjien toimesta eri projekteihin ja tuotantolaitteisiin.

ACKNOWLEDGEMENTS

“There is nothing soft in environmental responsibility”.

This sentence stuck in my mind when I was reading source material for this thesis. It seems that environmental responsibility is (finally) starting to be area that companies need to take seriously to be successful in business. When I started my studies in Lappeenranta 2013, I was idealistic and optimistic little freshman. After couple of years of studying, and especially after I saw the effects of climate change and other environmental issues in Svalbard 2017, I fell to cynical “everything is ruined” mindset. Luckily, last year have restored some drops of that hope, because there are things that can be changed, things that even I can change.

There are far too many people I feel gratefulness. First, I want to thank my supervisor Pirjo Janhunen and the examiners Risto Soukka and Kaisa Grönman for guiding me during this project. I want to thank Aleksi, my family and my friends for supporting me and kicking me forward when I was falling in despair. My awesome co-workers also deserve acknowledge for giving me mental support during this project. I will always be grateful to my friends and teachers in Svalbard, who helped me with my English – without them this thesis would have been impossible to write. And warmest thanks also to Miia, Harri and Marja, who enabled me to have “horse therapy” when I needed it.

July 2019 in Varkaus, Finland
Jemina Oksala

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LIST OF SYMBOLS

Subscripts

kg	kilogram
km	kilometer
kWh	kilowatt-hour
MWh	megawatt-hour
t	metric tons

Abbreviations

BF/BOF	blast furnace/basic oxygen furnace
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
EAF	electric air furnace
GHG	greenhouse gas
GWP	Global Warming Potential
IAS	International Accounting Standard
IMO	International Maritime Organization
IMOA	International Molybdenum Association
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	life cycle assessment
MOE	Japan’s Ministry of the Environment
NCASI	National Council for Air and Stream Improvement
RER	Rest of the Europe
RoW	Rest of the World
SETIS	Strategic Energy Technologies Information System
UNFCCC	United Nations Framework Convention on Climate Change
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

1 INTRODUCTION

Global warming is one of the most serious and well-known global environmental problems. It is estimated that human activities have already caused approximately 1.0 °C warming above pre-industry levels, and if temperatures continue to increase at the current rate warming is likely to reach 1.5 °C between 2030 and 2052 (IPCC 2018, 6). The warming is mostly caused by human activity, especially by increased amount of carbon dioxide in the atmosphere due to use of fossil fuels. It is already too late to reverse the climate change, but the international community has decided to try and limit warming under 2 °C (IEA 2015, 18; Climate Guide). Global warming would cause warming of extreme temperatures in many regions, increases in heavy precipitation in several regions, and increase in intensity or frequency of droughts in some regions and loss of species and ecosystems (IPCC 2018, 9-10). Limiting the warming under 1.5 °C instead of 2 °C is projected to lower these impacts (IPCC 2018, 9 & 10), but to reach this target greenhouse gas emissions have to be cut as much as 85% below 2000 levels by 2050 (WRI & WBCSD 2011a, 3). The reduction needs to be substantial and sustained, and it requires rapid and far-reaching transitions in energy, land, urban and infrastructure, and industrial systems (IEA 2015, 18; IPCC 2018, 17).

Industrial sector was responsible of 19% of global GHG emissions in 2014 (EEA 2016), and 36% of global total final energy consumption in 2014 (IEA 2017, 36). Even though greenhouse gas (GHG) emissions from industry have reduced by 37 % from year 1990 to 2014, it is still the sector with third largest GHG emissions in 2014 (EEA 2016). For example, pulp, paper and printing sector accounted for 5.6% of industrial energy consumption in 2014, fossil fuels constituting 42% of sector’s total energy consumption (IEA 2017, 42). However, it seems that estimations of emissions from pulp mills are usually focusing to the mills operations, rather than emissions from production of the factory itself during industrial investment project. For example report “Calculation tools for estimating greenhouse gas emissions from pulp and paper mills” by National Council for Air and Stream Improvement (NCASI 2005) does not include emissions from production and disposal of equipment to its guidelines. Still production, transportation and disposal of mean of productions, such as recovery boilers and washers, cause emissions. These so called value chain or supply chain emissions often represent the largest source of emissions for companies (WRI & WBCSD 2011a, 5), being on average 75% of emissions of industry sector’s carbon footprint. Despite this, it seems to be unknown how big these emissions are in Pulp, paper and printing sector, and especially emissions from companies that provide technology and system solutions for the sector seem to remain unknown.

Corporation action against climate change is vital for making progress in emission reduction and it also makes good business sense. Addressing its emissions companies can identify opportunities to bolster their bottom line, reduce risks, and recognize competitive advantages. It is expected that governments will set new policies and provide additional market-based incentives to drive emission reductions. These together with market drivers will direct economic growth on a low-carbon trajectory. Due to increased awareness concern about climate change, both investors and consumers are demanding more transparency and environmental accountability, and they becoming more vary towards companies that are not evaluating and managing GHG related risks. Companies receive more and more pressure from stakeholders to measure and disclose their effect on climate change, and this demand is not limited for the corporations own activities rather than to whole supply chain of the company. Companies increasingly understand the need of also account for emissions along their value chains and product portfolios. It is clear that proper management of GHG emissions and reporting the actions to stakeholders may help company to differentiate in an increasingly environmentally conscious marketplace. (WRI & WBCSD 2011b, 3-10.) Climate change is something that no corporation, especially those that operate in developed countries, can afford to disregard (Rosen-Zvi 2011, 542).

More and more companies around the world are voluntarily creating GHG emission inventories. Customized tool or model for emission calculation meeting the needs of the sector could decrease the time used for GHG inventory and increase the accuracy (WRI 2006, 10). There are many calculation tools and models available, but most of them appear to focus on companies’ own emissions rather than supply chain emissions. For example GHG Protocol (WRI & WBCSD) has published 30 calculation tools for industrial sectors and cities, and none of them is applicable for supply chain emissions. Finnish Environment Institute (2017) has several carbon footprint calculations tools that are suitable for citizens, municipalizes, or some specific industries, but are not suitable for supply chain emission calculations or companies that provide technology and system solutions for the pulp and paper sector. Because of this there seems to be demand for a GHG emission calculation tool that is suitable for companies of which main business are industrial investment projects, and therefore supply chains of those projects are the main source of their emissions.

1.1 Background of the research

Motivation for this study is coming from researcher's interest of life cycle emissions in investment projects. Ways of accounting and reporting emissions seem to vary quite a lot and it is interesting to see how the supply chain management from emission point of view could be improved. Nowadays all companies, naturally, claim that they are sustainable, environmental friendly, reducing emissions et cetera so it will be absorbing to look behind those claims.

1.2 Background of the empirical research

Empirical research was done in Company that provides technologies, systems and service solutions for industries around the world. Most of its operations are projects with varying nature and location. Company has estimated its energy consumption in offices and greenhouse gas emissions in manufacturing properties, but there have not been proper estimation of greenhouse gas emissions from investment projects and various products delivered by the Company. However, Company is increasingly concerned about climate change and wants to strengthen its competitiveness, and it is likely that demand for better understanding about company's GHG emissions will continue growing as common concern about climate change increases. As there is no stable production of similar products, it is hard to estimate the overall climate impact of company's operations. Besides this, Company does not have much of its own production but purchases most of the equipment from other companies, making so called supply chain emissions significant. Therefore, Company wants first to account emissions for some example products of certain projects, and then gradually expand the calculations.

Company wants to make emission calculations simple and effective, and hence performing full life cycle assessment (LCA) for every system that Company delivers would not be practical. Therefore, it was decided to develop a calculation model that would make emission calculations swift. Company expects the model to be easy to use and provide information about how different supply chain stages affect to the emissions. It should also be possible to compare different material choices, manufacturing locations and suppliers in model.

The accuracy of the model should be suitable for the intended use. At the first phase of model development the model should be accurate enough to show the emission hotspots of the investment projects and give Company some information about processes it can have an influence on. When model development continues, the information that model provides should be reliable enough to be used in decision making. Therefore, the requirements for accuracy of the model tighten when the development process continues.

1.3 Objective of the study

Goal of this study is to develop a model to calculate carbon footprint of investment projects with various products delivered by industrial companies.

The research question is:

- How GHG emission calculations can be made effectively and simply for investment projects with various products?

Other interesting questions related to the intended use of the calculation model are:

- How simple can emission estimations be without compromising accuracy?
- What are the most relevant stages of industrial investment projects from the GHG emission point of view?
- Is it possible to adduce the effect of origin of materials and manufacturing locations to GHG emissions with the model?

1.4 Research method

In this section, the research methods in this study are introduced. As the purpose of the study is to create new model and the researcher is active part of the organization, the nature of this study fulfills features of both constructive research and active research.

Constructive research is methology that produces innovative constructions or designs that aims to solve problems. The core idea of this method is new construction, which includes basically all manmade artefacts such as models, plans, mathematical algorithms, diagrams, information systems and commercial products. Common to all constructions is that they are not found but invented and created. By developing construction that differs from everything else that is already existing researcher creates something entirely new and thus new constructions develop new reality. The core features of constructive research are that it focuses on problems in real life and it produces innovative construction that is meant for solving the original problem. (Lukka 2001.)

Action research is research, where researcher acts as a change agent when solving problems. Research and changing the phenomenon or situation under the study are done at the same time. The idea of action research is to gain knowledge which can be used to modify the situation under the study, and to get exact information for specific situation and purpose rather than knowledge that can be generalized. Because of this, the results of an action research are useful only for the object of the study and study does not aim to get generalizable scientific results. Action research develops new skills or new approach to some specific case and solve problems that have straight connection to some practical issue. In action research researcher is participating actively in team or organization under the study, which is case in this study. It has also been argued that action research is not actually research method so much as it is setting for research. (Anttila 1998.)

Järvinen (2004, 124) defines action research as research method where previously mentioned building and evaluating sub-processes closely belong to the same process. Action research is characterized with six properties: it is future oriented, collaborative, it implies system development, generates theory grounded action, it is agnostic and situational. It is possible to identify three different research design for starting the action research:

1. Inspection. Is there something to learn from comparable, existing unit, or a unit that has existed before?
2. Imagination. Imagining a non-existing, but feasible and desirable alternative.
3. Intervention. In order to improve the unit at the same time it is studied, there is intervening with others. (Järvinen 2004, 124-126.)

The design of this study can be considered as imagination design, because a completely new model is developed “out of nowhere”. Although it is mentioned by Anttila that action research does not aim to get generalizable scientific results, in this study it is advisable that the results can be utilized by other organizations and sectors too.

1.5 Structure of the thesis

This thesis is divided for two sections: theoretical and empirical part. Theoretical part consists of three chapters. In the first section the supply chain in global investment project is reviewed, and issues concerning data collection are discussed. Chapter three introduces different aspects that have an effect to GHG emissions of industrial investment projects. Chapter four focuses on the theoretical background of model development: what are the phases of model development, and what kind of principles should be followed.

Empirical study in chapter five focuses on model development. Testing and analyzation of the developed model is done in chapter six. In the final chapters are the discussion and conclusions about model and its development process.

2 INTRODUCTION OF SUPPLY CHAIN IN INVESTMENT PROJECTS

This thesis will focus on estimation and management of company’s supply chain emissions in investment projects. First step is to define the supply chain in the global investment projects. In this chapter, different aspects and stages of supply chain and its management are discussed, and possible challenges that occur during data collection are reviewed.

2.1 Definition of supply chain in industrial investment projects

Supply chain is defined as a flow of business operations in an industry with stages of raw-material procurement, manufacture, transport, sales and end-of-life treatment. Business activities of companies are linked through purchasing and sales in supply chain. Naturally, emissions sourced from the same supply chain are called as supply-chain emissions. (MOE 2015, 1-3.) Supply chain stages can be defined in several ways, and the defining criteria can vary between organizations.

The Greenhouse Gas Protocol provides one guidance for supply chain emission management. GHG Protocol’s Corporate Value Chain (Scope 3) Standard divides company’s emissions into three main categories: scope 1, scope 2 and scope 3. All direct emissions from company’s activities are included in scope 1, while scope 2 and 3 are for indirect emissions. Direct emissions are defined to be emissions from sources that the reporting company owns or controls, while indirect emissions occur at sources owned or controlled another company due to reporting company’s activities. Scope 2 contains all emissions coming from purchased electricity steam, heating and cooling, and remaining indirect emissions fall into scope 3 category. These scope 3 emissions are therefore supply chain emissions. Complete GHG inventory includes all these scopes, and thus represent the total GHG emissions from company’s activities. However, scopes are mutually exclusive for the reporting company and as there is no overlapping and double counting, this categorization to scopes ensures that different companies do not account for the same emissions within scope 1 or scope 2. (WRI & WBCSD 2011a, 27.) These three categories and their sub-categories are presented in figure 1 below.

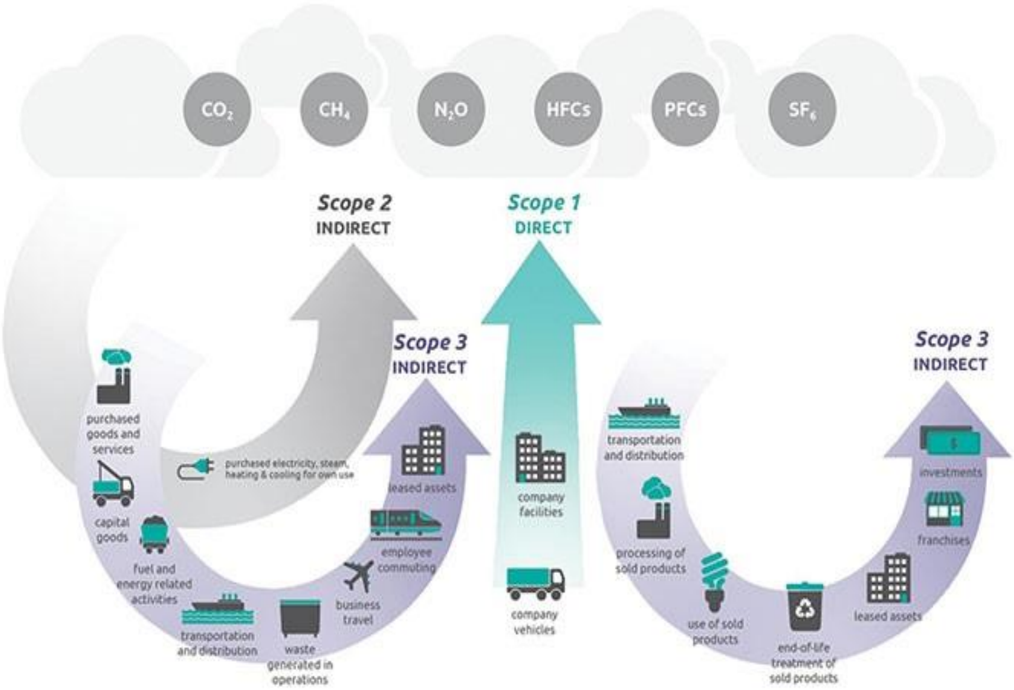

Figure 1. Supply chain (Scope 3) emissions according to WRI & WBCSD (2011a, 5).

On average, scope 1 emissions from an industry are only 14%, and the sum of scope 1 and scope 2 emissions only 26% of the total upstream supply chain emissions. Remaining 74% are scope 3 emissions, which are divided in two main categories: upstream and downstream emissions. Unlike in life-cycle assessment, where this division is based on material flow, in Scope 3 Standard it is are based on a flow of money. Upstream includes purchased goods and services, capital goods, fuel and energy related activities not included in scope 1 or scope 2, upstream transportation and distribution, waste generated in operations, business travel, employee commuting and leased assets. Downstream emissions include downstream transportation and distribution, processing of sold products, use of sold products, end-of-life treatment of sold products, leased assets, franchises and investments. (Huang et al. 2009, 8509; WRI & WBCSD 2011a, 27-31; MOE 2015, 4.)

Currently companies can choose to voluntarily disclose scope 3 emissions without strict frameworks or guidelines (Huang et al. 2009, 8509). Often companies do not account all of the 15 emission categories but rather focus on the ones they find to be the most important. Some categories, like leased assets, are not applicable for all companies, and many categories, such as employee commuting, are not traditionally viewed as a part of supply chain. On the other hand, some companies estimate their scope 3 emissions by only including categories that are not usually considered supply chain emissions. For example, Sulzer (2019) accounts only indirect emissions from the production and transport of fuel and gases not included in scopes 1 and 2, UPM (2019) accounts only emission categories that are greater than or equal to 100 000 metric tons $CO_{2eq.}$ and Nokia (2017) accounts only emissions from use of sold products. For these reasons resulting scope 3 disclosures are not often consistent or comparable between companies, not even between companies operating in the same sector (Huang et al. 2009, 8509).

Many of the scope 3 emission categories are relevant in industrial investment projects because they are supply chain emissions of the delivering company. Purchased goods and services, as well as upstream and downstream transportations, are part of every industrial project. Capital goods in scope 3 calculations is defined as "capital goods purchased or acquired by the reporting company in the reporting year" (WRI & WBCSD 2011a, 34). Systems delivered in investment projects are often capital goods of the customer company. However, for company that delivers the systems capital goods are in this case only those that are purchased or acquired specifically for the project. Therefore this category is often outside of the scope of investment projects. Manufacturing of the delivered systems cause emissions that fall in categories fuel- and energy- related activities and waste generated in operations. In cases when some systems are manufactured by company's own workshops also scope 1 and scope 2 emissions are generated. There is often a lot of business travel during global projects but it is unlikely that projects have notable effect on employee commuting. Emissions related to leased assets, franchises and investments are not relevant for investment projects. Whether processing, use and end-of-life treatment of sold products are inside of the boundaries of emission estimation of industrial investment project depends on the selected boundaries.

Nowadays many successful enterprises base much of their competitiveness on novel ways of managing their relationships with suppliers of materials, components and services. While importance off supply chain management has been growing, environmental matters have not traditionally been high on the supply chain managers' agenda. Material flows in the industry are the result of relationships between organizations, and therefore the sharing of responsibility that supply chain management promotes could help to reduce environmental burden caused by industry. Implementation of supply chain actions nearly always represents improvements in environmental performance. It is important to revise assessment scores and adjust maps to illustrate the likely of environmental impact reductions because it both shows progress and helps to focus attention on new management priorities. Practice of industrial ecology is always continuous, dynamic and iterative process. (Faruk et al. 2001, 14, 28.)

According to Faruk et al. (2001, 16, 23), there are six defined supply chain stages: materials acquisition, preproduction, production, use, distribution, and disposal. There are some notable differences between these stages from the environment point of view. For example, the environmental burdens tend to be greatest in the resource extraction stage. Company's amount of control over supply chain varies: some may be able to have control over whole supply chain, while control over some standard components used very widely in industry may be very limited. (Faruk et al. 2001, 16, 23.)

There are clear similarities between supply chain stages defined by Faruk et al. (2001, 16, 23) and Life Cycle Assessment (LCA). LCA addresses the environmental aspects and potential environmental impacts throughout a product's or service's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal. Different options for system boundaries for metal products can be seen in the figure 2. With LCA it is possible to estimate several environmental impacts caused by life cycle of product, for example Global Warming Potential (GWP), Acidification Potential, Eutrophication Potential and Oxone Depletion Potential. (ISO 14040:2006, 4-5, 7.) LCA is often performed with software developed specifically to LCA, for example GaBi, SimaPro or openLCA.

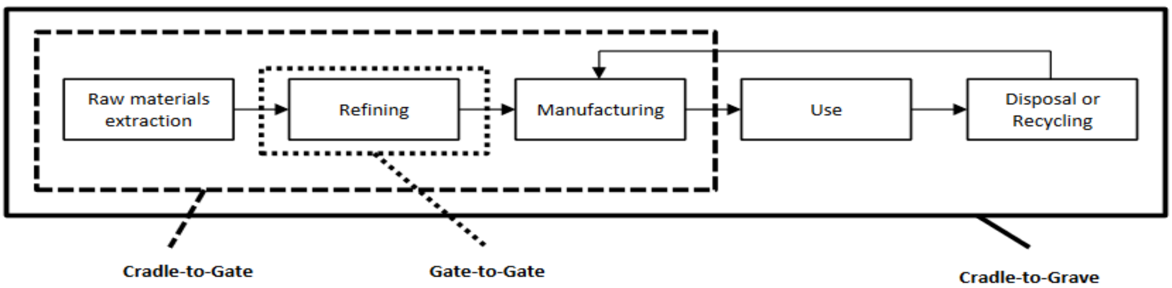

Figure 2. Options for Life Cycle Assessment boundaries. (IMOA 2014, 13).

The boundaries of cradle-to-gate approach presented in figure 2 are quite similar than supply chain stages defined previously. In companies whose core business are industrial investment projects based on external production, the supply chain of company can be seen as a combination of life cycles of delivered systems. Therefore it might be possible to estimate the emissions from investment projects by applying LCA method. Example of one supply chain in investment project can be seen in the figure 3.

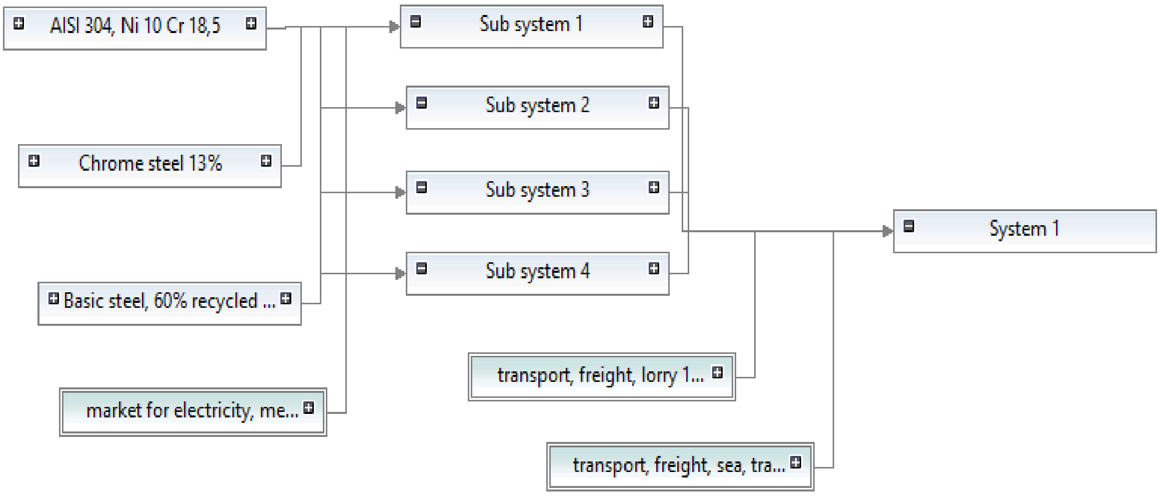

Figure 3. Example of supply chain in investment project.

In study of Faruk et al. (2001), actions to improve the environmental aspects in supply chain were divided in two groups: those that have consequences beyond the stage subject to the management action, and those that don't. Actions that do not have major environmental implications for other parts of the supply chain may be taken without reference to other stages. These "tactical actions" can be for example energy efficiency improvements in one supplier's operations. Tactical actions may include increasing efficiency in use of product or process materials, increase the proportion of environmentally friendly energy sources, reduce waste generation and using more environmentally benign modes of transport. Developing environmental data collection, monitoring and reporting capabilities falls also in this category. On the other hand, "strategic actions" may produce effects elsewhere and therefore they are needed to be put into larger context and require a stronger commitment to the management of a supply chain. For example, seemingly environmentally friendly improvements like increasing the recycling content of the used material might result different production processes upstream in the supply chain, and this new process might release more emissions than previous one. Good visibility of the environmental impacts associated with the entire extended supply chain is vital because these contingent effects need to be taken into account before making strategic actions. Strategic actions include often so called Design of Environment for the use of more environmentally benign product materials, use of product, product disposal and production process. It can also results for selection of alternative suppliers or products. (Faruk et al. 2001, 25-27.)

2.2 Definition of processes from management perspective

Analyzed systems can be differentiated into foreground system processes and background system processes. There are two definitions for them; from specificity perspective and from management perspective. From the specificity perspective, a foreground system contains those processes that are specific to it, and background system is those processes where a homogenous market with average or generic data can be appropriately represent the respective processes. Management perspective defines foreground systems to be those processes that are directly affected by the decisions analyzed in the study, and background processes are those that are not under direct control or decisive influence of the producer of the good. Foreground and background processes are illustrated in figure 4. (European Commission 2010, 96-99.)

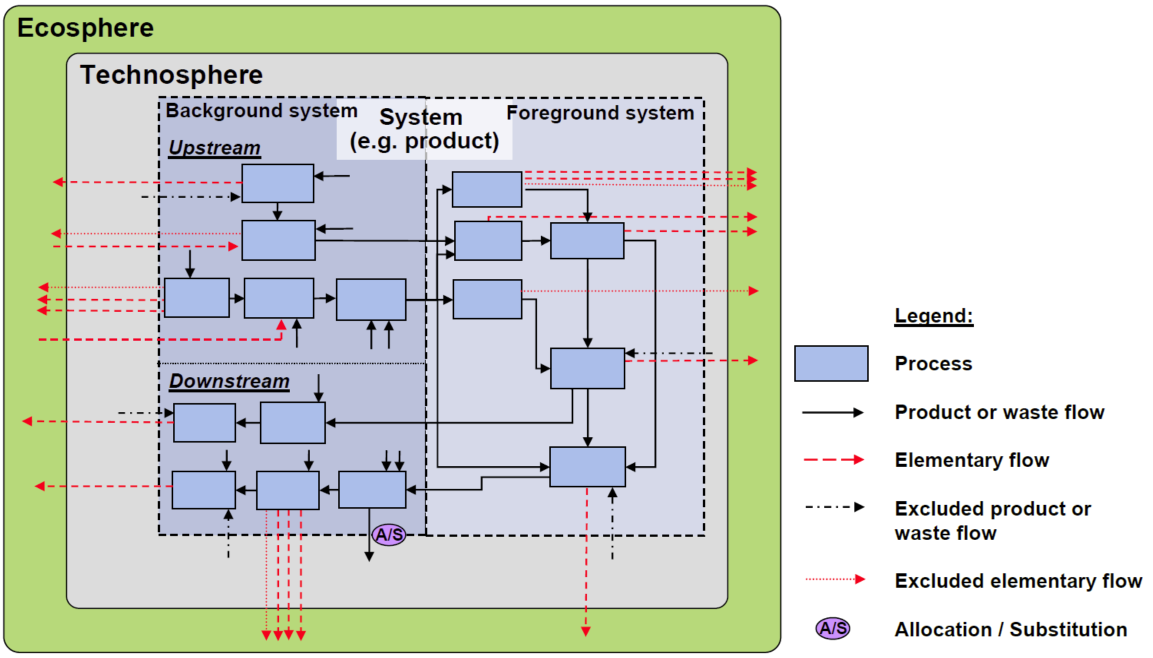

Figure 4. Foreground system and background system in the specificity perspective. The system is the exact sum of the background and the foreground processes. (European Commission 2010, 99.)

Foreground processes are those that are under direct control of the producer of the good or where producer has decisive influence. For estimating emissions from the foreground system primary data from the producer and secondary data from suppliers and downstream users or customers should be used. Average market consumption mix or other generic data from third party data providers can be used for the foreground system in cases when it has better overall quality than available primary or secondary data from direct suppliers or downstream operators. (European Commission 2010, 8, 97.)

Background processes are those that are not under the direct control of the producer. These are often processes at tier-two suppliers and beyond both upstream and downstream of supply chain. One example of background processes is steel production for steel parts purchased by a manufacturer of computer-casing. Background processes should represent the average market consumption mix and generic data from third party data providers can be used. They can also be used for the foreground system if they are of better overall quality for the given case than available primary or secondary data from direct suppliers or downstream operators. (European Commission 2010, 8, 97-98.)

Data should be collected and external data sources selected in an iterative manner to achieve the required precision with smallest possible effort. In cases where emission estimations are made for new technologies or complex product systems on which little previous experience exists, generic or average data can be used for the background system and some parts of the foreground system. To be able to identify the key processes and elementary flows of the product system, data collection can be combined with expert judgement. By identifying relevant parts of the system the main effort of data collection and acquisition can be focused on them. (European Commission 2010, 25.)

In investment projects foreground systems from management perspective are company's own manufacturing and in some cases tier-one suppliers and transportation. Company can have some control over tier-one suppliers and be able to define the materials used and the origin of materials used, while in some cases it might not have notable influence to the supplier. In some cases materials used in manufacturing might be purchased by customer company, and in those cases the company has most control over them. Whether transportation is foreground system or not depends on the project. During some projects transportation can be organized by company and thus is under its control, but in other projects transportation is organized by customer or supplier. Electricity production and waste management in manufacturing country are clearly background processes.

2.3 Availability and types of data

Collection of supply chain emission data is likely to require wider engagement within the company than usual projects and several internal departments, such as procurement, product design, logistics and manufacturing, might need to be engaged. A large multinational company may have thousands of facilities and buildings. This makes calculation of supply chain emissions or carbon footprint of product time and resource consuming, especially for the first time calculations are made. While accounting GHG emissions comes more popular, companies are now searching more cost-effective and less time consuming ways to account the emissions. Fortunately, the more calculations are made, the more the costs of calculation for one product goes down. (WRI 2006, 3; Antila, 2010, 44-45; WRI & WBCSD 2011a, 65.)

Emission calculations requires extensive quantities of data from companies, and activity data is necessary for the assessment of processes. Data can be divided in two parts: primary and secondary data. Primary data is specific for particular process, which should be used when specific supplier is used. Unfortunately, there is an inherent trade-off between how much primary data company can collect and what portion of their emissions this amount of data can capture. Using secondary data, for example average emission factors for industry, can reduce the cost and minimize the time and effort required to conduct GHG emission studies. This generic sector data might be even preferable in cases where system includes purchases from multiple sources. Often used secondary data are LCA databases, such as Ecoinvent and GaBi. (Huang et al. 2009, 8510; Bicalho et al. 2017, 888-889.)

It is well established that managing supply chains for environmental purposes demands supplier-specific information. Obtaining emission information from trading partners would be ideal, as it increases accuracy and helps to manage emissions with suppliers. From this point of view ready inventory databases are less useful in emission accounting. Data should be current, precise and from the relevant process and site. However, obtaining information on supply-chain emissions is not simple, and it can be the first obstacle for operators. Supply chain covers a broad range of operations and some data can be even "extremely difficult to obtain". One stage falling in this might be material extraction and other early stages of the supply chain, as it has been suggested that the quality of information that may be secured from suppliers decreases as the separation in the supply chain increases. Obtaining data even from all tier-1 suppliers can require impractical amount of time and resources from company, as there can be hundreds of companies or even sectors where the data should be collected. However, in some cases the information might be available because it is required under other environmental regulations. These cases can save significant amount of operators' time and trouble. (Faruk et al. 2001, 16, 23; MOE 2015, 2, 11.)

It becomes clear that companies should somehow prioritize the data collection efforts on the supply chain activities expected to have the most effect to GHG emissions, have most significant potential for GHG potential, or are most relevant to the company's business goals. Prioritizing allows companies to focus resources on the most significant GHG emissions in the value chain, setting reduction targets more effective and track and demonstrate emission reductions over time. To less important activities, or activities where accurate data is difficult to obtain the company may rely on relatively less accurate data. GHG Protocol's Scope 3 standard introduces several ways to prioritize activities for data collection. First option is to use initial GHG estimation or screening methods to estimate the emissions from each scope

3 activity by using for example industry average data of rough estimates, and then rank all activities from largest to smallest according to their estimated GHG emissions. This helps company to determine which activities have the most significant impact and where to focus on data collection. Second option is to prioritize scope 3 activities based on their relative financial significance. While the first option requires a lot of effort from company, the second one may lead to false results as spend and revenue may not correlate well with the emissions. Company may also base prioritizing to some other criteria, for example for activities that company has influence over, activities its stakeholders deem critical, or activities that contribute to the company's risk exposure. (WRI & WBCSD 2011a, 65-66.)

Study from Huang et al. (2009, 8511-8515) introduces another way of data collection. Instead of trying to get data from every supplier or only use secondary data, companies could focus on the most relevant suppliers. In the study it was found that approximately 50-70% of manufacturing sector's upstream scope 3 emissions can be tracked to their industry's top-10 suppliers. This indicates that company could focus only for 10 most important suppliers in its emission accounting and use secondary data to estimate the rest of its emissions.

Depending on the approach intended to use to define the organizational boundaries, data can be collected at various levels: corporate, facility, and unit level. Corporate level is the least specific level. This level is not well suitable for accounting supply chain emissions in investment projects, as a corporate can have several projects ongoing and corporate-level data would be needing allocation. Facility level data is more specific, and it could be used for estimating emissions from manufacturing. However, when calculating emissions from investment projects facility-level data, such as electricity consumption, needs to be allocated to single product delivered in project from that facility. Unit level data, for example fuel data from individual boiler or process stage, is the most specific. For investment project calculations unit level data would be suitable for tracking transportation emissions, yet for other stages it can be too specific to be practical. In some cases, it might be difficult to collect data at a particular level. Businesses making a corporate-level inventory often gather more precise data for units that represent larger percentage of their total emissions but gather corporate-level data for smaller sources. (WRI 2006, 17-18.)

3 ASPECTS THAT AFFECT TO GHG EMISSIONS OF INDUSTRIAL PROJECTS

The determination and management of companies' supply chain emissions is rising global trend. This is understandable, because while there might be great emission reduction potentials in supply chain, this potential remains unidentified if companies focus only to emissions from their core operations. Calculation and determination of emissions at each stage of the supply chain makes it possible to identify not only stages with the highest level of emissions, but also the greatest emission reduction potentials. Determination and management of GHG emissions in the supply chain allows companies to implement efficient measures for reducing emissions in the overall supply chain. Companies calculating their supply chain emissions are also raising awareness and promoting GHG emission reductions in their suppliers and customers by demanding information about processes and enabling cooperation. This way companies motivate their suppliers to have more effective corporate climate change policies. (Huang et al. 2009, 8509; MOE 2015, 1-5; CDP 2018.)

The scope of the supply chain emissions covers all emissions related to business activities, including for example purchasing and sales by the company (MOE 2015, 1). It is important that companies understand which aspects are essential for managing GHG emissions (CDP 2016, 14). Figure 5 below illustrates scope 3 emissions for over 35 500 companies per emissions source in 2014 estimated by CDP. It can be seen that the most important scope 3 categories were purchased goods and services and use of sold products. Fuel- and energy related activities, upstream transportation and distribution, and downstream transportation and distribution, caused relatively high emissions compared to other remaining categories. In the parentheses the number of companies for which each type of scope 3 emissions was calculated is presented. It shows that companies tended to focus on categories that were easy to account but caused relatively low amount of emissions, such as business travel, waste generated in operations, and transportations.

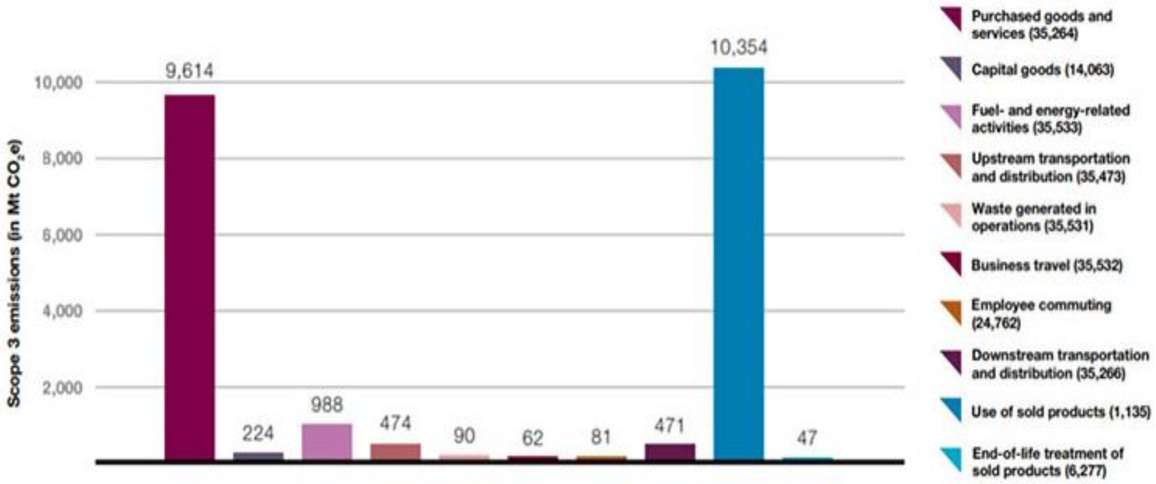

Figure 5. Scope 3 emission for 35 533 companies per emission source in 2014 (CDP 2018).

Huang et al. (2009, 8512-13) categorized supply chain emissions in industry sector analyzing 426 industry sectors, which were classified into 24 industry groups. They found that emissions from truck transportation appeared in top 10 list for 2/3 of all sectors in economy and ranked second in average portion of footprint captured. Despite this, tier-1 transportations suppliers generally contributed less than 5% of total analyzed footprint. Air business travel contributed less than 1%, and its contribution was even smaller for the manufacturing sectors. Employee commuting was also minor emission source in manufacturing sectors. Iron and steel mills ranked first in total analyzed footprint but appeared in only third of all sectors analyzed, indicating that embodied carbon footprint in input iron and steel materials is relatively high. Emissions from petroleum refineries were high in some sectors, but they appeared only in quarter of analyzed sectors. Motor vehicle parts manufacturing and grain farming played important role in only few cases. Power generation sector was the most ubiquitous and GHG-intensive supplier sector. Results indicates that only few supply chain emission categories are relevant for all industry sectors and the categories that are focused on emission accounting should be selected case-by-case.

Japan’s Ministry of the Environment (MOE) analyzed scope 3 emissions of six companies that have advanced emission accounting practices and global operations: one operating in chemical industry, three in manufacturing, and two in retail trade. It was found that there were significant differences in which emission category was the most important. Use of sold products was the most significant emission source for most of the companies, accounting even 70% of total GHG emissions. Purchased goods and services, which include raw material procurement, was other significant stage. Other stages with notable emissions were end-of-life treatment and transportation and distribution. (MOE 2015, 12-23.)

The report of CDP (2016, 14) and the study by Huang et al. (2009, 8512) both indicated that enterprise's focus is often in the easily measured sources of scope 3 emissions rather than the most important ones. CDP mentions that there is a large cap between the data-based estimates and the self-reported view of how important each category is, and companies often see emission categories that are easy to measure and understand more relevant than the categories that actually cause majority of their emissions. For example business travel and employee commuting are often mentioned in discussions about scope 3 efforts. They are particular interest of companies conducting footprint analysis because they are quite easy to account with local data sources without collecting data from suppliers, and companies can often directly influence to these emissions. However, business travelling and employee commuting often make only very little portion of overall emissions of company and thus focusing to them would leave a significant portion of the upstream scope 3 footprint unidentified.

While every sector's and company's scope 3 footprint profile is unique, studies indicate that the most important scope 3 category would be purchased goods and services. In investment projects it is predictable that the effect of purchased materials for delivered products have much higher footprint than purchased services, and most of the materials purchased are different kinds of metals. In one study iron and steel mills had high carbon footprint, suggesting that the production of materials should be included in purchased goods and services -category. Power generation sector appeared to be the most common and GHG-intensive supplier sector and thus should be included. Emissions from transportation and distribution were generally low in most cases, yet it was one of the most ubiquitous stages. According to these findings and discussion in chapter 2 about scope 3 categories in investment projects it would make sense to take a better look to following aspects: production of materials, transportation, electricity consumption, and other aspects of manufacturing. Business travel is important part of investment projects but considering that previous studies showed emissions from business travelling to be insignificant, it might be acceptable to leave this aspect out of the analysis. Use of sold products was important stage from the emission point of view, but it is often outside of the scope of investment projects.

First in this chapter the effect of material grade, production places and recycling content to GHG emissions from material production are considered. After that, the emissions from different ways of transportation are analyzed. Lastly the impact of electricity consumption and other manufacturing aspects are discussed.

3.1 Materials

Production of materials consumes about 21% of the global energy and its share of GHG emissions is about the same (Ashby 2013, 21). Most commonly used materials in industry are different types of metals, especially iron and steel (Lepola &Makkonen 2007, 13), and this is case in industrial projects too. Considering the size of these projects, the consumption of steel during them is huge. Iron and steel industry is one of the world's largest CO_2 emission sources (Fan 2016, 67). So to say, it is reasonable to consider material usage one of the main aspects affecting to the GHG emissions of projects. First in this chapter, life cycle of steel from cradle to gate is revealed. After that, the effects of recycling content and production country to the GHG emissions from steel production are discussed. Lastly, the differences in steel grades in terms of carbon dioxide emissions are reviewed.

Life cycle of material can be considered to start at the design process, as the environmental impact of product during its life cycle is largely determined by decisions taken during the design process by selection of materials and manufacturing process (Ashby 2013, 51). Still the actual life cycle of steel starts with mining the ore. After that, there are three main stages of steel production from ore: pre-treatment of ore, production of raw iron, and steel production. After this, the steel is shaped. The environmental impact of steel is emphasized in these phases, as they are very energy intensive and can also cause substantial air, water and soil pollution. Next phase, use, does not normally cause emissions, and while recycling process of steel causes emissions, it reduces the total emissions by replacing primary steel. (Ashby 2013, 49.) The routes of steel production are illustrated in figure 6 below.

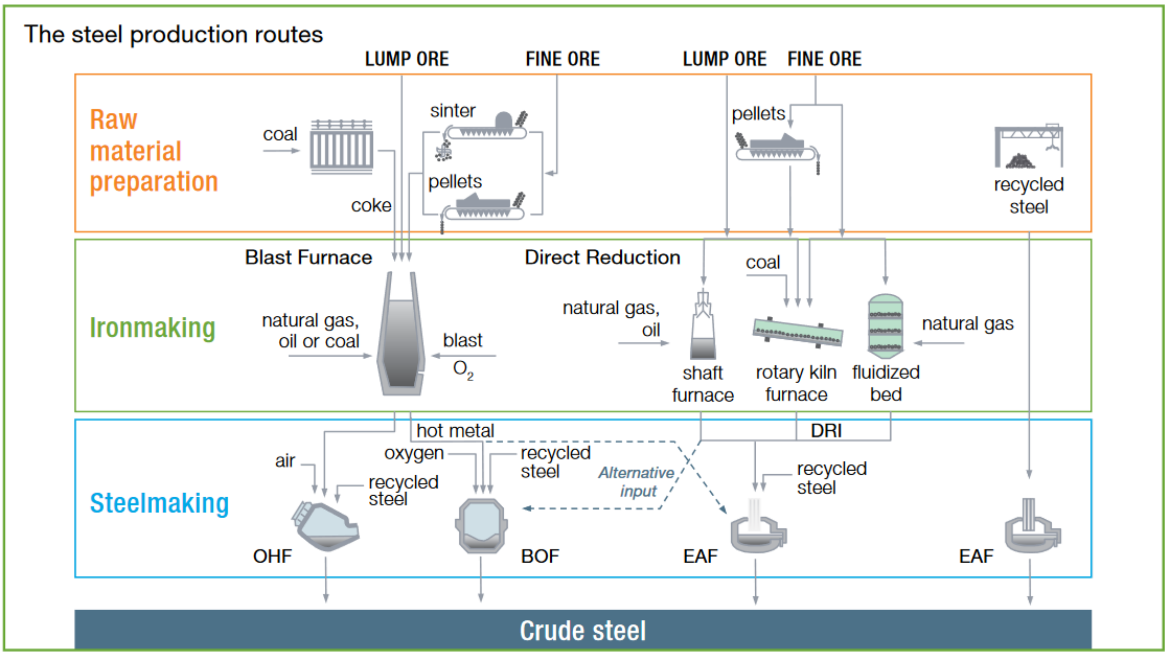

Figure 6. Steel production routes according to World Steel Association (2015, 15).

Below in figure 7 is illustrated the flow of iron and steel through the economy (Allwood et al. 2011, 5). Even though the figure 7 illustrates the situation in 2008, the big picture of metal production is still valid. It can be seen that most of the steel, 56%, was used in construction, and 16% for industrial equipment. Systems delivered in industrial investment projects fall in both of these categories. The biggest flow of metal loss happens during the steelmaking process in oxygen blown furnace.

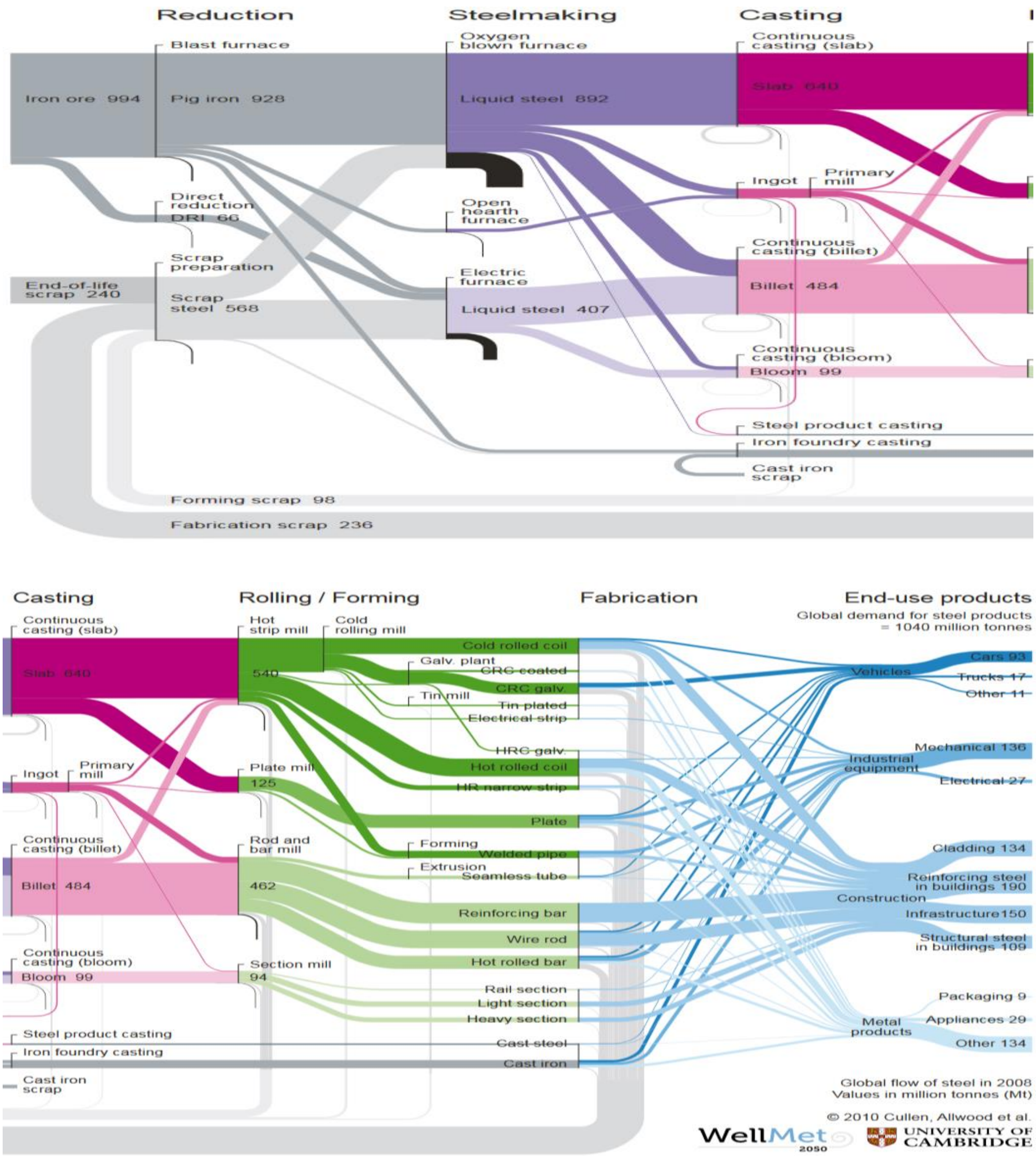

Figure 7. Sankey diagram for the flow of iron and steel through the economy (Allwood et al. 2011, 5), divided to two pictures. Useful metal flows have colored threads, scrap has gray threads, and metal loss black ones.

Estimations about average emissions for steel production vary between 1.7 – 2.04 t CO_2 $_{eq.}$/ton of steel produced (IEA 2014; Lisienko et al. 2015, 626). The World Steel Association reports that in 2017 greenhouse gas emissions were 1.83 t CO_2/ton of crude steel cast, while according to Ecoinvent database it is 2.29 t CO_2/ton of primary steel. Strategic Energy Technologies Information System (SETIS, 2019) claims the global average being 2.6 t

CO_2/ton of steel, mentioning that large steel volumes are still produced with emissions as high as 4 t CO_2/ton of steel, mainly in Eastern Europe, former Soviet Union, and Asia. Therefore, while it would be possible to use some of these average values for all steel used in investment project, it would be better to consider some aspects affecting to the these emissions to achieve better accuracy.

There are two dominating types of steel production: blast furnace/basic oxygen furnace (BF/BOF) and electric arc furnace (EAF) production. BF/BOF production uses iron ore, while EAF production re-melts steel scrap. Reduction process of iron ore to iron in a BF is the most energy-intensive process within the steel industry. Hot metal is produced by the reduction of iron ore by adding coke and coal to the blast furnaces, and this process gives rise to carbon dioxide. These aspects make BF/BOF production consuming more energy and producing more CO_2 emissions than EAF production. This is one reason why recycling content of steel affects GHG emissions of its production. (Hasanbeigi 2015, 1-18.) Estimations about scrap share in global steel production varies: according to UNEP (2015, 81), steel scrap represented less than 40% of total steel production between 2011-2014, while newer estimations (McKinsey & Company 2017, 7; Outokumpu 2019; SSAB) vary between 55-63%. While recycling and reuse also require energy, it often requires it much less than primary production (UNEP 2010, 68). According to SSAB, CO_2 emissions from recycling-based steel making are under 10% of emissions from ore based production. Figure 8 below illustrates the differences between embodied energy and carbon footprint of steels with different content of recycled material according to Ashby (2013, 131).

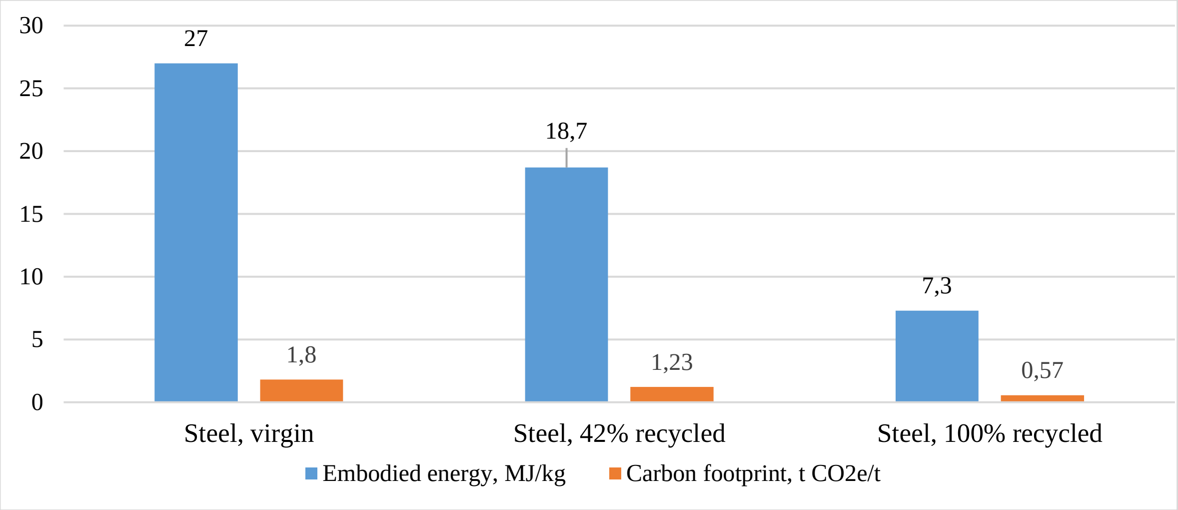

Figure 8. Approximately embodied energy and carbon footprint of steel according to Ashby (2013, 131).

China is one of the biggest producers of crude steel, accounting 44% of global crude steel production in 2010. Its impact to China's GHG emission is significant: since 2006 iron and steel industry has accounted more than 17% of country's total CO_2 emissions. Emissions from China's steel and iron industry are higher than in many other countries for two reasons: the main process of country's steel production is BF/BOF, and more than 70% of energy is produced with coal. In China CO_2 emissions from iron and steel industry are 1.548-2.148 t CO_2/t of steel output. (Fan et al. 2016, 67-68; Hasanbeigi 2015, 14.)

The European steel industry has made significant efforts to reduce carbon footprint of steel. According to SETIS (2016), GHG emissions per one ton of steel from conventional steelmaking have dropped from 3.5 t CO_2/ tonne of steel to 1.7 t of CO_2. Similar results have been achieved in electrical steelmaking, where emissions are on average 1 tonne of CO_2 per tonne of steel. Exact emission are depending on the origin of electricity. In the figure 9 below the emission reduction of EU27 steel industry according to Boston Consulting Group (2013) is illustrated. It can be seen that the emission reductions have been significant, yet the specific emission factors differ from SETIS estimations. It is said that blast furnaces in Europe are now reaching the limits of their technological capabilities of GHG emission reduction.

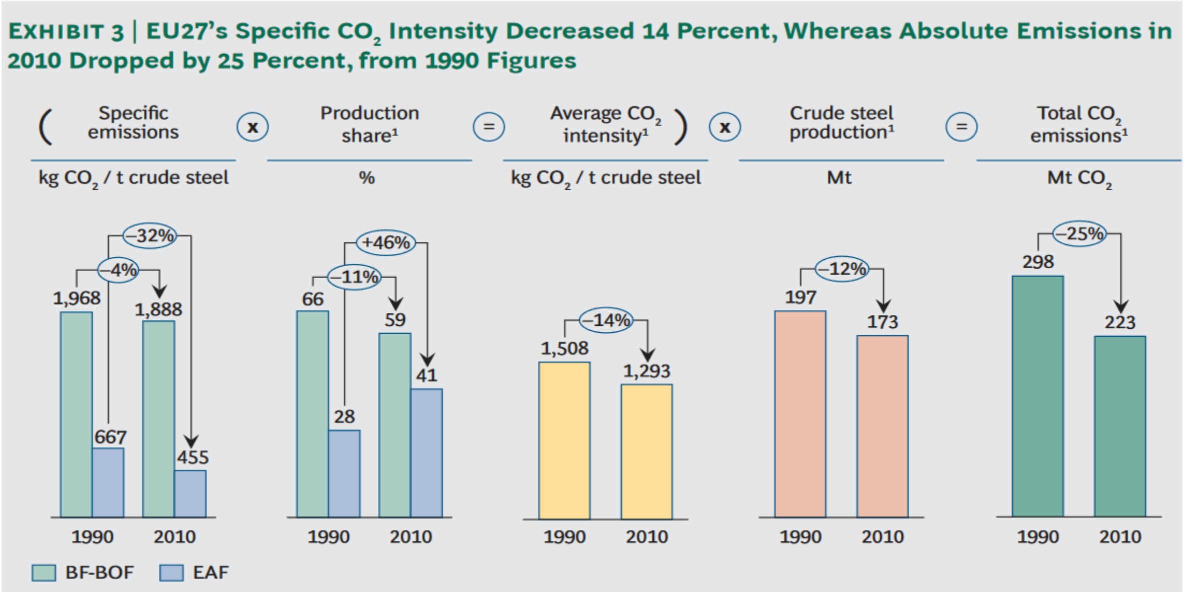

Figure 9. CO_2 intensity in steel production in EU27 countries (The Boston Consulting group 2013, 11).

Hasanbeigi et al. (2015) compared emission intensities of steel industry in several countries. According the study, the emission intensities in steel production were 2.148 t CO_2/tonne crude steel in China, 1.708 t CO_2/tonne crude steel in Germany, 1.080 t CO_2/tonne crude steel in Mexico, and 1.736 t CO_2/tonne crude steel in the U.S. in 2010. Mexico's steel production using EAFs accounted almost 70% of the total crude steel produced in 2010, and country's steel industry consumes a large share of natural gas compared to many other countries. Because of this, Mexico' steel industry has relatively low CO_2 intensity. The energy efficiency and CO_2 intensity of United States steel production has continually improved, and EAF steel production contributes 61% of country's total steel production. Despite low share of EAF in Germany's steel production, 30%, its emission intensity is almost the same than United States' production. (Hasanbeigi et al. 2015, 1-20.)

There are also other emission factors that can be found for single countries and companies. Fort example in Brazil the emissions from steel production are estimated to be 1.8-1.9 t CO_2/ tonne of steel (Brazil Steel Institute, 2018). Outokumpu (2019) claims that their emissions from steel production in 2018 were as less as 0.8 t CO_2/ tonne of steel. Nevertheless, these values cannot be compared with other values, as the system boundaries and other calculation methods used can be different.

There are some differences between metals in terms of environmental impacts. In the table 1 below, the metals that have the largest environmental impacts are presented. In the first column, metals are ranked based on the total impact that their production causes, and therefore the metals produced in largest quantities, such as steel and aluminum, are on the top. In the second column, metals are ranked based on the impact of one kilogram produced, which shows that rarer metals have relatively bigger environmental impact.

Table 1. Priority list of metals based on environmental impacts (UNEP 2010, 68).

	Impact of global production	**Impact per kg primary**
1	Iron	Palladium
2	Chromium	Rhodium
3	Aluminum	Platinum
4	Nickel	Gold
5	Copper	Mercury
6	Palladium	Uranium
7	Gold	Silver
8	Zinc	Indium
9	Uranium	Gallium
10	Silicon	Nickel

Metals used in industry are usually mixture of several elemental metals, as elemental iron is soft and weak. Mixing different metals to steel gives product the wanted features. For example steel is alloy with iron content at least 50% and carbon content of 0.003-2.06%, and stainless steel contains chrome and nickel. Heat resistance steels contain either molybdenum or molybdenum and chrome, and fire resistant steels chrome, nickel and silicon. Weather-resistance structural steels might contain small amounts of chrome, nickel and copper, and sometimes phosphorus. Chromium (Cr) is the most versatile of all metals used with alloyed steel. It increases the hardness and tensile strength of steel, but reduces resilience. Steels with over 12% of chrome are stainless steels. Chromium protects steel from corrosion. Manganese (Mn) is added to all steels to remove redundant oxygen, and it is the most used alloying element after carbon. Manganese increases the hardness and strength of steel.

Molybdenum (Mo) increases the strength and resilience of steel. It is relative expensive so it is not used as only alloy in material. Molybdenum is used in heat resisting steels, which are often used in turbines and boilers. Therefore it is likely that at least some products delivered in large investment projects contain molybdenum. Acid proof steel is produced by mixing about 2.5% of molybdenum to austenitic stainless steel. Nickel (Ni) increases the strength of steel, and increases the resilience of steel in both low and high temperatures. Stainless steel has normally circa 10% of nickel. Zink (Zn) is often used as coating against corrosion. Sometimes two different steel grades are combined together as compound steels, and for example tanks used in process industry are often made from compound. (Lepola & Makkonen 2007, 15-37, 63, 172-176, 261.)

Metals differ significantly in the extent to which they contribute to global warming (UNEP 2010, 67), and therefore the material composition of alloyed steel must be taken into account also in GHG emission calculations. In the figure 10 below the contribution to GHG emissions and terrestrial ecotoxicology of different metals are illustrated. It can be seen that iron and low-alloyed steel have relatively low contributions, while commonly used additional metals in steel, nickel and chromium, have much larger impacts.

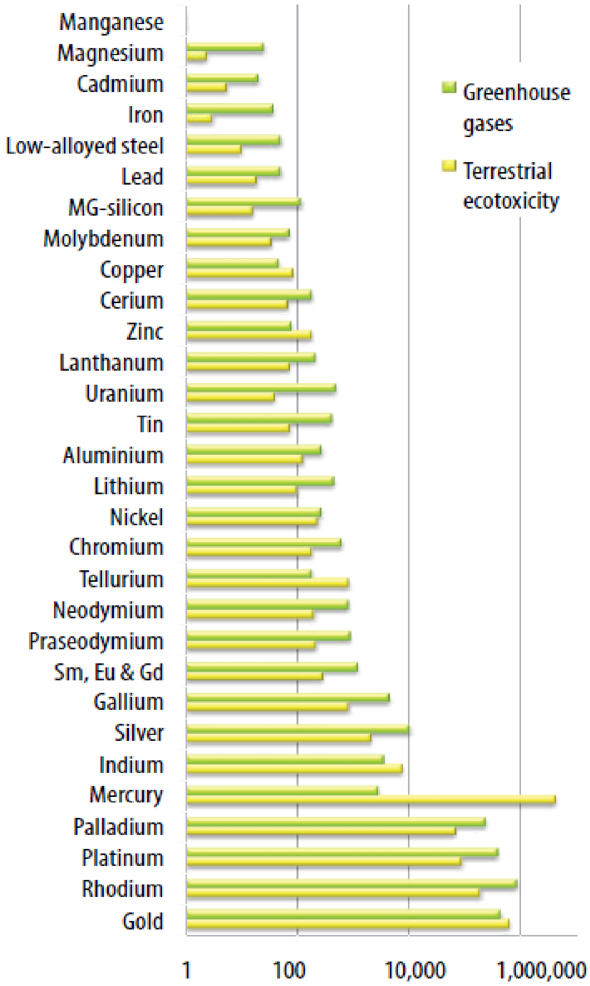

Figure 10. Contribution to terrestrial ecotoxicity and global warming of 1 kg of primary metal, normalized data (UNEP 2010, 67).

It proved to be challenging to find comparable GHG emission factors for steel production in different countries. As Hasanbeigi et al. (2015, 1-2) state in their study, it is difficult to provide single one CO_2 intensity value for steel production in an individual country for comparative purposes. Comparison is difficult or even impossible because the energy consumption and the energy intensity are often estimated based on different definitions of an industry's boundaries, and even international GHG accounting and reporting frameworks, such as IPCC, European Union Emission Trading System (ETS) and GHG protocol have set different boundaries. One question is how reliable it is to compare emission values from studies made in different years. This challenge must be taken into account when supply chain emissions are calculated and modelled.

3.2 Transportation

There are four alternatives for freight transportation: ship, truck, plane and train. Naturally they all are not always realistic options: transoceanic transportation requires shipment or air transportation, and reach with railroads can be limited. In addition the cost of transportation, the size and weight of the goods and the urgency of shipment needs to be taken into consideration when selecting the right transportation mode (Freighthub 2018). Transportation contributed 27% of the EU's total CO_2 emissions in 2016 and thus was Europe's biggest source of carbon emissions (EEA 2018; Transport & Environment 2018). Transportation was also the only sector in which emissions have grown since 1990 (Transport & Environment 2018). Even though passenger cars are the biggest source of GHG emissions with 43.7% share, emissions from freight transportation should not be ignored. Maritime emissions account 13.6%, trucks and buses 27.4% and aviation 13.3% of total transportation emissions, yet these numbers include also passenger transportation.

Road freight with trucks is one of the most common of all modes of transportation (Freighthub 2018). It is cost-effective, flexible and quick mode, but it is affected by weather, road conditions and traffic, and the size of transported items might be limited (Freighthub 2018). According to VTT's LIPASTO database (2017), emissions are 630 g $CO_{2\,eq}$./km from 40 t EURO VI truck, 796 g $CO_{2\,eq}$./km from 60 t EURO VI truck, and 872 g $CO_{2\,eq}$./km for 75 t EURO VI truck, when trucks are empty. Naturally, emissions increase when vehicle size increases. While it seems that it would be better to use smaller trucks for road freight, it must be taken into account that emissions per one ton of freight might show something else. In the table 2 below emissions from several types of trucks are compared.

Table 2. $CO_{2\,eq.}$ emissions from truck transportation according to VTT's LIPASTO database (2017).

	EURO III (2001-2005)		**EURO VI (2015 ->)**	
	70%	Full	70%	Full
Truck, 40 t, g $CO_{2\,eq.}$ /tkm	50	39	46	35
Truck, 60 t g $CO_{2\,eq.}$ /tkm	39	31	38	30
Truck, 75 t g $CO_{2\,eq.}$ /tkm	-	-	35	28

It can be seen from the table 2 that transportation with bigger trucks is more efficient in terms of GHG emissions. Similar factor has load of the truck: full loaded truck causes circa 10 g less $CO_{2\ eq.}$ emissions per ton kilometer than truck that is loaded only 70% of its capacity. European emission standard stages (EURO I-VI) have not so significant effect on GHG emissions. This indicates that for road transportation companies should use as large trucks as they can pack full. For accurate emission calculation this means that both truck capacity and how full it is should be known. However, transportation is usually handled by other company and information of specific can be hard and time consuming to gather, especially in bigger projects with numerous road transportations. This alongside the fact that transportation emission do not usually have large share of total supply chain emissions, company should avoid focusing too much in this aspects. It might be good solution to estimate beforehand which truck type and load rate is mostly used and use it in the calculation model and calculations, and then detail it if necessary.

Seaborne trade accounts for 90% of the global trade (Freighthub 2018). Ocean freight has many benefits: it is often cheapest option, it can be used for cargo with large size and mass, and it is said to be the most environmental friendly transportation mode (Freighthub 2018). Downsides are long transportation time and dependence on water routes (Freighthub 2018). Shipment is often only option for transoceanic transportations of large components. Emissions from shipping are depending on the type of ship, used fuel, and as with truck transportation, size of vehicle. In table 3 below, emission factors according to VTT database are presented. Emissions per load tonne of container cargo are calculated to be bigger than those of bulk cargo, since the mass of the container increases energy consumption and emissions, even though these emissions are allocated only to freight. (VTT 2017.)

Table 3. Emissions from shipments (LIPASTO 2017). TEU, Twenty Foot Equivalent Unit, is the unit capacity of a container ship. Emission factors include both directions, thus return trip need not to be calculated.

	Deadweight tonnage (DWT) (t)	**Fuel consumption (g/tkm)**	**$CO_{2\ eq.}$ emissions (g/tkm)**	**$CO_{2\ eq.}$ emissions (g/ship km)**
Container ship, 1 000 TEU, 65% usage	14 000	13	42	188 346
Container ship, 2 000 TEU, 65% usage	32 482	8.9	28	253 034
Bulk carrier, medium, usage 60%	14 000	4.0	13	105 004
Bulk carrier, large, usage 50%	32 000	3.0	9.4	149 601
General cargo, small, 40% usage	4 000	8.8	28	50 007
General cargo, multi-purpose carrier, 40% usage	4 000	9.1	29	50 007

Other option for transoceanic shipments, air freight, is forecasted to grow 4.2% per year on average (Freighthub 2018). Air freight is the fastest transportation mode and it decreases the likelihood of damage or theft due to less handling of cargo, but it also is the most expensive option and has its size and weight limitations (Freighthub 2018). This mode is infamous for its large GHG emissions for a reason: long-distance freight plane emits 600 g $CO_{2\ eq.}$/tkm (VTT 2009). Emissions from shorter international flights are even bigger, 1 416, and from domestic flights as high as 1 933 g $CO_{2\ eq.}$/tkm.

Fourth option is train transportation, which is often considered to be "green" and to have lowest emissions. The cost-effectiveness of train depends on the distance: it is cheaper than truck transportation for long distances, but more expensive for shorter distances (Freighthub 2018). Train is most effective form of land transportation, and has reliable transit times and schedules. The amount of emissions still depends on which fuel is used (Freighthub 2018). Emissions from general cargo train using diesel are 25.5 g $CO_{2\ eq.}$/tkm and from diesel driven container train 18 g $CO_{2\ eq.}$/tkm. Sometimes emissions from trains using electricity are counted to be zero, as VTT (2017) does. However, if electricity is produced with fossil fuels, it is arguable if electricity train really is carbon neutral.

While the exact emissions factors vary depending on the source, the order of transportation modes stays same. In the figure 11 comparison between transportation modes according to IMO can be seen.

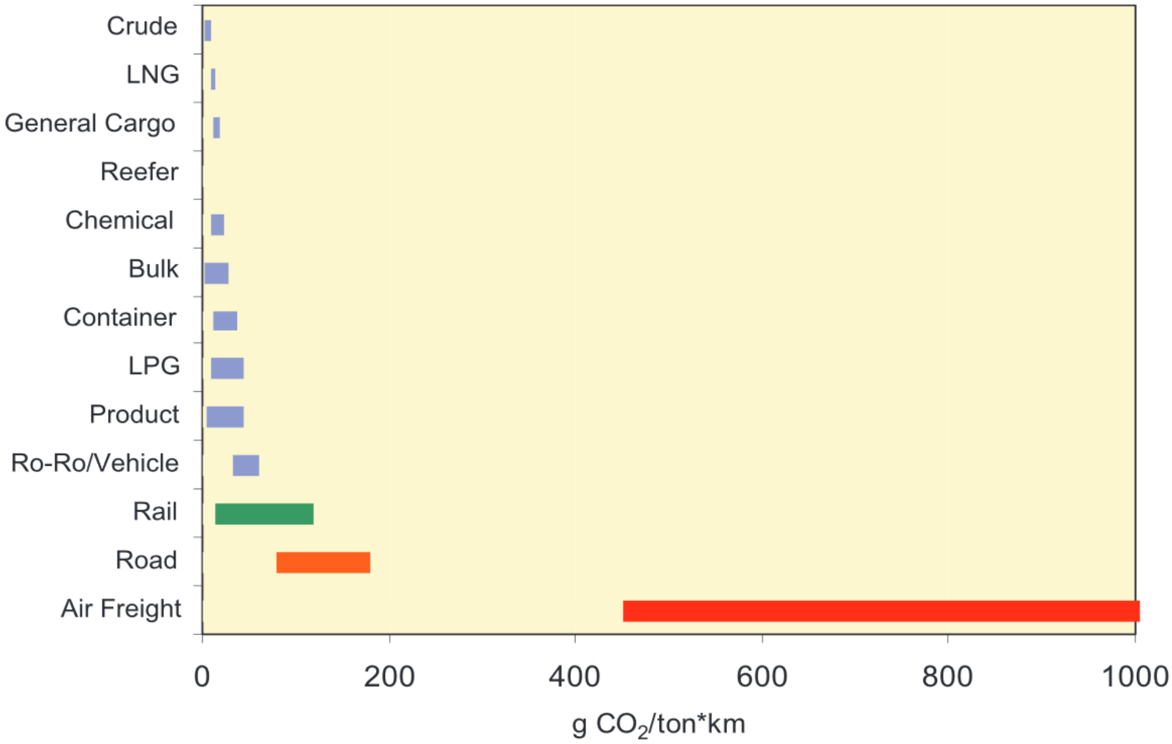

Figure 11. Typical range of CO_2 efficiencies on freight transportation (IMO 2009, 134).

It seems that the best transportation option in the terms of emissions is train or ship, and worst option plane. However, companies usually cannot or would not made the selection of transportation method based on emissions of the method. This reduces the possibilities to lower the supply chain emissions by changing transportation modes, yet there is always room for some improvements. Already, many companies often use multimodal transportation, combining different modes of transportation, and thus switching one mode to another at some phase of transportation might be possible. On the other hand, more different types of transportation have been used, more complicated emission calculation and modelling those processes will be.

3.3 Energy production and use

Production place is one factor that affects to the life cycle emissions of product due to different type energy production and environmental regulations. For metal production, the energy requirements for mining and extraction are large: already ten years ago metal industry used 7% of the world's energy, and will only increase due to falling ore grades (UNEP 2010, 68). Therefore the GHG emissions from electricity production will affect to both raw material extraction and production stages.

Shaping process of material also consumes energy, and the average values for some of primary shaping methods are presented in the table 4. It can be seen that the energy consumption varies greatly within and between shaping processes. For this reason data about electricity consumption from manufacturing used in GHG inventory should be primary data gained from manufacturer. Using average consumption factors could lead to low reliability of results.

Table 4. Energy consumption and carbon emissions per kilogram of usable shaped parts of metal from primary shaping processes (Ashby 2013, 133).

Shaping process	**Typical range of energies (MJ/kg)**	**Carbon, $CO_{2eq.}$ (kg $CO_{2eq.}$ /kg)**
Casting	8-12	0.4-0.6
Rough rolling, forging	3-5	0.15-0.25
Extrusion, foil rolling	10-20	0.5-1.0
Wire drawing	20-40	1.0-2.0
Metal powder forming	20-30	1-1.5
Vapor phase methods	40-60	2-3

The carbon intensity of electricity production can vary notable depending on the geographic location due to different electricity generation portfolio (Huang et al. 2009, 8514). The carbon intensity of electricity in different countries can be seen in the figure 12 below. It can be seen that the differences in carbon intensity between countries are notable yet not strictly depended on the geographical area: while Northern Europe stands out positively, the difference between Germany and China is not so notable. It must be noted that these intensity values are from 2010 and in nine years significant changes might have happened. However, it is clear that country- or region-specific emission factors for electricity have to be used in emission estimations. As changes in electricity production occur, the emission factors used should be updated regularly to preserve accuracy.

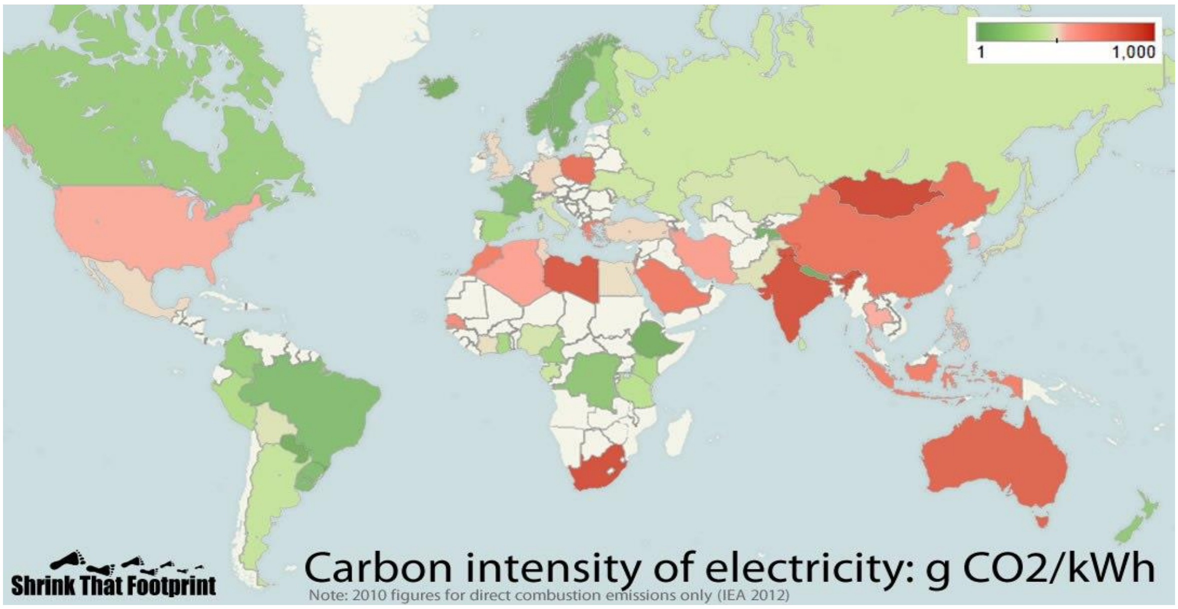

Figure 12. Carbon intensity of electricity production in 2010 (Shrink that footprint).

3.4 Other aspects in manufacturing

In addition to electricity, there are other aspects in manufacturing that should be taken into account in cases where data about them is available. Fuels such as diesel and liquefied gas might are used in some workshops in processes or transportation, and in cold areas buildings need to be heated.

Industry consumes about 10% of the total water consumption, energy production being half of it. The production of steel requires water at many phases: for the extraction of the minerals, for material conditioning pollution control, and for cooling equipment and quenching ingots. (Ashby 2013, 27.) In addition, workshops may use water in their processes. If workshop is located in the water scarce area, a production of water might cause notable GHG emissions. For example some desalination plants have high electricity consumption and high associated environmental impacts (Yu et al. 2016, 54).

While end-of-use of systems delivered in project might be outside of the scope of GHG inventory, waste created during manufacturing of supplied systems should be included in the inventory. Industrial sector produces 21% of global solid waste (UNEP 2015, 54) and according to IPCC, the direct contribution of the solid waste and wastewater sectors to GHG emissions it 3 to 5% (UNEP 2015, 13). Proper waste management does not only reduce direct emissions from landfills and open burning of waste, but also reduces emissions from primary production by displacing virgin materials with recycled materials. Direct energy savings during production by recycling process is 35% in glass production, in steel and paper production over 50%, in plastic production over 70% and in aluminum production over 90%, to mention few. In the figure 13 the relation of waste management and climate change is illustrated.

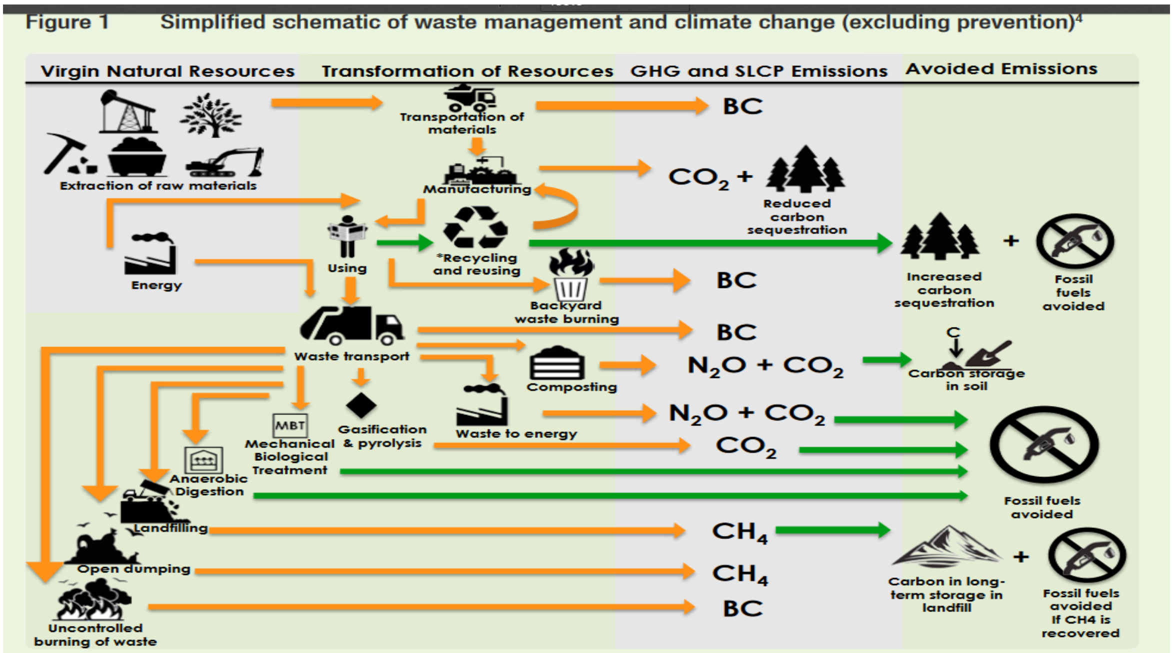

Figure 13. Simplified schematic of waste management and climate change, prevention is excluded (UNEP 2015, 13).

Including waste management in a calculation model might be complicated as there are many variables and data might be scarce. The amount of waste created in a workshop is often tracked at workshop level. Hence there is no data about waste from production of a specific system. Even though allocation might be needed, broad estimation about the amount of waste helps to draw a picture about its effect on total GHG emissions from investment project. In cases when subcontractor don’t measure the amount of waste generated in its operations or don’t want to give waste data, this aspect has to be left outside. In the production of industrial equipment for pulp and paper industry, it can be assumed that at least waste metal is generated, but other types of waste generated during manufacturing depend of the workshop and the system that is manufactured. One more variable to a model comes from large number of options for waste management, ranging from effective re-use and recycling to open dumping and illegal burning. When a model for emission calculation is developed, one must decide how emissions from waste management are handled. While recycling and energy recovery may reduce the total amount of GHG emitted, it is arguable whether these processes reduce the emissions from supply chain. If for example industrial waste management with energy recovery is considered emission-negative in a model, results can indicate that in order to lower their emission, workshops should increase the amount of waste created in processes.

4 THEORETICAL BACKGROUND OF MODEL DEVELOPMENT

In addition to theoretical knowledge about supply chain in investment projects and different life cycle stages causing emissions, some theoretical background about development of model is needed. However, there seems to be only little guidelines and studies available about calculation model development for emission accounting. In this chapter one of the applicable sources, the GHG Protocol's guidebook "Designing a Customized Greenhouse Gas Calculation Tool", later called The Tool Guidebook, is utilized. Even though it is meant for designing already existing GHG Protocol's calculation tools, it may be used to develop new GHG calculation tools (WRI 2006, 2), or in this case calculation model. GHG Protocol's other standards give general principles for emission accounting in different situations, and if model is wanted to be in harmony with GHG Protocol's standards, those principles constitute framework that should be utilized as principles for model development. In addition, The Tool Guidebook suggest that before customizing a calculation tool the developers should be familiar with the accounting and reporting concepts from Corporate standards (WRI 2006, 2). After reviewing the principles from standards, the other principles that model should follow are discussed.

4.1 Building a calculation tool or model

The primary purpose for a GHG calculation tool or model is to ensure consistency and credibility in the calculation of emission for a specific use and to clarify which methods are needed to quantify emissions. Existing tools might not be suitable for entities need, because national quantification methods may be too broad to produce the level of quantification certainty needed for an entity's inventory. In addition, source-specific guidance need to be aggregated for the entity-level tool. Developing a new tool will take longer than customizing already existing tool, as determining suitable boundaries and conventions might be difficult. Key steps in developing entity-level GHG inventory are presented in the figure 14 below. (WRI 2006, 3, 14.)

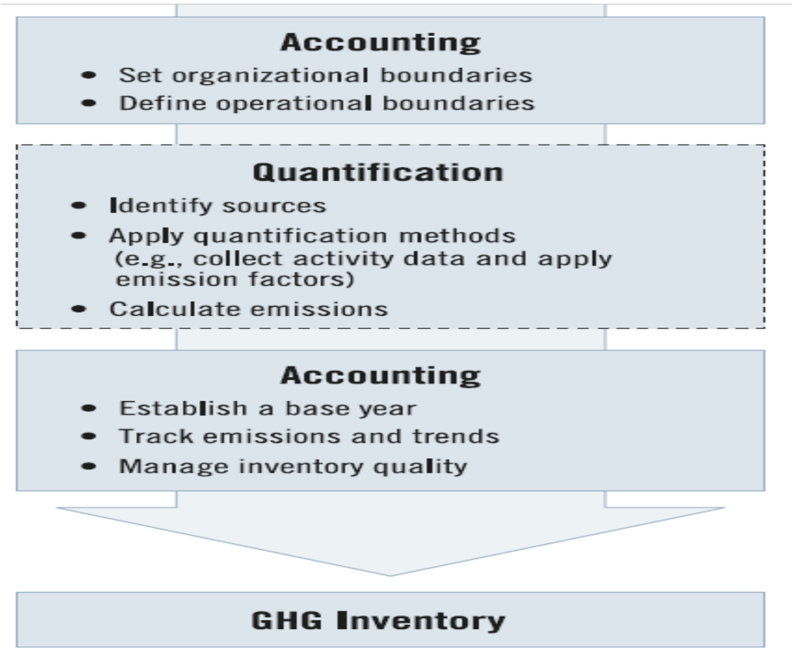

Figure 14. Key steps in developing entity-level GHG inventory (WRI 2006, 7).

During the first step, accounting, the user of calculation tool defines emissions sources that will be included in the inventory, and how they will be classified and reported. User needs to also set organizational and operational boundaries. Organizational boundaries determine the operations owned or controlled by the reporting company. Operational boundaries determine the direct and indirect emissions associated with operations owned or controlled by reporting company. It allows a company to establish which indirect emissions to include that are consequence of its operations. (WRI 2006, 7, 38.)

In the second step, quantification, the actual emissions from various sources are estimated. Emissions can be estimated by either direct measurements or calculations, and there are several quantification methods. Direct measurements are often expensive and limited to stationary combustion sources, and therefore not suitable for estimating emissions from investment projects. GHG emissions are usually derived from a calculation-based approach such as using mass balance basis specific to a source or process or by using documented emission factors. Most emission factors are averages of all available data of acceptable quality, and they generally are assumed to represent long-term averages for all facilities in the source category. They are generally more accurate for stationary and mobile combustion sources than for process, fugitive emissions, and waste sources, and often there are more than one emission factor available, some being more accurate than others are. Model developers should determine which quantification methods apply to the GHG sources covered by their tool and provide the best combination of accuracy and practicality. GHG inventory is ready when these two steps are completed. (WRI 2006, 7-8, 11, 21.) For estimation of investment projects' emissions, using the documented emission factors seems to be the most practical method.

Last phase, accounting, includes establishing a base year, tracking emissions and trends, and managing inventory quality. Base year is defined as a historic datum against which a company's emissions are tracked over time. It can be a specific year or an average of over multiple years. Inventory quality means the extent to which an inventory provides a faithful, true and fair account of an organization's GHG emissions. (WRI 2006, 7, 37-38.)

4.1.1 Effect of intended use

The intended use of and context of the calculation tool customization determines which quantification methods are relevant for achieving the intended goal. Uses for calculation tool can be divided for three categories: mandatory programs, voluntary programs, and internal business management. Most strict demand for rigorous quantification methods and compliance are in mandatory programs, which can be divided in to three classes: market-based programs, command-and-control programs and emission inventories. Most accuracy estimates or measurements are required in market-based programs, because they are essentially cap-and-trade programs for emission trading. Command-and-control-programs require entities to meet specific emission or operational limits, and need high-quality data to ensure that compliance is being fairly determined. Emissions inventories means that emission reports over a specific period of time are required, and data can be used as a preliminary step to developing specific emission reduction program. Therefore the need for accuracy is not as big as with other two mandatory programs. (WRI 2006, 14.)

Voluntary programs have various structures and are often created to prepare entities for future regulations. Choosing the appropriate estimation or measurement approach for such programs sometimes means balancing among ensuring business participation, measuring the effects of program, and meeting the long-term objectives, such as future data quality needs. The approaches presented to users are often more flexible than for mandatory programs, and users can decide how much accuracy in estimation or measurement approaches is needed. Third option for use, internal business management, is the most flexible one. Many companies develop internal mechanisms to track their emissions even though they are not reporting the emissions under a program, mandatory or voluntary. In these cases users can decide how rigorous estimation or measurement approaches are appropriate. (WRI 2006, 14-15.)

Companies are often want to track emissions and emission reductions over time. For that, the company needs to choose base year and draw up a base year emission recalculation policy. Customized sector-specific tool can provide significant guidance on both. (WRI 2006, 18.)

4.1.2 Stakeholder engagement

It would often be beneficial to engage stakeholders, such as companies, government bodies, industrial associations and not-for-profit groups in calculation model development. Including stakeholders in the customization of the calculation model ensures that it will be valuable for the intended users. Working with the future users of model while customizing it helps to create more effective model, and in addition builds capacity and momentum for the adaption and implementation by companies and other possible stakeholders. Stakeholders may be able to offer a useful perspective in the tool customization process and may have expertise or contacts that help the tool customization. In addition, they might provide resources for outreach and training on the tool. (WRI 2006, 2, 10, 28.)

Engaging stakeholders, in other words stakeholder process, is the organization of a transparent, open, and inclusive approach that engages multiple stakeholders in the development and eventual adoption of the customized tool. Stakeholder process creates more dialog among different types of stakeholders, and increases the model developer's understanding about how the sector and business operate. On the other hand, the tool developers have a chance to offer information and education regarding the calculation model, emissions accounting and quantification issues. Participating in the model development process, stakeholders may get a greater sense of ownership of the final product, and it purposes and applications. This often encourages the adoption and utilization of the model by business and relevant programs. The stakeholder process allows members from diverse communities, such as business and environment NGO's, to discuss their interests and expectations in a particular calculation tool. (WRI 2006, 28.) Despite these clear benefits, it is not always possible to engage many stakeholders in the development process. If model is developed for the use of one company, the customer might not want to share confidential information about their process to outside of the company. In these cases, it is still possible to benefit from stakeholder process by ensuring that future users and other company's employees are engaged in development process.

4.2 Principles in model development from GHG Protocol

GHG Protocol's standards give guidelines to accounting and reporting of GHG emission. One part of these guidelines are five accounting and reporting principles: relevance, completeness, consistency, transparency, and accuracy (WRI & WBCSD 2011a, 23; WRI & WBCSD 2011b, 19). These principles are the general guidance for the "spirit" to be followed in developing an inventory (WRI 2006, 2, 10), and they are also covered in previously mentioned guidebook for designing customized calculation tool. They are defined quite similarly in all three standards utilized in this study. Because calculation model should be in harmony with GHG Protocol, it would be reasonable to follow the same principles in model development too. Next, these principles are introduced and it is discussed how it can be ensured that model is consistent with them.

4.2.1 Relevance

A relevant GHG study is a study that serves the needs of the intended user, containing all the information that users need for their decision making. Principle of relevance should be used when the activities that are included or excluded from inventory boundary are selected. It also helps to decide data sources: data quality should be sufficient to ensure that the inventory is relevant to the company. Selection of data sources depends on a company's individual goals and needs. If the intended use of results is only to get broad idea of company's emissions, GHG inventory can be much less accurate than if results are used in carbon trading and still remain relevant. (WRI & WBCSD 2011a, 23-24; WRI & WBCSD 2011b, 19.)

Relevance of emission estimation could be ensured by including all possible emissions occurring from supply chain without leaving anything out from model. Obviously, this option would require huge amount of data and exhausting amount of work, which, in business world, is often equal to money. It is not realistic option to include everything in companies that have tens or hundreds products, especially if products are customized for every project. For companies starting the GHG calculations and those who have no stable production, better option could be that they carefully select the most important stages in the supply chain stages or the most important products, and start model development focusing on them. Later, when more experience is gained, it is easier to expand the model to cover more products or supply chain stages.

4.2.2 Completeness

Completeness means that the emission inventory appropriately reflects the GHG emissions that are estimates, serving the decision-making needs of users. Companies should not exclude any activities that would compromise the relevance of the results. If some exclusions are made, it is important that they are documented and justified. In case some emission assurances are given, the providers of assurance can determine the potential impact and relevance of the exclusion on the overall inventory results. (WRI & WBCSD 2011a, 23-24; WRI & WBCSD 2011b, 19.)

Completeness is ensured if the inventory report covers all product life cycle GHG emissions or supply chain stages within the specified boundaries. Any significant emissions and reductions that have been excluded from calculation need to be disclosed and justified. Utilizing previous emission inventories might help to define the important supply chain stages and emission hotspots that need to be included in inventory to ensure completeness.

4.2.3 Consistency

Users of GHG information typically track emissions information over time in order to identify trends and assess the performance of the company, and consistency allows meaningful comparison of a GHG inventory over time. The consistent application of accounting approaches, inventory boundary, and calculation methodologies is essential for producing comparable data over time. If there are changes to the inventory boundary, for example previously excluded activities, methods or data are included, they need to be transparently documented and justified. After changes, also the base year emissions might have to be recalculated, especially if the inventory boundary has been changed. (WRI & WBCSD 2011a, 23-14; WRI & WBCSD 2011b, 19.)

In model development, principle of consistency should be taken into account in documenting data sources. For example, the GHG emission factors for electricity production may change a bit every year and workplace where system is produced might move towards more energy-efficient direction. If model does not contain information about year when data was collected, it can give false results after couple of years of use. To ensure consistency the data in calculation model should be easy to update and updates easy to document.

4.2.4 Transparency

Transparency relates to the degree to which information on the processes, procedures, assumptions and limitations of the GHG inventory are disclosed in a clear, understandable, factual, and neutral, manner, and based on clear documentation. A transparent report will provide a clear understanding of the relevant issues and a meaningful assessment of emissions performance of the company under the study. Transparency is ensured by addressing and documenting all relevant issues in a factual and coherent manner. Any relevant assumptions should be disclosed and appropriate references to the methodologies and data sources used should be made. Information should be recorded, compiled and analyzed so that internal reviewers and external assurance providers are able to attest the credibility of information. Clearly, explaining any estimations and avoiding bias ensures that the report faithfully represents what it purports to represent. As mentioned previously with other principles, exclusions need to be clearly identified and justified, and appropriate references provided for the methodologies applied and the data sources used. The information should be transparent enough to enable someone external to the inventory process to derive the same results if provided with the same source data. (WRI & WBCSD 2011a, 23-25; WRI & WBCSD 2011b, 19.)

From model development point of view transparency means that information about assumptions, system boundaries, data sources etcetera should not be in separate document in the reach of only model developer. This type of information should be available for users of model and also those that will be using the results – as in large, global companies the results can be used by tens of employees. It might be ideal that the information is shown in the model itself, so anyone using the model could see where the results come, and estimate how reliable they are.

4.2.5 Accuracy

Accuracy means that reported emissions and removals are not systematically greater than or less than actual emissions and removals. Uncertainties should be reduced as far as practicable. Sufficient accuracy of results allows users to make decisions with reasonable confidence as to the integrity of the reported information. Estimated data should be as accurate as possible to guide the decision-making needs of the company and ensure that the emission inventory is relevant. Improving accuracy over time and reporting on measures taken to ensure accuracy helps to enhance transparency and promote credibility. (WRI & WBCSD 2011a, 23-25; WRI & WBCSD 2011b, 19.)

Emission factors are commonly used as an estimation approaches. Once developed, they are the least expensive option. In case company wants to use site-specific emission factories to increase accuracy, it might need to use some money to perform measurements. (WRI 2006, 25.) In any case, there is often need for compromise between accuracy and practicality. The more rigorous data is used, the more time consuming it usually is to collect. There should not be many parameters in calculation model if it is wanted to be simply and easy to use. However, in complex systems such as investment projects there are many variables. The more variables there are, the more parameters are needed to handle them in model, but practicality of model decreases when the number of parameters increases.

Considering geographic content increases both accuracy and relevance of the model and it is significant objective of many customizing projects. Geographic circumstances can affect a number of elements in a calculation tool, such as which emission factors to use and which emission sources to include. Companies operating in different countries might use different technologies and local regulations are rarely same. Model could be done more user-friendly by making country-specific defaults for example for energy production or steel making process. Likewise, some emission sources might be excluded if they are not relevant. (WRI 2006, 2, 10, 13.) However, country-specific information is not always available and thus cannot be utilized.

4.3 Other requirements

In addition to five principles listed earlier, other principles can be added by the customizing of GHG accounting tool. Issues, for example uncertainty and materiality thresholds are examples of when such principles might need to be considered. Guidance on quick and rough estimations may be helpful when it is decided whether a source will be material and should be included in the GHG inventory. (WRI 2006, 2, 15.) When model is developed for investment projects' emission calculation, principles of accessibility and scalability come into mind.

4.3.1 Accessibility

As stated in chapter 2.2, companies should prioritize data collection to make it effective. One option for prioritizing was to use initial GHG estimation methods to estimate the emissions from its activities (WRI & WBCSD 2011a, 66). Because there are limited amount of information available about emissions from industrial investment projects, it would be hard to use industrial-average data for the estimation. However, company might have some projects that are somewhat similar with each other. Using some previous projects as a baseline project and including all possible activities in the GHG calculation would give company knowledge about emission hotspots, and results would help to focus on the most important activities in data collection for actual calculations and model development.

The calculation model should be easy to use and understand. People who are using the calculation model might not have deep understanding about GHG calculation or life cycle assessment, and therefore it must be ensured that model is suitable for them too. Calculation model that is hard to use would not stay in use. Accessibility is even more important when calculating investment projects, as they are rarely similar and parameters in model needs to be modified. In addition, the parameters or emission factors in model need to be updated time to time: new manufacturing technologies might be adapted and average emissions from energy production might change. It should be easy to update the model, and the date when data has been changed should be clearly visible.

4.3.2 Scalability and formability

Global investment projects are seldom similar with each other. Therefore, suitable model would be scalable and easy to modify for different projects. As previously was discussed, geographical location, modes and distances of transportation, and large range of different materials all have their effect to GHG emissions of investment projects. Model should be made so that these variables are easily modified.

Range of different types of materials can be large, and defining each material separately to model would be quite time consuming. Varying recycling contents and origin of the materials also increase the number of materials needed in model. However, it might be possible to classify materials into several groups, based on their material content. This would simplify calculation. Industrial systems can have typical material composition, which can be utilized in model. If typical shares of each materials are included in model so that “base system” weight one unit (mass or kilogram), model can be scaled by simply multiplying base system by mass.

Depending on the workshop, it can be sometimes assumed that manufacturing aspects, such as electricity, fuel and water consumption and waste production are same per one ton of product. Therefore, it could be possible to define coefficient for these variables, and then simply multiply the variable with total tons of the product. Taking geographical location of the workshop into account increases both accuracy and formability of model.

4.4 Utilization of life cycle thinking in model development

In chapter 2 the similarities between supply chains and life cycle of systems delivered in investment projects were discussed. It might be possible to utilize life cycle thinking in model development. For example relevant supply chain stages can be defined by taking a look to life cycle assessment with similar products. System boundaries of investment projects may be the same than in cradle-to-gate approach of LCA. However, performing full LCA that follows relevant ISO standards for large global project would be enormous process. In addition, defining functional unit would be challenging in projects where product can be some part or even whole of the modern mill. LCA with cradle-to-gate approach focusing only to GHG emissions would be quite abridged version of LCA. It seems that calculation model could be inspired by LCA but it should not be defective copy of that.

4.5 Implementation of the model

After model have been developed or customized to certain industry, the next step is deciding on the guidance to be provided for accounting and quantification. Discussion of the broader GHG accounting issues in the guidance portion of the model can simplify the development of a company's GHG inventory by consolidation of all the information in one document. Model can offer sector-specific guidance on issues, such as which sources can be probably be disregarded during the inventory. Guidance for the use of model should include definition of setting organizational boundaries, defining operational boundaries, tracking emissions over time, identifying and calculating emissions, managing inventory quality, and reporting emissions. (WRI 2006, 2, 16-17.)

New calculation model should also be road tested. A road tester is a representative company or companies that are willing to test a draft of the model to develop a GHG emission inventory. During the road testing tester can address issues in the model, such as difficulties to collect data or understand the model. While road testing usually takes place after the draft of customized model has been completed, road tester brought in at the beginning of the model customization process can also help with the design of model or act as the sector expert. (WRI 2006, 29.)

The final step is to ensure that the users will adopt the model and that it is relevant to them. One way to do this would be organizing launching event for stakeholders, and continue with follow-up trainings to model use. Launching event provides opportunity to discuss with the stakeholders about the merits of the tool. The Tool Guidebook provides also advices how to organize successful launching event. (WRI 2006, 2, 31-31.)

5 DEVELOPMENT OF EMISSION CALCULATION MODEL

In this chapter, the model development process is explained. A large old investment project, Project 1, was utilized as a base project for development process. First, the boundaries and systems to be included in model development were selected. Second step was data collection, followed by the actual model development phase. Data collection and model development were based on the findings of the most relevant supply chain stages previously in chapter 2. Results from emissions inventory of Project 1 are presented in chapter 5.4. Lastly, the sensitivity analysis of model is carried out.

The importance of stakeholder engagement was discussed in chapter 4.1. In this development project one stakeholder, the intended user of model, was strongly part of the project. This helped to customize model for the user, as Company offered perspectives and recommendations for the model. Engaging the main stakeholder in the process ensured that model will be suitable for intended use and it will be valuable for the intended users.

5.1 Selection of the boundaries

Organizational boundaries determine the operations owned or controlled by the reporting company. In this study Company wanted to identify its supply chain emissions, which are caused by its operations but not necessarily in its control. For example manufacturing of product by supplier is caused by customer company's operations but customer has very limited possibilities to affect to electricity consumption of manufacturing. Therefore in this study all operations caused by Company's activities are inside the organizational boundaries.

Defining operational boundaries was based on the theory about supply chain emissions and scope 3 emissions in chapters 2 and 3. As mentioned before, the scope 3 emission categories presumably relevant for industrial investment projects are purchased goods and services, upstream and downstream transportation, fuel- and energy related activities, waste generated in operations, and business travel. The most relevant stage was estimated to be purchased goods, which includes raw material accusation, processing of materials and manufacturing. It was decided to treat raw material accusation, processing of materials and manufacturing as their own stages to show their effect on emissions mode detailed. Transportation of goods was found in some studies to cause notable emissions and therefore all transportations that were known were included in model. Only foreground processes were manufacturing in Company's own workshops and transportation of systems to customer's gate. All other processes were background processes in which Company has very limited possibilities to affect. In order to keep model simple enough it was decided to use four main stages for model. Stages included in model are illustrated in figure 15. It can be seen that there are many similarities between intended calculations with model and LCA. However, while this model was influenced by LCA, it will not perform like a full LCA. With cradle-to-customer's gate approach and focusing only one environmental impact, this study is more like a first move towards a proper life cycle assessment.

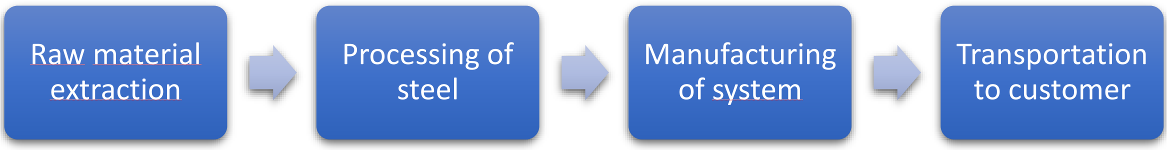

Figure 15. Main stages included in calculation model. Manufacturing and transportation of systems are foreground processes, and raw material extraction is background process. Processing of steel can be foreground or background process depending on how much Company had effect on the process.

Beforehand it was planned to include also business travelling into the model, as there is always a lot of travelling during Company's investment projects and it is one of the scope 3 emission categories determined by GHG Protocol. However, the system where data about business travel is gathered was not yet in use during Project 1. In addition, as discussed in chapter 3 business travel usually causes relatively low emissions. For these reasons business travel was left outside of the scope. Emissions from use phase and end-of-life of delivered systems were decided to left outside of boundaries because the Company determines that those phases are in customer's scope.

5.2 Selection of systems included in calculation

It was decided to select some example systems to be base for the model development, and later expand the GHG calculations and model when more experience and information are gained. The Company delivers hundreds of different systems, and there was a lot of discussion about which systems would be the most representative for model development. It was agreed that example systems should be made from different materials and produced in different countries, and company’s own production and engineering as well as systems coming entirely from suppliers should be represented. This way larger variety of materials and transportation distances would be covered. For the Company’s purposes especially production in China and Finland needed to be included, as big portion of Company’s own workshops and suppliers operate in these countries. One criteria was system’s mass: if system has relatively small mass compared for other systems, it might not give representative results. Six systems were selected for the first calculation.

System 1 is Company’s own production, and the information about production is well available. It is almost always made in Finland. System is composed from two main materials: basic steel and Duplex-materials.

System 2 is Company’s own engineering, but it is produced by supplier. In the Project 1 the system was made in Finland and was mostly made from basic steel. Information about materials is well available, but not so much is known about production process.

System 3 is the largest system with tens of sub-systems and mass of several thousand tons. Sub-systems are produced and transported individually, and the assembly of System 3 is done on mill site. The sub-systems are produced in different locations, both in Company’s own workshops and supplier’s workshops. Engineering is mostly done by Company. Large variety of materials are used, and Company had determined materials and their thickness. Availability of information about production varies: Company’s own production and used materials are well known, while not so much is known about production in China.

System 4 is produced and engineered entirely by supplier. Information about its materials and production might be quite difficult to get.

System 5 and System 6 were engineered by Company and produced by the same supplier. Material composition of both systems was known.

5.3 Development of the calculation model

The purpose of this study is to develop a model, where it is possible to input the weight of the equipment and get GHG emissions as output. Calculation model should be simple enough to be used by almost anybody without the need of deeper understanding about LCA.

5.3.1 Data collection

First step was collection of data. Collection started with purchase plans and part lists of all three products. Different parts were classified to subclasses, and then classified according to production companies. During this, the components that were excluded from model development were selected. These exclusions are justified later in this chapter. Next step was to find out the materials and actual masses of components, which proved to be challenging as some data was not available. After all available data about components' materials, masses and producers were found in sufficient accuracy, transportations from production places to mill were mapped.

Model development was based on the Company's own documents about materials and production, mostly on purchasing plans, shipping plans and material documentation. For System 1 and 2, Company's internal experts were interviewed. It was soon noticed that the level and availability of data differed from system to another. This made it challenging to handle data collection from all four systems similar way.

As stated before in chapter 2.2 that companies should collect primary data about foreground systems, on the other words all processes that are under their ownership or control. It is arguable if suppliers' operations are under Company's control. While suppliers have their individual operations, Company gives them some requirements about products purchased by the company, for example about the materials used. Without any data from suppliers, the GHG calculation would be based almost entirely on secondary data from databases and results would not be not be satisfying quality. Therefore Company wanted to collect primary data from its suppliers.

Data collection from companies was planned to have two phases. In first phase, companies would answer to written inquiry about their sustainability in general, and emission data about specific product. First part of inquiry considered supplier's overall view of corporate sustainability, their supplier management and management of GHG emissions. Second part of inquiry actual data about energy consumption, material use, recycled metals used and carbon footprint of products was asked. Inquiries were sent to supplier of System 4 and supplier of System 5 and System 6 by e-mail.

Suppliers did not answer all of the questions, mainly because they did not measure data that was asked. Therefore it was impossible to include some aspects about manufacturing to the calculations. Exact material composition and recycling content of materials remained unknown for few systems hence average values needed to be used for them. The supplier of System 4 answered to question about the amount of recycled materials used in the steel, but did not give other information about System 4. Supplier of System 5 and 6 answered to questions about manufacturing, and reported consumptions of electricity, heat, liquefied gas and water, and amount of waste generated during manufacturing. Origin of the materials and share of recycled steel used in materials remained unknown. In the table 5 the aspects known for each system are illustrated. It can be seen that there are significant differences between systems. After supplier inquiries were finished, data collection was ready.

Table 5. Available information of each systems. Green color indicates that data was well available, yellow that some data was known and red that no data about that aspect was available for calculations.

	Materials used	Recycled content of materials	Origin and transportation of materials	Manufacturing data	Waste from manufacturing	Transportation to customer
System 1						
System 2						
System 3						
System 4						
System 5						
System 6						

While all systems weighted tens of thousands kilograms, they all contained much smaller parts. Therefore it was reasonable to make some exclusions. All systems were handled separately, as their masses and specificity of data were different. Data about System 1 was quite rough and it was more estimation from engineers than exact production data. This was agreed to be satisfying, because regardless the project the material composition of System one remains almost the same. System 1 is mainly composed of four main material groups, and it was estimated that other materials used for smaller parts like seals and tubes form so small portion of the system that they can be excluded from model without having an impact on results.

System 2 contained a lot of small parts such as screws and nuts yet only few larger parts. Exclusion was first planned to do based on the mass of the part, and only include parts with mass of 1% of the total mass. However, it was noticed that this would exclude too many sub-systems and thus simplify the calculation and lower the accuracy too much. It was then decided to include all parts weighting over 0.1% of total mass. This exclusion simplified model development enough to be practical without leaving too many sub-systems outside.

Exclusion of parts of System 3 was long process and was done gradually. First components excluded were those that have no actual effect on functionality of the System 3: stairs, doors, windows, elevators and safety equipment. These parts are always designed and produced outside of the Company and it was estimated that Company have only little effect on the environmental impact of the production of these parts. After that, the parts with small mass were sorted out. Mass limit was decided to be 0.02% of the total mass of System 3, 1 000 kg, because results without parts lighter than 1 000 kg would still be very accurate. Higher mass limit, such as 1% of the total mass would leave some important sub-systems outside of the model. As there was dozens of parts with mass only some tens of kilograms, these exclusions simplified model development considerably without compromising accuracy.

System 4 came entirely outside of the Company, and there were no separate equipment to model. For this reason no exclusion of parts was needed. However, there were more specific information about transportation. System 4 was transported with five different shipments, but two of them covered under 0.1% of the total mass of the system. In addition, these two shipments were much shorter distance transportations than the three bigger shipments.

Because of these aspects it was estimated that excluding these shipments would not lower the accuracy of the results.

Systems 5 and 6 were entirely manufactured and designed outside of the Company. Neither of the systems contained subsystems. All materials used for production of System 5 and System 6 were included. Workshop where these systems were produced is located so near of the harbor where they were transported by trucks, that this first truck transportation was excluded from model. Shipments and truck transportation from harbor to mill site were included in model.

5.3.2 Development of the calculation model

It was decided to utilize life-cycle assessment tool for model development, and for that openLCA software from GreenDelta was found suitable. OpenLCA was chosen after prices and usability of several software were compared. Usability of software was considered main factor because it has strong impact on the accessibility of model. It was chosen to use Ecoinvent database as a main data source, because Ecoinvent was already used in estimation of Company's Scope 1 and 2 emissions. Impact assessment method used was CML (baseline) [v4.4, January 2015] and normalization method used was EU 25 [year].

To understand how model development and model itself works, some background info about openLCA is needed. OpenLCA has four stages: flows, processes, product systems, and projects. Flow is the base of the system, products and materials. Input flow can be for example material, electricity or sub-system used in production process, and output can be the system produced or emissions to air. The amount of flows can be typed in to system as values, formulas and/or parameters. Parameters are divided into three class: global parameters, input parameters, and depended parameters. Global parameters can be found and are valid on all levels. Input parameters are usually defined as simple value and they are only valid for the process in which they are saved. Depended parameters are defined with other parameters, and they include either input or global parameters in their formula. Types of parameters are illustrated in figure 16. Process is defined as production or modification of products and materials. Product systems are process networks that are necessary to calculate inventory results and impact assessment, and are equal to life cycle model of a product.

Projects can be created to compare product system variants. (GreenDelta 2017, 32, 44-45, 56.)

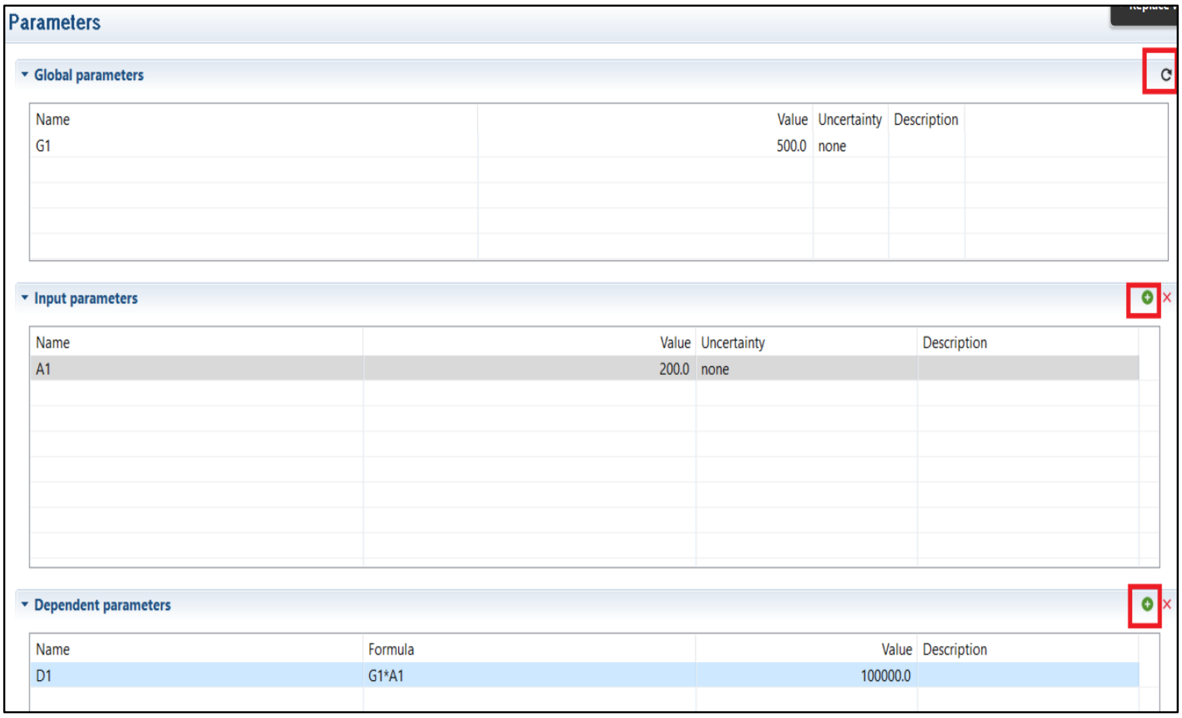

Figure 16. Parameters in open LCA (GreenDelta 2017, 46).

Material production was assumed to be the biggest source of emissions and therefore most emphasis was on that stage. Products under the study are mainly made from different metal materials, especially steel. Around 50 different steel grades were identified, and it was clear that modelling each one separately would be unnecessary slow and complicated process. As noticed in the chapter 3, recycling content of steel and amount of additional materials affect to the GHG emissions caused by steel production. On that account, steel grades were divided in 17 categories. Additional materials taken into account in this case were (Ni), chromium (Cr), and molybdenum (Mo), because they were only alloying materials with over 1% share. Composition of materials were defined in Company’s internal documents. There was challenges in collecting information about recycling content of materials hence it was decided to use global average. Therefore, for most steel grades recycling rate of 60% was used. Outokumpu (2019) states in its website that the recycling content of its products is over 80%, and therefore for Duplex-materials from Outokumpu the recycling content of 80% was used. Names of main categories and their compositions are listed in the table 6 below. In addition, origin of the steel was made possible to be selected in the model. For every steel grade, two options were made: Rest of the Europe (RER) or Rest of the World (RoW). If there was no information about origin of the material or product was made outside of Europe, RoW was selected. “Basic steel” grades are later referred as basic steel, and other steel grades as special materials.

Table 6. Metal categories.

Category name	**Ni %**	**Cr %**	**Mo %**	**Recycled content %**
Basic steel	0	< 2.5	0	60
Basic steel, 80%	0	< 2.5	0	80
Basic steel, 97%	0	< 2.5	0	97
Steel 1	42	21,5	3	60
Steel 2	0	10	1	60
Steel 3	0	4	1	60
Steel 4	20	21,5	3	60
Steel 5	10	18,5	0	60
Steel 6	12	17,5	2,5	60
Steel 8	0	18	0	60
Steel 9	31	27	3,5	60
Steel 10	5,5	22	3	60
Steel 11	18	20	6,1	60
Duplex 1	5	22,5	3	80
Duplex 2	4,5	23	0,3	80
Duplex 3	7	25	4	80

Ecoinvent database was used as a data source for material production. Only exception of this is production of molybdenum, which was not found from database. For modelling molybdenum production, LCA database from International Molybdenum Association (IMOA) was received and used. During the data collection only the amount of metal that was in the finished system was taken into account, and material losses during manufacturing were not considered. Data about material losses was scarce and not available for most of the systems. Including some average factors for material losses during manufacturing might have complicated model unnecessarily as material losses are unlikely to be same for all materials and systems.

There were many transportations during project, because vast majority of the parts were produced in different continent than the mill was located. They were quite challenging to map, as there was available data only about main shipments. Initially transportations were planned to be mapped for each equipment separately, to ensure that the data is as accurate as possible and model is detailed. However, this appeared to be challenging and time consuming as parts from same equipment were in different shipments, and in same vessel there were many parts from different equipment. Calculation this detailed would have required a lot of unpractical allocation, and allocation should be avoided according to standards and guidelines used in this study. There were no information about exact transportation distances, and therefore average values had to be used. It was decided that route data from website Ports.com (2018) would be accurate enough. Emission factors from VTT LIPASTO (2018) database were used to calculate GHG emissions from shipments. All shipment routes used during example project were added to model as a base shipments so that the distance and emissions from transportation one ton of product were already included. This way emissions from shipment could be calculated by multiplying base shipment by mass of the transported system. Users do not need to add kilometers to model every time by hand. This is illustrated in figure 17 below. First, shipment for example to Hamburg is selected as an input flow, and then “provider” is selected to be the route from harbor of departure to Hamburg. There can be hundreds of shipments during one investment project but they often use same routes. In the Project 1 there was only 4 destination harbors. For these reasons creating base shipments saved a lot of time.

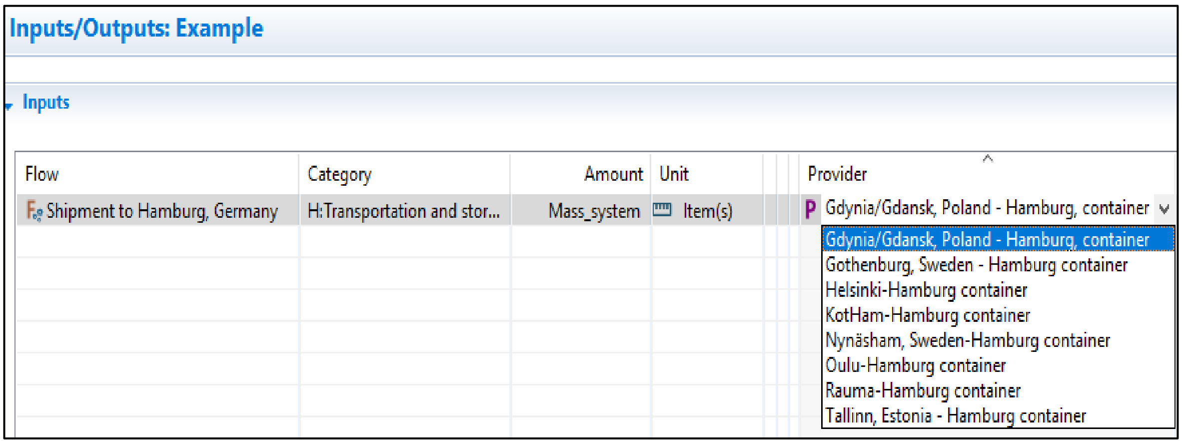

Figure 17. Example of modelling shipments. Harbors are example harbors, not actual ones from Project 1.

Truck transportations were modelled by using Ecoinvent database values. There are two options for the geographical location of road freight processes: Rest of the Europe (RER) and Rest of the World (RoW). In transportations known to happen in Europe the RER values were used, and for other transportations RoW values were used. It was assumed that most of the trucks used were not compatible with the newest EURO emission standard, and therefore the EURO 3 emissions standard was used. As illustrated in chapter 3, the emissions standard class did not affect to GHG emissions significantly and therefore this assumption is not likely to affect to the results too much. The size of the truck was selected case-by-case.

Most of the transportation in the Company's projects is done by ships and trucks, but sometimes some air freight is also used. In the Project 1, air freight was used only for two subsystems of System 3. They were modelled with Ecoinvent database project for intercontinental flights (RoW). For the estimation of distance ICAO's Carbon Emission Calculator (2016) was used, yet it was difficult because exact route was not known and there were not enough options for airports in that calculator. Therefore there is quite much uncertainty in the distance and therefore in the model.

Electricity consumption was assumed to be the most important aspect of production of equipment, as production of electricity causes a lot of GHG emissions. Unfortunately, there was very little data, primary or secondary, available about electricity consumption during production. Electricity data was known for Company's own production, System 1 and two sub-systems of System 3, and also for systems 5 and 6 from supplier. It was estimated that the System 1 production for the example project of the total production contained 30-40% of that year production in the workshop. It was decided to allocate 35% of energy consumption in that year to System 1. For the model development, the electricity consumption of the System 1 was divided by the mass of System 1, and thus the electricity consumption per one ton of production was found. Electricity consumption for two sub-systems of System 3 that were produced in Company's other workshop, were estimated similarly: their production was around 25% of the whole year production, and 25% of year's electricity consumption was allocated to those systems. Electricity consumption per one ton of product for System 5 and 6 was received from supplier interviews. Emission factors from Ecoinvent database were used for electricity production. The accuracy of the factor for electricity production in Finland was checked to be in line with Motiva's (2019) CO_2-factor. Other emission factors were not verified in this case.

Other production data available from own workshops and production of System 5 and 6 were the amount of water consumed, amount of fuels such as propane and diesel consumed, and the waste produced. These flows were allocated in similar way than electricity for System 1 and sub-systems of System 3 produced in Company's own workshops. Supplier of System 5 and 6 reported data in unit per one ton of product hence the consumptions and waste generated were only multiplied with the mass of system. For these aspects the ready processes of Ecoinvent database were used.

Waste flows from workshops producing System 1 and sub-systems of System 3 were industrial waste, paper and cardboard, plastic, wood, and hazardous waste. Wood, industrial waste and hazardous waste were transported to energy-to-waste power plants, and other wastes were recycled by various industries. Transportation of waste was modelled with EURO 3 lorry weighting over 32 tons. Waste flows known from production of System 5 and System 6 were metal waste, industrial waste and hazardous waste. According to supplier, metal waste was recycled, but other information about waste management was not given. It was assumed that industrial waste and hazardous were both burned. Transportations of waste were left out because there was no information about them. Ecoinvent database emission factors were used for all waste management processes.

Manufacturing aspects were selected to be those environmental aspects that Company's own workshops already measured: consumption of electricity, consumption of other fuels, consumption of water and waste management including the transportation of wastes. Heat consumption of workshops were left outside of the scope of the study, because production of the systems did not have effect on heating of buildings. At the beginning of model development, manufacturing data and amount of waste were included in each system separately. After first test it was noticed that this would take a lot of time and in addition the share of manufacturing and waste of total emissions needed to be calculated manually. Therefore it was decided to make four processes for manufacturing: Production in workshop 1, Waste from Workshop 1, Production in Workshop 2 and Waste from workshop 2. Screenshot from Production in Workshop 1 is in the figure 18. The amount of each input is parametrized and depended on the mass of the produced system.

Inputs

Flow	Category	Amount	Unit	U	Provider
electricity, medium voltage	351:Electric power genera...	Ee	kWh	n	market for electricity, medium voltage | electricity, medium voltage | Cutoff, S ...
light fuel oil	192:Manufacture of refin...	LF	t	n	market for light fuel oil | light fuel oil | Cutoff, S - Europe without Switzerland
natural gas, vented	061:Extraction of crude p...	NG	m3	n	market for natural gas, vented | natural gas, vented | Cutoff, S - GLO
tap water	360:Water collection, trea...	W	t	n	tap water production, conventional treatment | tap water | Cutoff, S - Europe w...

Figure 18. Manufacturing data in openLCA.

Models for each system were developed individually. All models were created in a similar way, only expectations were caused by the complexity of the systems. For this reason, only the model development for System 4 is written down in this paper as an example. Model for System 4 was quite easy to develop due to lack of sub-systems and special metals. According to the supplier, the recycling content of materials used for System 4 was as high as 97%. New steel type, low-alloyed steel with recycling content of 97%, was created by combining 3% of converter steel and 97% of electric steel. It would have been ideal to use data about GHG emissions or electricity and material consumption during the production. However, the supplier did not measurements of this type of environmental data. Therefore it was only possible to create model based on the materials and transportations. Parts of the system 4 were shipped to the mill by five different routes, but two of them were excluded. Remaining shipments were one shipment from Europe to South America, and two shipments from China to South America. Based on the shipment plan, most of the transportation was done with big container ships, and the shipment processes created for bigger type of container ship was found suitable for modelling. There were also several truck transportations to and from the harbor. There was no data available about truck transportations to harbor of departure as exact production places remained unknown, but truck routes from harbor to mill site were known. It was assumed that because of the large size of System 4, mainly biggest trucks were used. For these trips process “lorry >32 metric ton, EURO 3, RoW” from Ecoinvent database was found suitable.

Development of model for System 3 differed from others because of its many subsystems. Calculation models were first made for each sub-system, which were then combined to a final system. It was noticed that all transportations need to be added manually to each sub-systems, leading to the problem that they could not be included straight to the calculation model. The simplified product system and system boundaries in model are illustrated in figure 19.

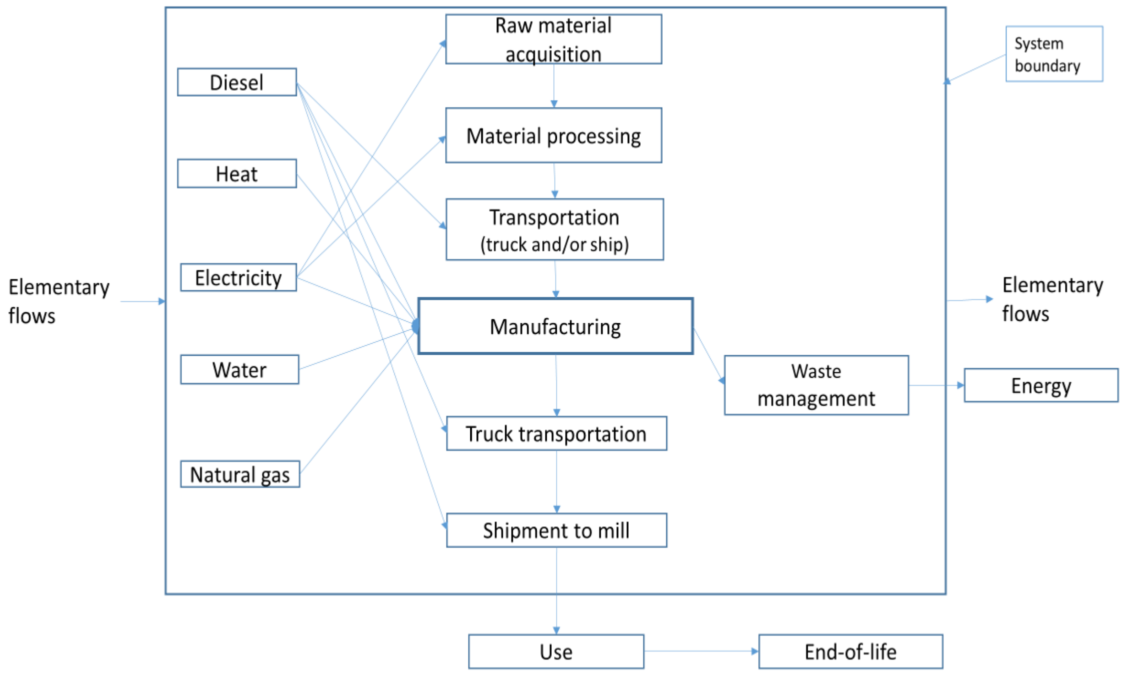

Figure 19. Simplified product system. Rectangle shows the system boundaries.

5.3.3 Presentation of the model

All calculation models were developed in the similar way. Model was first developed for System 1, and that model was then copied and modified to be suitable for other systems. On that account only final model for System 1 is presented here, and other models can be found in Appendix 1. First, process for each system production was created. In that process mass of the system was set as independent parameter, and both material composition and manufacturing data were set as depended parameters, as their amount is depended on the mass of the system. Transportation distances unique to that system were set as independent parameters, while transportation routes used often in example project were defined as global parameters that could be used in every system. Two of these global parameters were distances from harbors to mill site. Parameters for System 1 can be seen in table 7 and model graph in figure 20. Values of these parameters were used in the calculations are not presented in this paper due to confidentiality. Instead, they are market as coefficients. Because of the confidentially and the fact that there was tens of different harbors, they are not referred by names but simply as Harbor 1 (harbor of departure) and Harbor 2 or Harbor 3 (harbor of arrival).

Table 7. Parameters in model for System 1.

Parameter	**Type of parameter**	**Unit**	**Equation**
Mass of the system, M	Input parameter	t	-
Mass of basic steel, M_steel	Depended parameter	t	M_steel=M * x
Mass of Duplex grade 1, M_D1	Depended parameter	t	M_D1 = M* y
Mass of Duplex grade 2, M_D2	Depended parameter	t	M_D2 = M * y
Mass of Duplex grade 3, M_D3	Depended parameter	t	M_D3 = M* y
Production in Workshop 1, WS	Depended parameter	-	WS = M* z
Waste from workshop 1, W	Depended parameter	t	W = M * k
Distance from material supplier 1 to workshop	Input parameter	km	
Distance from supplier 2 to workshop	Input parameter	km	
Distance from workshop to harbor 1	Input parameter	km	
Shipments from harbor 1 to harbor 2, S	Depended parameter	t	S = M
Distance from harbor 2 to mill site, D_site1	Global parameter	km	

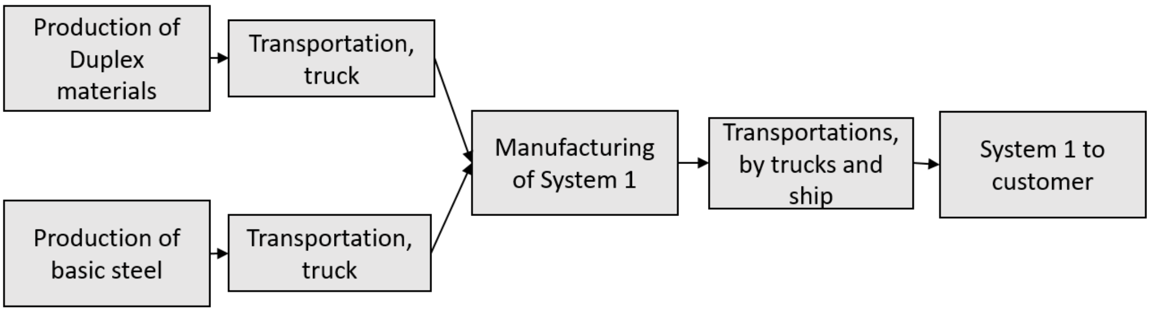

Figure 20. Model graph of System 1.

5.3.4 Changes after model testing

Test run was made with each of the systems. The test runs showed that the most important stage was material production, especially the production of special materials. Transportation with ships caused surprisingly high share of emissions in some systems (28%), while in some systems it was only 10%. Test run with System 1 showed that emissions from production in workshop were not significant: electricity consumption caused 4.4% of emissions, and other flows combined only 0.4%. Transportation of waste caused only 0.02% of total emissions of System 1, and it turned out that waste transportations were hard to model. System's 3 sub-systems showed similar results, and therefore it was decided to leave transportation of wastes out of the final model.

Electricity consumption was found to be the most notable source of GHG emission from manufacturing. Therefore it is important that the data used is accurate and updated regularly. Data about electricity consumption was received from workshop, but allocation method used for this study might not have been the best one. For future calculations with the model it would be recommended to receive electricity in unit kWh / ton of production instead of yearly consumption which was used this time. Emission factors for electricity production were taken from the Ecoinvent database. Although the values were similar than Motiva's values, they should be checked annually to ensure they reflect the real GHG emissions from country's or area's electricity production. It was also discussed if only electricity consumption would be taken into account from workshop flows, as other flows have so little effect on the results. These changes were not yet made during this study.

Modelling of other manufacturing, especially waste management, had similar problem than modelling electricity consumption. Modelling was not made in most effective way and after couple of test runs the process was simplified. Improvement of model was proved to be continuing process, and more changes might be needed for manufacturing process when model will be used for new investment projects.

Manufacturing in Company's own workshops were made as separate flows. This means that manufacturing location could not be changed in model but had to be known at the beginning of model customizing. There was no own manufacturing flow for supplier's workshops and data was added by hand. It was decided to combine manufacturing processes under one flow so that model would be simpler to use. This way it would also be possible to compare different manufacturers from emission point of view. New way to select manufacturing location is illustrated in figure 21.

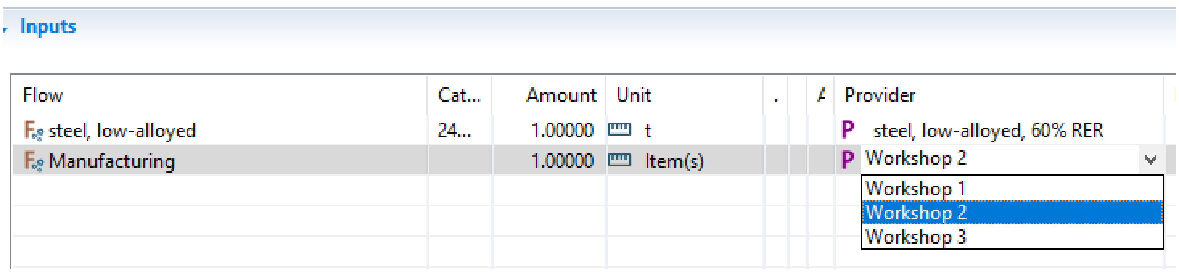

Figure 21. Changed way to select workshop were product is made.

Before first tests, all parameters were either input parameters or depended parameters. It was soon noticed that measuring transportation distances again every time model was modified took unnecessary time and effort. Routes that were most used during the project were chanced to be global parameters. For future projects it is recommended that the most used transportation routes are estimated before starting calculations, and then added to model as global parameters. This would increase the accessibility of the model.

5.4 Results from Project 1

GHG emissions from delivering key systems to Project 1 were calculated first. Total emissions from only this one project were substantially larger than Company's yearly Scope 1 and Scope 2 emissions have been. This showed that it is reasonable for Company to calculate also Scope 3 / supply chain emissions. Before calculations started it was speculated whether it would be possible to estimate all emissions from investment project by using single emission factor. This was researched by comparing emissions per one ton of system delivered. Emissions were allocated for one ton of system by dividing total emissions from delivering system with the mass of the system. The results showed that calculating emissions for whole project with some average value would not give accurate results. Emissions allocated to one ton of system were in same magnitude yet the biggest emission value was over double the amount of smallest value. The difference between emissions per one ton of system and average emissions per system are presented in figure 22.

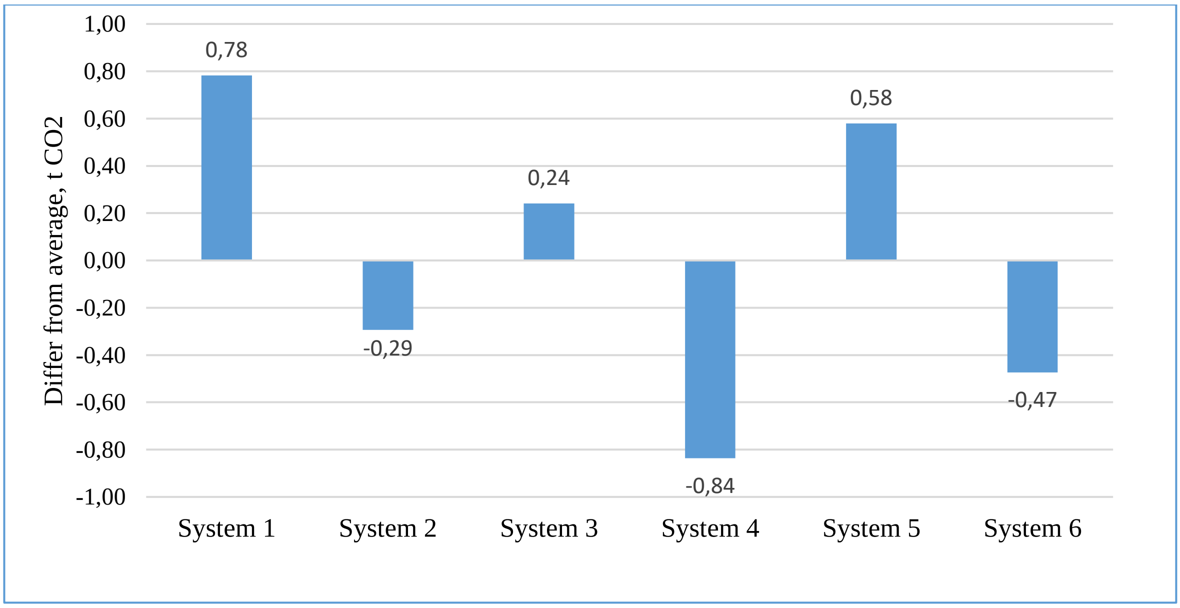

Figure 22. GHG emissions per one ton of system delivered.

It can be seen from the figure 21 that biggest emissions per one ton of system came from System 1. This is because high amount of special materials needed for production, and the availability of manufacturing data. System 4 had lowest emissions per ton due to high recycling content of materials and lack of special materials and manufacturing data. System 5 and System 6 had almost same emissions from manufacturing and transportation hence the difference in emissions came from materials used. System 5 contained both basic steel and alloyed steel (Steel 5), while System 6 contained only basic steel.

Due to varying nature of investment projects and the high effect of transportation distances to results, emissions from different industrial projects are too varying to be estimated simple way. However, if only manufacturing and material production were taken into account, it might be possible to use some average value for rough estimation. In any case, using one average value for each system would demand that system and its sub-systems are always produced in same manufacturing location.

Results helped to identify GHG emission hotspots in industrial investment projects. As can be seen in figure 23, production of materials is distinctly biggest source of emissions causing 68-88% of all emissions. Emissions from transportation of systems caused 11-32% of total emissions. Emissions from shipments are highlighted in results because distances that systems were transported with ships were so long compared to transportations with trucks. Transportation by plane was used only for two sub-systems of System 3 and mass of air freight was under 3% of mass of System 3. Despite this, it caused 10% of emissions from delivery of System 3. Even though the uncertainty of air transportation distances are high this results indicates that even small amounts of air freight must be included in emission inventories, because excluding it results to underestimation of GHG emissions. Results also address that more reliable and accurate data about flight routes and distances is needed for calculation of future projects. High uncertainty in a life cycle stage this significant can lead to low accuracy or even false results. Range of emissions caused by manufacturing was large, from 0.04% to over 10%.

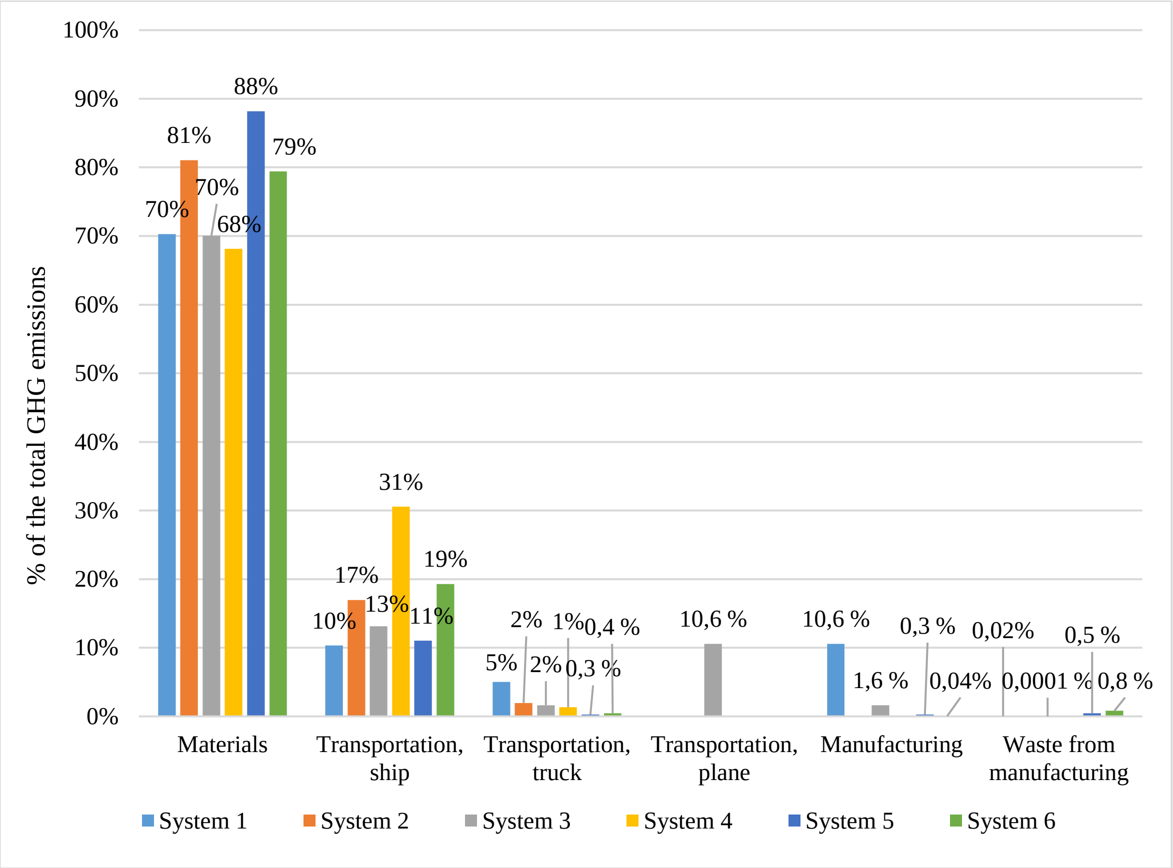

Figure 23. Share of supply chain stages of total emissions produced during example investment project, Project 1.

The importance of taking special materials into account is illustrated in the figure 24. Even though the share of Duplex-materials in the System 3 was under 40% of the system's mass, production them caused almost half of the total emissions. If calculation was made without taken special steels into account, the accuracy of results would be low. Including special steels in the model is one of the improvements of accuracy at the expense of accessibility in the final model.

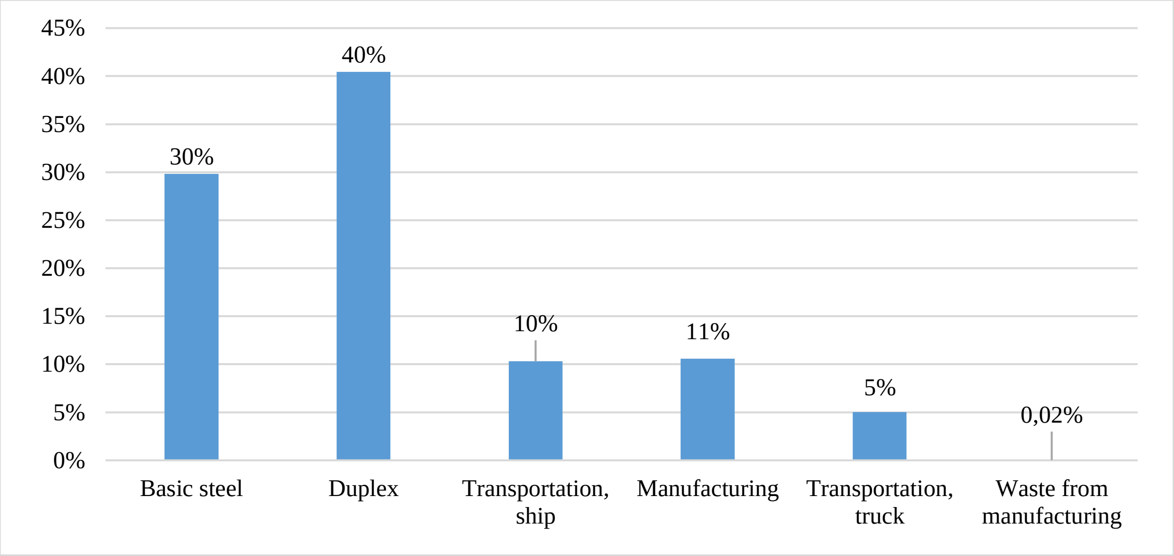

Figure 24. Share of emissions from delivering System 1.

5.5 Realization of sensitivity analysis

Sensitivity analysis was carried out to examine how much each parameter effects on results. One sensitivity analysis was done for each model, testing different parameter for each system. Sensitivity analysis was not done for waste parameters because of their small proportion of total emissions during this study, but might be carried out later. For this development project the uncertainty of parameters was not known, but it should be estimated for future project's data. Without knowing the uncertainty of data and how much each parameter affects to the total emissions from investment project, the accuracy of emission inventory is hard to estimate. "Projects" function of openLCA was utilized in sensitivity analysis because it makes comparing different scenarios effective.

Manufacturing caused 10% of the GHG emissions from delivering System 1. Manufacturing data is well available and quite simple to update hence it was interesting to see how much changes in it would affect to total emissions. Option 1 was situation in Project 1, in Option 2 all manufacturing aspects are 50% higher than in option 1, and in option 3 they are 50% lower than in Option 1. The results can be seen from the figure 25. Emissions from Option 2 were 5.5% higher than from Option 1, and emissions from Option 3 were 3.2% lower than from Option 1. This indicates that even greater uncertainty in manufacturing data would not affect to results dramatically.

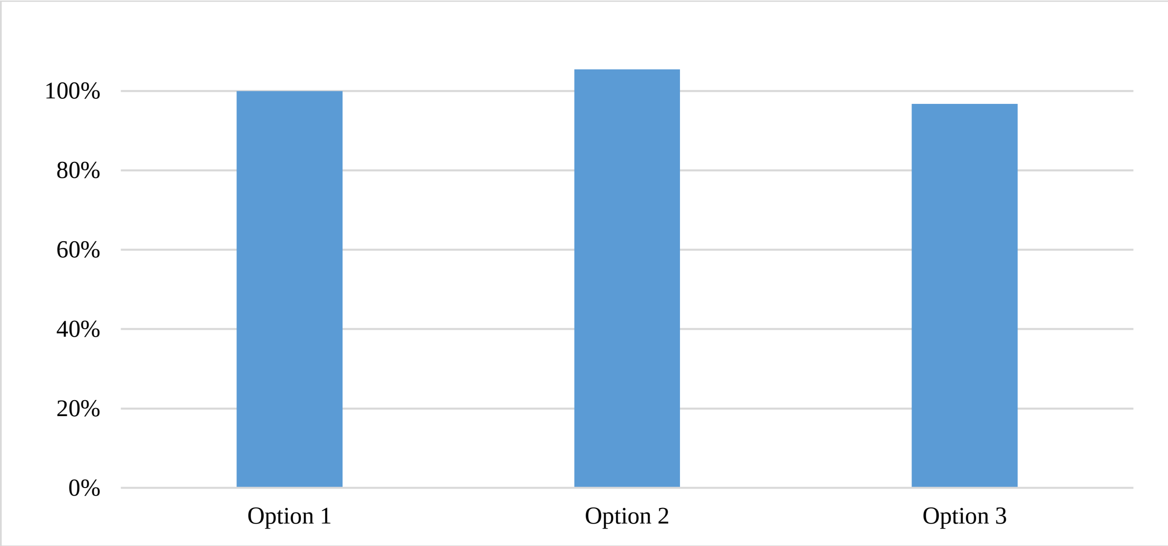

Figure 25. Sensitivity analysis of model for System 1.

Air freight caused 10% of emissions from delivering System 3 despite the small amount of transportations by plane. Therefore it was tested how increasing or reducing the amount of air transportation of one sub-system would affect to results. Option 1 is the actual case, in Option 2 mass transported by plane is doubled, reducing the mass transported by ship, and in Option 3 air freight is replaced with shipping. Despite the intention to carry out sensitivity analysis for whole System 3, it seems that the capacity of openLCA was not adequate for processing so many sub-systems. Therefore sensitivity analysis was done for only one sub-system of System 3. Air freight was used transporting 12% of total mass of the sub-system, yet it caused 53% of total emissions in Option 1. Results are presented in figure 26. In Option 2 emissions were 50% higher and in Option 3 50% lower than in Option 1.

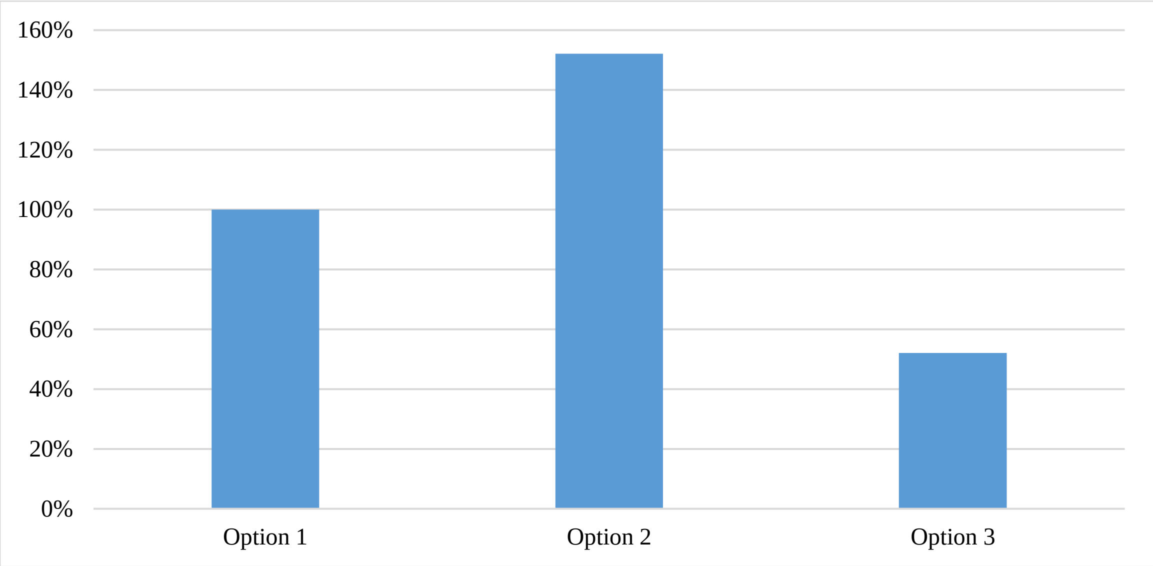

Figure 26. Sensitivity analysis of model for sub-system of System 3.

System 4 results showed that material production caused 68% of total $CO_{2eq.}$ emissions. Sea freight contribution was 31% and road transportation only 3%. The recycled content of metals used in production of System 4, 97%, was exceptionally high, and it is likely that lowering the recycling content the results will change. Therefore the sensitivity analysis for System 4 concerned recycling content. Results from System 4 (Option 1) were compared to the situation where the recycling content of metals is 80% (Option 2) or 60% (Option 3). The results can be seen from the figure 27 below. It can be seen that GHG emissions from Option 2 are 21% higher and emission from Option 3 47% higher than the emissions from Option 1.

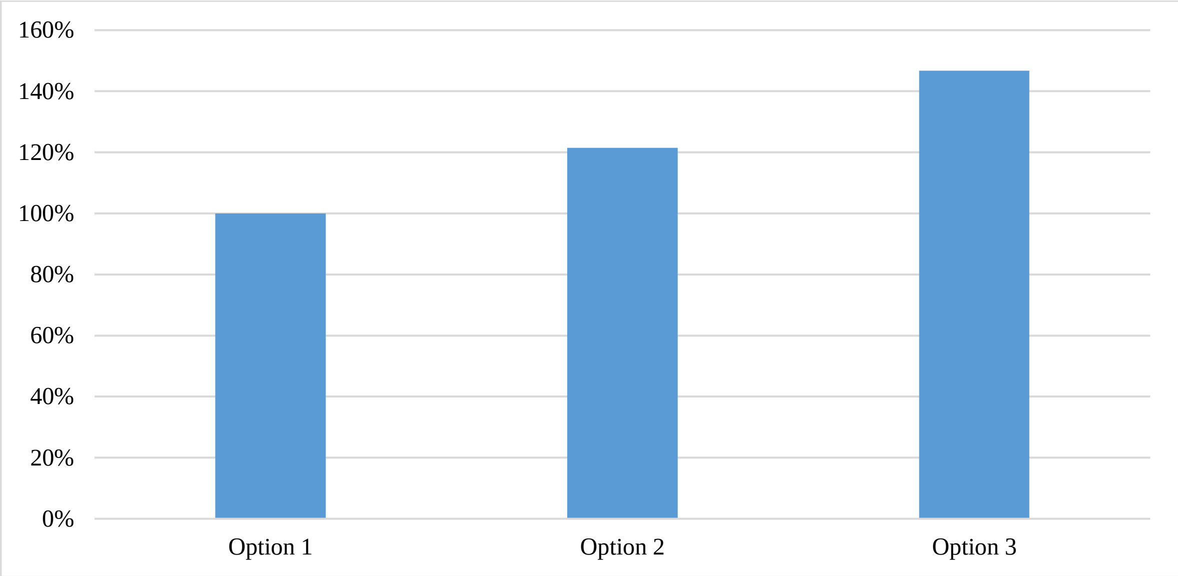

Figure 27. Sensitivity analysis of model for System 4.

System 5 contained both basic steel and Steel 5, and production of them caused 88% of GHG emissions from System 5 delivery. There was also some uncertainty about the amounts of these materials. Therefore it was tested how increase or decrease of the amount of Steel 5 would affect to the results. In Option 2 amount of Steel 5 increases 20%, and in Option 3 it decreases 20%. The results can be seen from the figure 28. In option 2 emissions were 8.4% higher and in Option 3 8.4% lower than in Option 1. While this is not radical difference, it indicates that high uncertainty in material composition would most likely lead to inaccurate results.

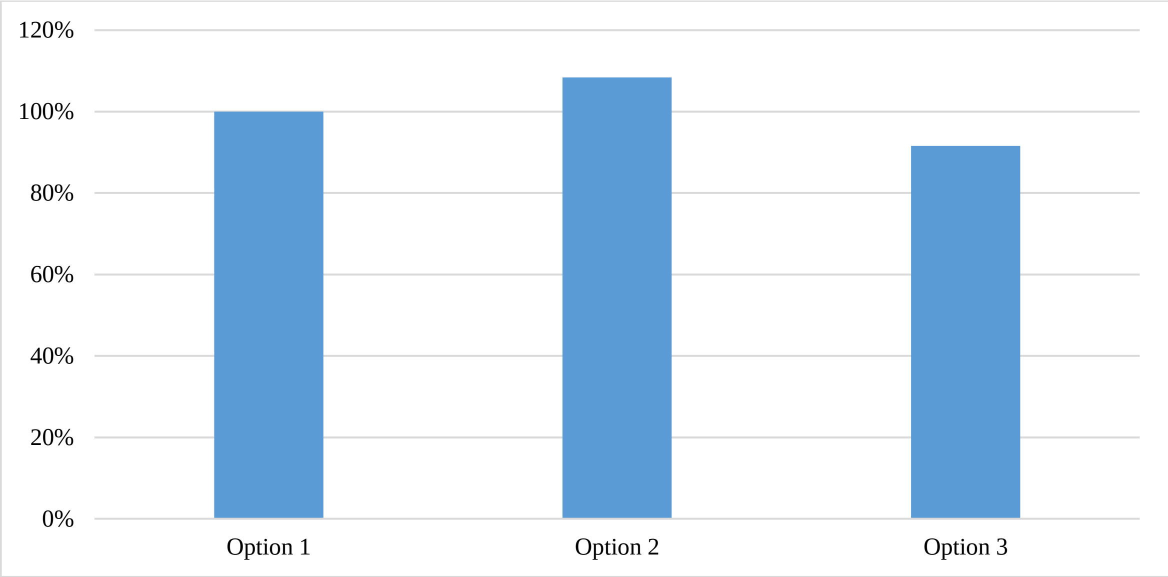

Figure 28. Sensitivity analysis of model for System 5.

The amount of special steels was low in System 2, and there was no manufacturing data available. Quite similar situation was with System 6: no special materials, and effect of manufacturing to total emissions was low. Therefore it was chosen to test effect of shipping distance to the results of both systems. Option 1 is situation in Project 1, in Option 2 shipping distance is 20%, and in Option 3 it is 20% or shorter than in Option 1. Both systems were shipped so long distance that 20% uncertainty in distance means difference of 3000 km. The results can be seen from the figure 29. Changes in shipping distance affected a bit more to System 6 than System 2, but in both systems the effect was pretty low, around 3-4%. This indicates that while transportation has clear effect to total emissions, the uncertainty of distance would not affect to emissions dramatically.

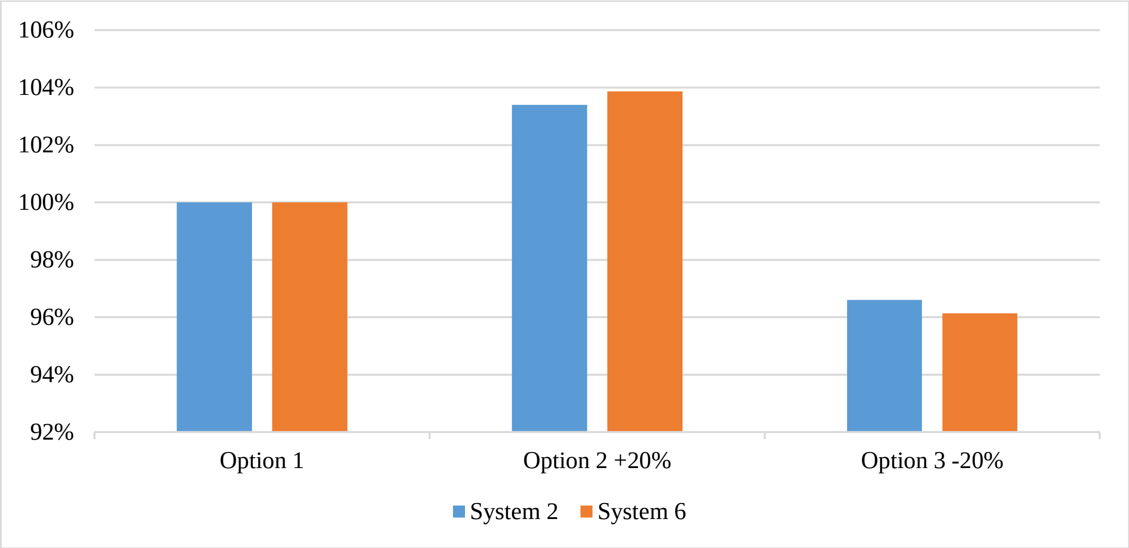

Figure 29. Sensitivity analysis of model for System 2 and System 6.

Sensitivity analysis showed that in 20% uncertainty of manufacturing or shipment parameters would not radically change the results the models give. Parameters considering amount air freight seem to have outstanding effect on total emissions, highlighting the need for better data quality. Changes in recycling content of System 4 materials had clear effect on the total results, and change in material composition of System 5 had some effect. This is most likely caused by the higher contribution of material production to total GHG emissions compared to other aspects. However, these results must be interpreted with caution, as only one parameter of each system was tested. Sensitivity analysis should be done for all parameters and with different uncertainties for all systems to get analysis that could be utilized in calculations. This was not possible within this research due to time limitations but it is likely that more comprehensive sensitivity analysis will be carried out when the model is used for future projects.

6 ANALYSATION AND TESTING OF MODEL

The main objective of this project was develop a calculation model for emission calculations, and for that old Project 1 was utilized. Because Company was active part of the development process, all decisions made took the intended use of model into account. The model was developed by following steps defined by GHG Protocol in figure 14. First phase was accounting, where organizational and operational boundaries were defined. During second phase, quantification, emission sources were identified, data about activities were collected and emissions from Project 1 were calculated. In last phase, accounting, base year is established, emissions and trends are tracked and inventory quality is managed. Instead of defining base year, Company chose to establish baseline emissions with baseline project, Project 1. Estimating baseline was one objective from Company. Baseline emissions help Company to set emission targets and define which emissions Company can affect. Last two steps of accounting phase are outside of this thesis scope, as both steps are continuing processes. Inventory quality can be managed and improved by upgrading both quality and amount of data used in emission inventories.

6.1 Following the principles of model development

Principles for calculation model development were introduced in chapter 4. These principles were followed as well as possible during model development. Relevance of the model was ensured by starting model development from the key systems delivered by Company. These systems were estimated to draw representative picture of the Company’s supply chain emissions and help to identify emission hotspots in investment projects. Completeness was ensured by accounting and reporting on all GHG emissions sources and activities within the inventory boundary that were estimated to be significant. There were some exclusions of components, but they were justified by the irrelevant mass of the component or material. All greenhouse gases that were emitted were included in calculation. Consistency was confirmed by using consistent methodologies, and following the principles and guidelines of GHG Protocol. All changes in the data, boundaries, methods and other aspects were documented transparently. To ensure transparency all relevant issues were addressed. Assumptions were written down clearly and justified and limitations of calculations have been honestly reported. Although most data that was used in calculations was secondary data, it was from widely-used databases, such as Ecoinvent or databases from international associations, such as IMOA database.

Principle of accuracy was somewhat compromised, as some of smaller components and rarer materials were excluded. Material losses during manufacturing were not taken into account. These things might result to smaller emissions than actual emissions are. Transportation distances used were more average that real values and it was not considered how full the used vessels were. However, considering the results from sensitivity analysis it is unlikely that these limitations would result for unrealistically small emissions and non-relevance GHG inventory. Results would be accuracy enough to enable users to make decisions with reasonable confidence as to the integrity of the reported information.

6.2 Model testing and implementation

The model was tentatively tested for a new investment project. Even though scope of this project differed from Project 1 and some of the systems were not delivered in baseline project, it was possible to estimate most of the GHG emissions with a model. Based on this test it seems that accessibility of the model is good but scalability could still be improved. Nevertheless, actual usability and usefulness of the model will be determined later when it will be used for calculation of new investment projects.

Model was used for emission inventory for another system, System 7, which was manufactured in same location than System 1. This system had different material composition than System 1 but manufacturing was assessed to be similar than in System 1. It was substantially faster and simpler to modify the process that was used for System 1 to be suitable for this new system, and calculate GHG emissions from production of System 7 than previous calculations, taking only couple of hours. This showed that model fulfills its purpose by making emission estimations easier and more effective even in cases where new materials are used. Model also proved to be scalable.

Implementation of the model was outside of the scope of this work, as this thesis focuses on model development.

7 CONCLUSIONS AND DISCUSSION

This calculation model developed in this study proved to be functional and fulfilled its purpose. However, model development is a continuous project and the final model will be modified in the future when more experience of its use is gained and more data is collected. During this study one of the biggest challenges was the continuous development of model: the more experience researcher gained, the more decisions made in early stage of this study turned out to be unpractical and the model had to be changed.

7.1 Findings in the study

Theory about supply chain/Scope 3 emissions showed that there is some variation in how supply chain is defined and which stages should be included. Caution must be used when supply chain emissions that company includes in emission inventory are selected. It might be tempting to estimate emissions only from those supply chain stages that are simple to understand, measure and reduce. Yet those stages might not be even relevant when compared to the total emissions from the company. It was found that most of the emissions caused by investment projects are the life cycle emissions of delivered systems, and life cycle assessment theory could be utilized in model development.

The most important supply chain stages were found to be production of materials, transportation and manufacturing. Estimating emissions from steel production proved to be challenging due to high amount of variation in estimated average emissions. The composition of the alloyed steel and the amount of recycled materials used were decided to be taken into account during model development. Origin of the steel should be included in calculations but comparable emission factors were not available during this research. There were notable differences between transportation modes in terms of GHG emissions. Data used for other aspects such as electricity production and waste management should be country- or region specific.

Principles that should be followed during model development process were defined by GHG Protocol: relevance, completeness, consistency, transparency and accuracy. Considering the intended use of model, it was decided that the research should also follow principles of accessibility, scalability and formability. It was noticed that life cycle thinking could be utilized in model development.

Before the development process started, it was stated that the model should make emission calculations simple and effective. It should give users information about the most emission-intensive stages of industrial investment projects. Model should show how the manufacturing location and origin of the materials affect the GHG emissions, and also show differences between suppliers. While the requirements for accuracy were not high on the first phase of model development, it should be possible to increase the accuracy of the results later.

The model development process followed the principles defined in theory part of this study. Based on the analyzation of the model it complies well with the principles of relevance, transparency and accessibility. Consistency and completeness are followed quite well. It seems that there is still room for improvement for better accuracy and scalability. It can be concluded that while the model follows the principles quite well, continuous improvement is needed.

Utilization of the base project in model development helped to identify emission hotspots. Results from both calculation of Project 1 emissions and sensitivity analysis showed that production of the materials is the most important stage in investment projects. Therefore main focus should be in that stage during model development and data collection. However, data availability might be an issue, as it might have an effect to the results and make it difficult to compare options. The option where accurate data is available might seem to cause much more GHG emissions than the option where accurate data is not available or the accuracy of the data is unknown. The quality of manufacturing data is an important challenge to identify when different options are compared.

The model seems to be modifiable enough to be suitable for also other industrial sectors. Generally, all industrial investment projects have the same supply chain stages and the emission hotspots probably lie on the same stages. In the Project 1 systems were transported long distances from one continent to other hence in other projects transport phase might not be as significant as in this project. Due to the nature of the analyzed systems most emphasis was in steel materials and material groups were created only for the steels used in Project 1. However, while the model is well suitable for investment projects where systems made from steel are delivered, it is likely that in projects where different materials are used the model and material groups have to be customized. For example chemicals, plastics and wood materials were not taken into account during the model development. More steel grades and other material groups can be easily added to the model when needed.

The effect of the origin of materials and manufacturing locations to the GHG emissions would be good to be illustrated in the model. While geographical locations were taken into account in development process the model itself does not yet illustrate how it affects to the total emissions. Comparison between location choices is possible in the model, but requires the use of more complicated functions of openLCA software or manual calculation. Before this challenge is solved, the model is not as effective as it should be. Another challenge proved to be the comparison of suppliers. Production data was difficult to receive and it was not possible to estimate the accuracy of received data. This makes comparison of suppliers at least inaccurate, and therefore comparing suppliers by the results that the calculation model gives is not yet recommended. However, this problems comes more from the data availability than from actual functionality of the mode.

In this study business travelling was left outside of the system boundaries. However, the significant effect of air freight to total GHG emissions suggests that it might be reasonable to include at least business travel by plane. It is also one of the scope 3 emissions that are always caused in industrial investment projects. On the other hand, relatively low emissions from truck transportation indicate that business travelling by car might not have notable effect on total emissions. It is recommended to test the effect of business travel to total emissions for couple of next projects, and make the decision about this aspect based on the results.

7.2 Recommendations

It was noticed that GHG emissions per one ton of product were not same in every system. This indicates that even though it would simplify the emission estimations dramatically, it is not possible to choose single emission factor for future calculations as it would give false results. Material composition of systems differ from each other and emissions caused by the manufacturing workshop vary. Perhaps for systems that are always produced in same workshop and have always the same material composition, single emission factor could be utilized in preliminary emission calculations that are intended to use only as rough estimation. Using single emission factor is not recommended for the calculations which results are intended to be used for communication with stakeholders.

Transportation emissions are another aspect that makes using single emission factor impossible. In business where projects can be located anywhere and production usually happens far away from project site, transportation distances are in most cases unique. It could be possible to calculate all transportations separately, which could be even easier and simpler way for companies which consider the shipping to be in their own operational area. If the main goal of emission study is only to estimate the total GHG emissions of investment project, separate emission estimation for transportation might be the best option. However, if company intends to use emission estimations to compare different production places for a certain system from the emission point of view, transportation should be included in same calculation model than other life cycle stages of the system. Transportation of systems is one part of their life cycle and calculating one stage separately from other stages could reduce the possibility of utilizing life cycle thinking in model.

Based on the results from Project 1, there are some tactical and strategic actions that companies delivering industrial systems could do in order to reduce emissions. First recommended tactical action is improvement of environmental data collection, monitoring and reporting, because during this study it became clear that more data is needed. Another good tactical action would be increasing the use of environmentally benign transportation modes, such as replace air freight with sea freight. As air freight caused clear spikes in GHG emissions when it was used, this could reduce emissions from investment projects distinctly. Electricity consumption was the most important aspect of manufacturing, and therefore energy efficient improvements and increasing the proportion of environmentally friendly energy sources in company’s own workshops could be reasonable tactical action. These actions would naturally reduce the emissions from company’s supplier’s manufacturing, yet it is often not possible to affect to supplier’s operations.

Number of possible strategic actions is much lower. One could think that there lies great emission reduction potential in using more environmentally benign materials in systems. However, special materials are used in industrial capital goods because of their qualities such as heat and corrosion resistance, and material changes would most likely affect negatively to functionality of the systems. The origin of the material has some effect to GHG emissions, and therefore choosing steel produced in Europe over steel produced in China could reduce the GHG emissions from investment projects. Preferring steel that is produced in less emission-intensive way might be one possible strategic action companies could take. Selection of more environmentally responsible suppliers would be other good strategic action, but it would require a lot of good quality data about suppliers’ operations.

There are also other actions that would reduce the emissions, but they are not realistic. Reduction in the transportation distances would reduce the emissions, but it would require selecting suppliers that are located closer to the mill site than their competitors. Even so, suppliers can rarely be selected only because of their location. If supplier closer to site is less environmentally responsible or unreliable, that type of decision could lead to even more emissions. In this study it was not taken into account how fully loaded the used vehicles were hence more study is needed before actions regarding to aspects could be done.

It must be noted that the model needs to be updated regularly due to changes in manufacturing, systems, used emission factors or other processes. Carbon emission factor from electricity production need to be checked if there happens changes manufacturing location’s or country’s energy production. Also other manufacturing data must be kept up-to-date, as changes in manufacturing practices might happen. Data about steel production still needs to be improved and made more country-specific. Transportation industry aims to reduce the GHG emissions from transportation, and thus also these emission factors need to be up-to-date. Changes in delivered systems, such as their composition, needs to be updated in the model. In the model these type of changes are simply to make, yet it is recommended to make some type of policy for updates to ensure they are done.

Even though the model proved to fulfill its purpose it is not perfect. During the development many processes that seemed to be ready had to be modified later for better accuracy or accessibility. Problems of scalability came up when model was intended to use calculation of other systems or projects. Need for better accessibility came up also during first presentation of model for Company employee, and it will be the next thing on focus. Improving the accuracy of model is ongoing process, as new and more accurate data about processes and materials are gained.

8 SUMMARY

This study focused on development of model suitable for calculating GHG emissions from global investment projects. The study was carried out in co-operation with future user of the model. Emissions from investment projects are supply chain emissions of the delivering company, and available theory about supply chain emissions was utilized in model development. Most of the emissions caused by investment project were life cycle emissions of delivered systems, and therefore also life cycle assessment theory was utilized when it was estimated which supply chain stages should be included in model.

Model was first developed for six key systems that case company delivers. Following stages were included in final model: production of materials, manufacturing, waste from manufacturing and transportation of materials and systems. It was found that one simple model is not suitable for all systems, and the crated “base model” needed to be modified for every system. However, this modification took much less effort than creating new emission calculations from nothing. Customized models made GHG calculations for new projects much faster, as only mass and transportations needed to be changed. Model development process also showed that it is not recommended to use one emission factor for all systems delivered in one project.

Preliminary results from calculations done with the model showed that the most important aspects in global investment projects are most likely material production and transportations. In cases where air freight was used it was the biggest source of transportation emissions, and shipments caused 10-30% of total GHG emissions from delivery of system. Truck transportations had only a little effect on total emissions, but it must be noted that the transportation distances were relatively short in this case. Manufacturing of systems caused 0.04-10% of emissions, yet it should be kept in the model because it is one of the few foreground systems that companies have in global investment projects. Emissions from waste management were generally low.

Developed model fulfilled the requirements set before the study started, and development process followed defined principles of model development. Some aspects, such as accuracy and scalability, still need to be improved. Both aspects will be improved when new data and processes are added to the model. Data used in model also needs continuous revision and updating. Model development will hereby be continuous process.

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Parameters and model graphs for systems 2-6

Table 1. Parameters in model for System 2.

Parameter	Type of parameter	Unit	Equation
Mass of the system, M	Input parameter	t	-
Mass of sub-system 1, M1	Depended parameter	t	M1 = M * a
Mass of sub-system 2, M2	Depended parameter	t	M2 = M *b
Mass of sub-system 3, M3	Depended parameter	t	M3 = M * c
Mass of sub-system 4, M4	Depended parameter	t	M4 = M *d
Distance from workshop to harbor 1	Input parameter	km	
Shipment from harbor 1 to harbor 2, S	Depended parameter	t	S = M
Distance from harbor 2 to mill site	Input parameter	km	

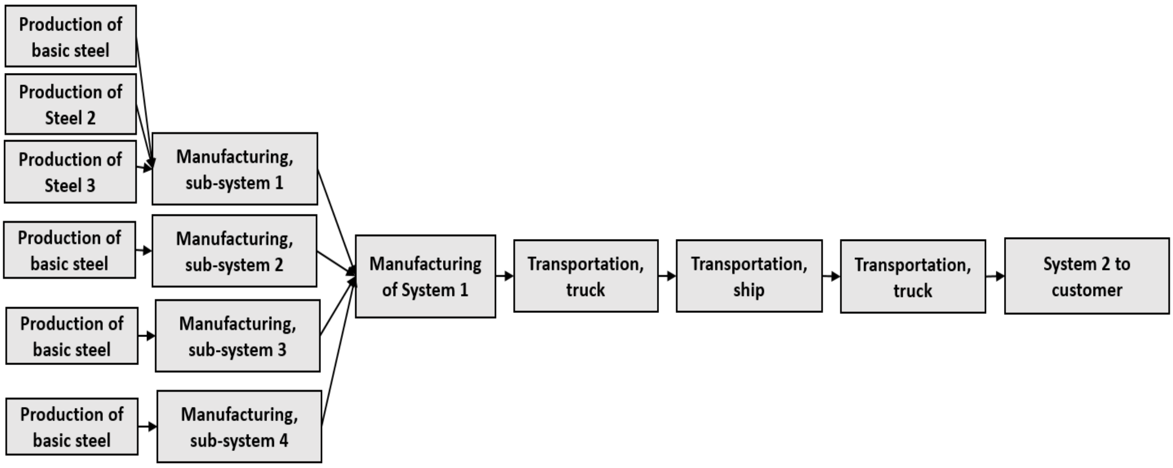

Figure 1. Model graph of System 2.

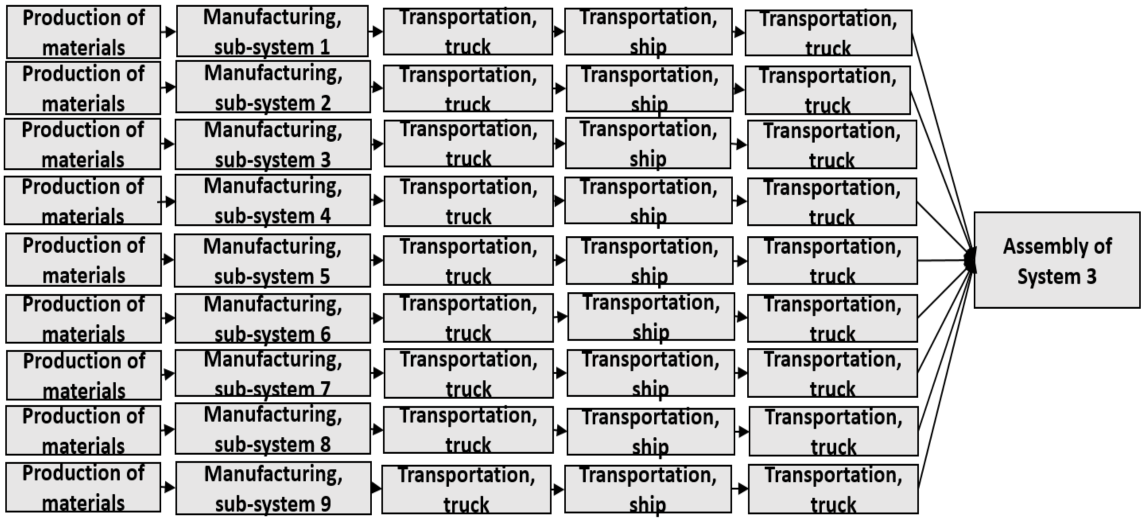

Figure 2. Simplified model graph of System 3.

Table 2. Parameters in model for Sub-system 5 of System 3.

Parameter	**Type of parameter**	**Unit**	**Equation**
Mass of the system, M	Input parameter	t	-
Mass of steel from supplier 1, M1	Depended parameter	t	M1 = M * a
Mass of steel from supplier 2, M2	Depended parameter	t	M2 = M * b
Mass of basic steel, M_basic	Depended parameter	t	M_basic = M c
Mass of steel 1, M_steel1	Depended parameter	t	M_steel1 = M* d
Mass of steel 5, M_steel5	Depended parameter	t	M_steel5 = M * e
Mass of refractory material, M_ref		t	M_ref = M * f
Production in Workshop 2, WS	Depended parameter	-	WS = M
Waste from workshop 2, W	Depended parameter	t	W = -M
Distance from material supplier 1 to workshop	Input parameter	km	-
Distance from supplier 2 to Workshop 2	Input parameter	km	-
Distance from Workshop 2 to harbor 1	Input parameter	km	-
Shipment from harbor 1 to harbor 2, S	Depended parameter	t	S = M
Distance from harbor 2 to mill site	Global parameter	km	-

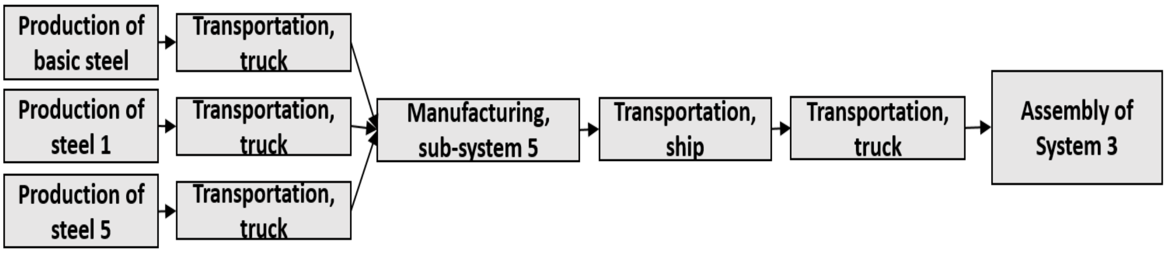

Figure 3. Model graph of sub-system 5 of System 3.

Table 3. Parameters in model for System 4.

Parameter	**Type of parameter**	**Unit**	**Equation**
Mass of the system, M	Input parameter	t	-
Mass of shipment 1	Depended parameter	t	M1 = M * a
Mass of shipment 2	Depended parameter	t	M2 = M * b
Mass of shipment 3	Depended parameter	t	M3 = M * c
Distance from harbor 2 to mill site	Global parameter	km	-
Distance from harbor 3 to mill site	Global parameter	km	-
Mass transported by truck from harbor 2 to mill site, M4	Depended parameter	km	M4 = M1 + M2
Mass transported by truck from harbor 3 to mill site, M5	Depended parameter	km	M5 = M3

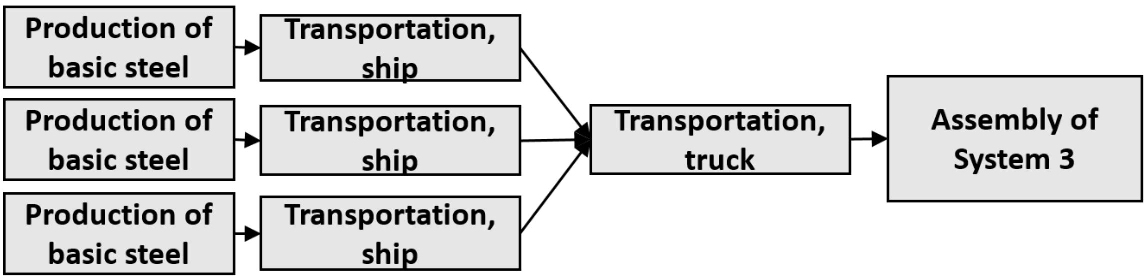

Figure 4. Model graph of System 4.

Table 4. Parameters in model for System 5.

Parameter	Type of parameter	Unit	Equation
Mass of the system, M	Input parameter	t	-
Mass of basic steel, M_steel	Depended parameter	t	M_steel = M * a
Mass of Steel 5, M_steel5	Depended parameter	t	M_steel5 = M * b
Electricity consumption, E_e	Depended parameter	kWh	E_e = M * c
Consumption of liquefied gas, LG	Depended parameter	m^3	LG = M * g
Generated metal waste, M_metal	Depended parameter	t	M_metal = M * m
Generated industrial waste, M_ind	Depended parameter	t	M_ind = M * i
Generated hazardous waste, M_haz	Depended parameter	t	M_haz = M * h
Shipment from harbor 1 to harbor 2, S	Depended parameter	t	S = M
Distance from harbor 2 to mill site	Global parameter	km	-

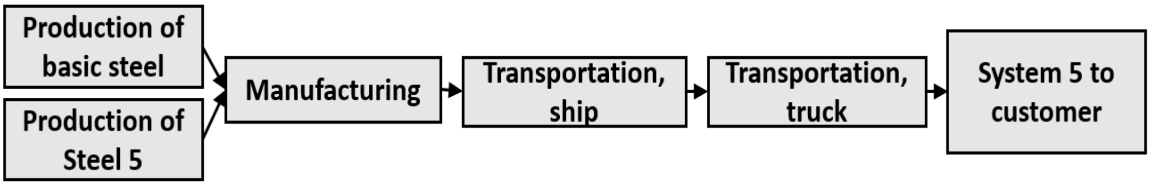

Figure 5. Model graph of System 5.

Table 5. Parameter in model for System 6.

Parameter	Type of parameter	Unit	Equation
Mass of the system, M	Input parameter	t	-
Electricity consumption, E_e	Depended parameter	kWh	E_e = M * e
Consumption of liquefied gas, LG	Depended parameter	m^3	LG = M * g
Generated metal waste, M_metal	Depended parameter	t	M_metal = M * m
Generated industrial waste, M_ind	Depended parameter	t	M_ind = M * i
Generated hazardous waste, M_haz	Depended parameter	t	M_haz = M * h
Shipment from harbor 1 to harbor 2, S	Depended parameter	t	S = M
Distance from harbor 2 to mill site	Global parameter	km	-

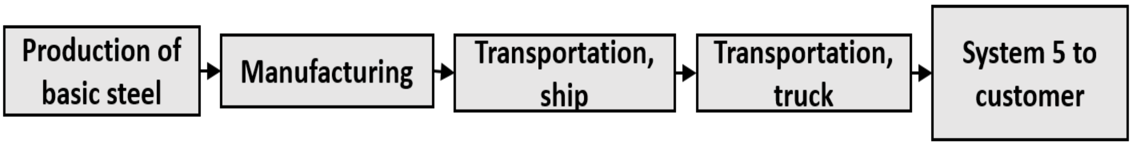

Figure 6. Model graph of System 6 in openLCA.