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CARBON FOOTPRINT CALCULATION OF SHIPBUILDING

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CARBON FOOTPRINT CALCULATION OF SHIPBUILDING

The purpose of this thesis was to calculate the carbon footprint of shipbuilding. The target of the study was a 150 000 GT cruise ship with a lightweight of 60 000 tonnes. The scope of the study was the seven major materials of the ship, energy consumption in the shipyard and waste produced in the shipyard. These seven materials were the steel structures, insulations, cables, windows, staterooms, fitted carpets and air-conditioning ducts.

The thesis subject came from Royal Caribbean Cruises Ltd.. The company wanted to know what the carbon footprint of building a cruise ship was. Increased environmental awareness of cruise ship customers was one of the reasons why ship owners were even more interested to know the environmental aspects of cruise ships. To acquire all the needed data for the calculation, cooperation with Meyer Turku was needed.

This thesis was an empirical study. It was based on concrete observations of the study target by analyzing and measuring it. The study method was a quantitative study. It included different categorizations, comparisons and results that are explained with numbers. The thesis was based on literature and information gained from experts at Meyer and from other suppliers. Data from the experts was collected via email, phone and meetings.

The total weight of the calculated materials was approximately 80 % of the total lightweight of a 150 000 GT cruise ship. To achieve the 80 % of a 60 000 tonne cruise ship, the collected materials needed to be scaled. This was due to the missing data of the studied materials. The carbon footprint of this study target was 101 097 t CO_2eq. The carbon footprint is thereby approximately the same as the fuel emissions of a 150 000 GT cruise ship during operation in 340 days, which is approximately one year. Over half of the produced carbon dioxide came from steel structures, which was not surprising considering that the steel weight was over 50 % of the calculated material. Second came the staterooms and third the energy consumption in the shipyard.

The calculations in this work consist to a large extent of estimations, uncertainties and scaling. To summarize, this study can not be used as a point of comparison to other similar studies unless the study is made with the same boundaries and the same percentages of the materials. The carbon footprint was approximate, which is an indication of the need of further research on the topic. For future reference, this type of study should be carried out with stricter limits to ensure a more accurate outcome.

KEYWORDS:

carbon footprint, shipbuilding, cruise ship, calculation, shipyard, materials, energy consumption

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LAIVAN RAKENTAMISEN HIILIJALANJÄLJEN LASKEMINEN

Opinnäytetyön tarkoituksena oli laskea laivan rakentamisen hiilijalanjälki. Tutkimuskohteena oli 150 000 GT risteilyalus, jonka paino oli 60 000 tonnia. Työ oli rajattu seitsemään suurimpaan materiaaliin, energiankulutukseen telakalla ja telakalla tuotettuun jätteeseen. Nämä seitsemän materiaalia olivat: rungon teräs, eristeet, kaapelit, ikkunat, hytit, kokolattiamatto ja ilmastointikanavat.

Työn aihe tuli Royal Caribbean Cruises Ltd. omistusyhtiöltä, joka halusi tietää risteilyaluksen rakentamisen hiilijalanjäljen. Laivojen omistajat ovat yhä enemmän kiinnostuneita risteilyalusten ympäristövaikutuksista, koska asiakkaiden ympäristötietoisuus kasvaa**.** Opinnäytetyö tehtiin tiiviissä yhteistyössä Meyer Turun kanssa, jotta tarvittava tieto saatiin kerättyä.

Työ oli empiirinen tutkimus. Se perustui konkreettisiin havaintoihin tutkimuskohteesta, mittaamalla ja analysoimalla sitä. Tutkimusmetodi oli kvantitatiivinen tutkimus. Se sisälsi erilaisia kategorisointeja ja vertailuja, ja tulokset oli selitetty numeroilla. Opinnäytetyö perustui kirjallisuuteen ja Meyerin ja alihankkijoiden asiantuntijoiden tietoon. Tietoa kerättiin asiantuntijoilta puhelimitse, sähköpostitse ja järjestetyissä kokouksissa.

Laskettujen materiaalien paino yhteensä oli noin 80 % koko 150 000 GT risteilyaluksen painosta. Kerätyt materiaalimäärät piti skaalata 60 000 tonnin painoiseen risteilyalukseen, jotta saatiin 80 % painosta laskettua. Tämä johtui puuttuvista materiaalitiedoista. Tämän tutkimuskohteen hiilijalanjälki oli 101 087 t CO_2eq. Suuruus on melkein sama kuin 150 000 GT risteilijän polttoainepäästöt 340 päivän riesteilyn ajalta eli melkein vuoden pituiselta ajalta. Yli puolet tuotetusta hiilidioksista tuli rungon teräksestä, mikä ei ollut yllätys koska teräksen paino lasketusta materiaalista oli yli 50 %. Toiseksi tulivat hytit ja kolmanneksi energiankulutus telakalla.

Tämä työ sisältää paljon arvioita, epävarmuuksia ja skaalauksia. Tätä työtä ei voi käyttää vertailukohteena ellei työ ole tehty samoilla rajauksilla ja samoilla materiaaliprosentteilla. Hiilijalanjälki on kuitenkin suuntaa antava ja kertoo asian merkittävyyden ja tutkimusten tarpeellisuuden. Tulevaisuuden kehitystä varten tällainen työ kannattaisi toteuttaa tiukemmilla rajauksilla, jolloin tulos olisi mahdollisimman tarkka.

ASIASANAT:

hiilijalanjälki, laivan rakentaminen, risteilyalus, laskeminen, telakka, materiaalit, energiankulutus

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LIST OF ABBREVIATIONS

absorb	To soak up energy, or a liquid or other substance caused by chemical or physical action.
CLIA	Cruise Lines Internation Association, cruise industry trade association (CLIA, 2019)
climate change	Climate change is a trend where the climate changes in the long run. Earth’s climate has changed for many times during time mostly caused by small variations in Earth’s orbit. Today climate change trend is most likely caused by humans. (NASA, Global Climate Change, 2019)
CO_2 equivalent	Metric measure to compare different greenhouse gases based on their global warming potential.(Eurostat, 2019)
database	Collected information in one place where it can be updated, deleted and downloaded.(TechTarget Network 2019)
direct and indirect	
emissions	Direct emissions come from source owned or supervised by the reporting entity. Indirect emissions are connected with the action but owned or supervised by some one else. (Greenhouse Gas Protocol 2019)
dry dock	Dock where the ship is built.
EN ISO 14067	Standard published by International Organization for Standardization, Greenhouse gases-Carbon footprint of products-Requirements and guidelines for quantification and communication. (SFS, EN ISO 14067:2018, 2019)
Environmental Product	
Declariation	Document that is independently verified and it has transparent and comparable information about the life cycle environmental impact of product.(EPD 2019)
EPA	United States Environmental Protection Agency
EURO 5	Emission standard for transport in Europe. What higer EURO value the cleaner vehicle. Values are EURO 1 – EURO 6. (Motiva 2019)
GHG Protocol	Standardized framework to measure and adminster greenhouse gas emissions. (Greenhouse Gas Protocol 2019)

Greenhouse warming potential	Value that allows the comparison of global warming impacts between greenhouse gases. Measure is how much energy a certain amount of gas will absorb over specific time horizon, relative to CO_2 emission. (EPA 2019)
GT	Volume of the ship not weight. It is calculated from internal volume of the ship [V] with a formula GT=V*(0.2+0.02*log(V)).
IPCC	Intergovernmental Panel on Climate Change.
LCA	Life cycle assessment, it is analysis of a products´s whole life-cycle from the point of view of sustainability. (Pre-Sustainability 2019)
lightweight	Weight of the ship without fuel, passenger, cargo and water.
official emission trading	EU system to keep GHG emissions of industrial and energy production plants and flights below the EU-wide emissions standard. Companies have choice to reduce their own emissions or buy emission allowances which mean that one emission allowance permits the company to emit one tonne of carbon dioxide. (TEM, Emmission trading 2019)
PAS	Guidebook how to assess the life cycle of GHG emissions of goods and services. (PAS 2050)
parametrization	Process of defining the parameters.
RCCL	Royal Caribbean Cruises Ltd.
Telecom Expanse Management report	Presents business intelligence that grows operational efficiency and support in planning. (Amtel, 2019)
thermal radiation	Electromagnetic radiation from material and it is effect of the heat of the material. (ScienceDirect, 2019)
VTT	Technical Research Centre of Finland

1 INTRODUCTION

Shipping plays a a big part in Finnish and international freight traffic. Approximately 80-90 percentage of freight traffic of the world is shipped by sea. The freight traffic of Finnish foreign trade goes 83 percentage by sea. Marine traffic has developed during the years towards a more environmentally friendly direction. Environmental efficiency of vessels can be more effective for example with environmentally friendly energy systems such as solar panels , wind turbines and fuel cell systems. The environmental efficiency is also important to take into account in the design part and in the whole life cycle of a vessel. Petra Erkkola, a consultant of environmental management and environmental technology solutions for shipyards, predicts that marine traffic emissions are going to rise in the future due to an increase in marine traffic. (Monnonen 2018)

Cruise ship manufacturing is going to increase in Finland according to the Finnish Marine Industries´ CEO. In the world, the cruise ship order book reaches until 2027 and in Finland up until the mid 2020's. (Kontiainen 2018) The association of Finnish Marine Industries launched the ResponSean project in the spring of 2018. ResponSean is for the whole marine industry to focus on the processes and to reduce the stress for the environment, people and materials. It is not only the operational phase that is focused on when talking about reducing environmental impacts but is the whole life cycle of the ship. Accountability is one of the goals that is encouraged. The acting CEO of the association of Finnish Marine Industries verifies that accountability has a growing significance in the field, and Finnish Marine Industry is a pioneer of environmentally friendly solutions and developing products. Meyer Turku is one of the initiators of this project. Meyer Turku wants to concentrate on the design of solutions which help to reduce the environmental impacts of the whole life cycle of the ship, including the shipbuilding processes. (Meriteollisuus ry 2018)

This thesis is focused on the carbon footprint of the shipbuilding stage. Usually, the carbon footprint calculation concentrates in the operational part of the ship but this time it focuses on the materials and the shipbuilding process in the shipyard. The need for this kind of study arose both from the shipyard itself but also from their customer, Royal Caribbean Cruises Ltd. (later RCCL). RCCL had limited information about the carbon footprint impact of the shipbuilding stage. What also makes this study important for the clients is the increased environmental awareness of the consumers. Consumers may even pay a little bit extra if the product is more environmentally friendly than the other available products. (Green growth opportunities in the EU shipbuilding sector 63)

The thesis starts by explaining the purpose of the work. After that comes the theoretical part. The theoretical part includes an introduction to cruise ships and shipbuilding, carbon footprint in general terms and how it is spreading towards business and industry. After that, carbon footprint calculation methods and software that has been used in the study are described. Next, actual research material and results are presented. The result is the amount of carbon dioxide equivalent (later CO_2eq) of the specific shipbuilding stage.

2 THE PURPOSE OF THE WORK

The purpose of this work is to estimate what the carbon footprint of the ship itself and the shipbuilding process of a cruise ship are. From the Internet different carbon footprint calculations of operational stage of the cruise ships can be found, however not much information is available on what it is before the operational part. This refers to the materials of the ship and the carbon footprint of materials, the energy consumption of shipbuilding and the waste that is produced in the shipyard. Lately, more attention has been set to the life cycle assessment (later LCA) of ships and this study also tries to highlight the bottlenecks of carbon dioxide (later CO_2) emission calculations. The idea is to calculate the materials of the cruise ship and their carbon footprint. The energy consumption of the shipyard is also part of the calculations and the waste that is formed at the shipyard.

With the information from different ships, the purpose is to gain an overview of the different factors and magnitude of impacts on a total carbon footprint. Studied ship sizes vary between 100 000 to 200 000 Gross Tonnage (later GT). For the calculation, a ship size of 150 000 GT has been used.

Royal Caribbean Cruises Ltd. is a global cruise holding company founded in 1985. Its headquarter is in Miami, Florida. It has six brands: Royal Caribbean International, Celebrity Cruises, Silversea Cruises, TUI Cruises, Pullmantur and Azamara Club Cruises. These brands forms sixty ships in totally. (RCCL 2019)

Meyer Turku is a shipyard and part of this work due to the fact that the shipbuilding data is derived from the company. Meyer Turku Oy is owned by the Meyer family. The Shipyard of Turku was founded in 1737. In total, the Turku shipyard has built over 1300 ships. This includes some vessels made in Rauma and Helsinki. Meyer Turku is specialized in building cruise ships, car-passenger ferries and special vessels. (Meyer Turku 2019)

3 THE CRUISE SHIP

Historically, cruise ships were much more used as a transport from place to place with comforts. Popularity of cruise ships has grown all the time and one of reason for that may be the luxury lifestyle at the cruises and the variety of activities they provide. Cruise ships today are called floating hotels or more widely floating resorts. Cruise ships try to bring land-based modern conveniences such as restaurants, bars, sport facilities, shopping centers and entertainment venues on board a ship. Cabins are larger and finer and the number of cabins has increased. Today, most cabins have balconies and bigger windows. (The Cruising industry 2006, 3) Since the late 1960s, the cruise ships have grown bigger, more than fifteen times the size of predecessors. (Munsart 2015, 14) The basic form of the cruise ship is a hull and a superstructure on top of it. The hull provides flotation, power generation and propulsion. On top of the hull are passenger amenities and the control and a navigation systems. (Munsart 2015, 15) The cruise industry is growing rapidly. The brand of the cruise ships is important. It can be seen in names such as Carnival Cruises, which attributes “fun ship”. Disney’s Cruises attributes “ship for children”.(The Cruising industry 2006, 3) The rapid increase in growth of the cruise industry made the projects grow, and to focus also on developing sustainability, safety and quality of the product. (The Cruising industry 2006, 5) CLIAs report, “2019 the State of the Industry”, shows that the passenger capacity in 2018 was 28.2 million passenger, when in 2009 it was 17.8 million. In 2019, the number of passengers is expected to reach 30 million. The total output in 2017 was 134 billion dollars. Most of the cruise ships are located in the Caribbean (34.4 %), Mediterranean (17.3 %), and Europe (11.1 %). (CLIA report 2019)

3.1 The building process

Today, a shipbuilding process in a shipyard is mostly about assembling components together. Most of the parts are manufactured somewhere else and then brought to a shipyard for assembling. Different actors such as system and device manufacturing, designing, consulting and material suppliers form together a shipping cluster.The 2013 Telecom Expanse Management report by the Ministry of Employment and the Economy Finland shows that 80 % of the Finnish ship industry are employed outside the shipyards. (Pulli 2013, 21)

The shipbuilding process starts with a request for proposals. After that, the shipyard makes a concept design, which takes it to the contract negotiations. Then the basic design and material acquisition commence. After the basic design starts the production design of steel, the material acquisition of steel, the production design of outfitting and the material acquisition of outfitting. The next step is the production of steel and outfitting. At the very end is commissioning and delivery. (Räisänen 2000, 30-1.)

A specification of the request proposal is made in the concept design phase. The specification includes ship properties, a general arrangement and a cost estimate. The basic design phase includes constructing the systems and calculating the performance figures of the devices. Systems are defined with the shipowner and the most important devices are chosen and bought. In the production design phase, the manufacturing drawings are made with a component catalogue and the rest of the devices and materials are bought. The production of a steel phase manufactures the hull and deck components, assembles them as blocks and in the end connects them together to a hull. In the outfitting phase, all the other components such as windows, doors, ducts, cables, floors and furniture are installed. In the commission phase, the operation of all the systems is tested. (Räisänen 2000, 30-1.)

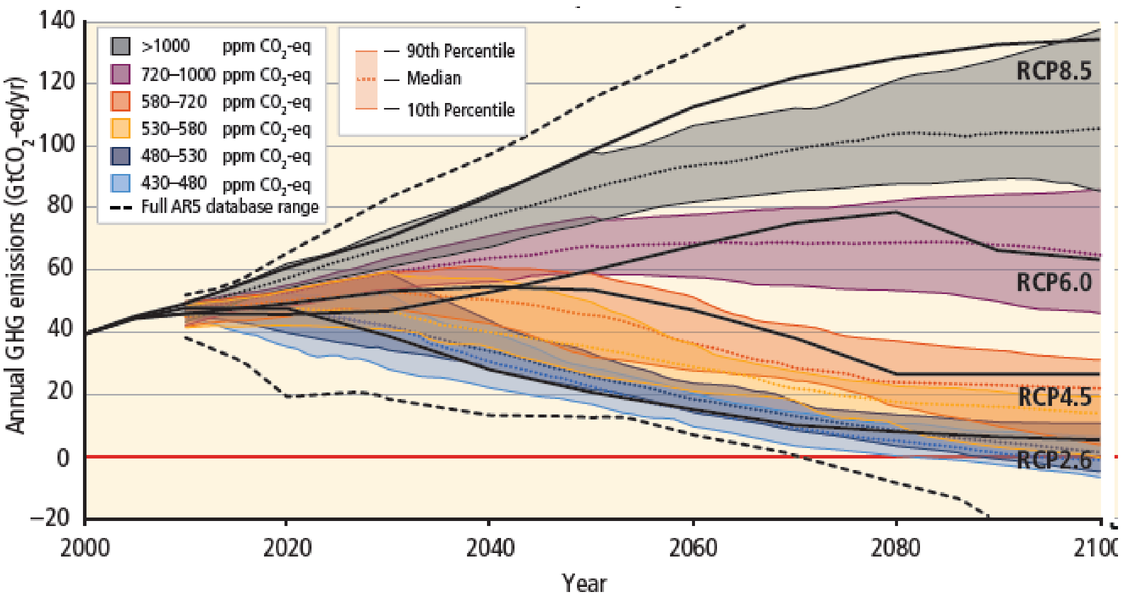
4 CARBON FOOTPRINT

Juan Carlos Enriquez, project manager at Gaia, writes that climate change is changing our development models. It is not just the matter of scientists and organizations but also of individuals and businesses and industries. Because of this, business management has adopted new concepts such as the carbon footprint to battle against climate change. Clean energy, low emissions at transportation and in supply chains and other activities are also part of climate competitiveness. Climate competitiveness gives the economy the tools to be sustainable. Countries and regions are competing in the climate competitiveness index which monitors the development of low-carbon economy. The index analyses low carbon leadership, performance and accountability. In 2010, the Nordics had the highest index. (Climate Competitiveness Index, 2010) The effects are also seen in international trade where the carbon footprint of products and services is starting to be in demand. According to Enriquez, the carbon footprint will be one of the central tools for evaluating performance. “It is the objective, transparent and verifiable measurement of the greenhouse gas emissions (later GHG) resulting from the actions of an individual, company, region, city or country, in a year”, says Enriquez. (Gaia, 2019)

Worldwide maritime transport emits approximately 940 million tonnes of CO_2 annually, which is 2.5 % of global GHG emissions. This number has been predicted to increase if no actions are taken to decrease the emissions. In the EU transport sector, the shipping emissions represent 13 % of GHG emissions. (EC, EU Action, Shipping, 2019) In Finland, the CO_2 emissions of traffic were 12 million tonnes in 2017. 91.7 percentage of emissions came from road traffic, 0.5 % from railway traffic, 1.6 % from inner air traffic and 4.2 % from water traffic. (Ilmasto-opas, 2019)

The Intergovernmental Panel on Climate Change (later IPCC) is an intergovernmental body for assessing the scientific basis of climate change. The IPCC has published The Synthesis Report, which confirms that humans have an effect on the climate change and this effect is increasing. The report has four different scenarios about 21st century GHG emissions and atmospheric concentrations, air pollutant emissions and land use, which are called The Representative Concentration Pathways (later RCP). These scenarios are: the tight mitigation of the climate change scenario named RCP2.6, two intermediate scenarios named RCP 4.5 and RCP 6.0, and the fourth the scenario with very high GHG emissions named RCP8.5. The scenario without additional emission limitations leads to pathways between RCP6.0 and RCP 8.5. Scenario RCP 2.6 keeps the global warming temperature below 2°C degree above pre-industrial temperatures. Scenario RCP4.5 is the one most likely to exceed 1,5 °C degree but not 2°C degree. Picture 1 shows these pathways until the year 2100. The vertical axis reflects the annual GHG emissions and the horizontal axis reflects the time. When there is no limitation to the emissions, (scenarios RCP6.0 and RCP 8.5) the curves continue to rise. In the scenarios that include actions in decreasing emissions, the GHG emissions continue to rise for a while but start to decrease after 2020. (Synthesis Report 2014)

Picture 1. IPCC The Representative Concentration Pathways about 21st Century. (source, Synthesis Report 2014)



Worldwide GHG emission calculations are based on different scenarios, which means that nobody knows the real emission amounts. There are also groups of scientists who do not believe that humans have an effect on global warming.

4.1 Definition

The definition of the carbon footprint is far from unambigous. It is some kind of measure of gaseous emissions, which has an effect of some kind on global warming. Either only CO_2 emissions or all the greenhouse gas emissions can be calculated. There is no set definition for either the calculation or measuring method. (Wiedmann & Minx 2007, 2) Thomas Wiedmann and Jan Minx are trying to find the best definition for the carbon footprint in their scientific article, Ecological Economics Research Trends. It only includes CO_2 emissions, both direct and indirect emissions. The source of the carbon footprint can be individuals, populations, governments, companies, organizations, processes or industry sectors. The reason why it is CO_2 is that there is data about it, and it is among the substances with the most significant greenhouse warming potential. (Wiedmann & Minx 2007, 5)

EN ISO 14067 is one of the standards that defines a carbon footprint of a product: “it is the sum of GHG emissions and GHG removals in a product system, expressed as CO_2eq and based on a LCA using the single impact category of climate change”. (SFS, EN ISO 14067:2018, 3.1.1.1) The GHG removals signify greenhouse gases that are retreated from the atmosphere. (SFS, EN ISO 14067:2018, 3.1.2.6) It takes the whole life cycle of the product into account, from the raw material, design, production, transportation and use to disposal. (SFS, EN ISO 14067:2018, 19)

4.2 Global warming potential

Greenhouse gases warm the Earth. The gases allow most sunbeams trough but absorb the thermal radiation from the earth's surface, causing the greenhouse effect. Different greenhouse gases have different impacts. There are two features that differ between the gases: their ability to absorb energy, and the amount of time they stay in atmosphere. The global warming potential (later GWP) allows the comparison of global warming impacts between these gases. A measure is how much energy a certain amount of gas will absorb over a specific time horizon, relative to the CO_2 emission. The larger the GWP, the more the gas warms the Earth. Usually the time period for GWP is 100 years. CO_2 GWP is used regardless of the time period due to the fact that the gas is comparative to the other gases. Methane GWP is estimated to be 28-36 in a period of over 100 years. Methane stays in atmosphere for s shorter time than CO_2 but it absorbs much more thermal radiation than CO_2. That is why the GWP of methane is higher than that of CO_2. In this thesis, the result may include other substances than CO_2 because some of the data from the suppliers was expressed in CO_2eq, which can include many different GHG. (EPA 2019)

4.3 Calculation

There is a lot of variation between the carbon footprint calculators. There are basic online calculators, life cycle analysis programs and input-output based methods and tools. (Wiedmann & Minx 2007, 1)

Publicly Available Specification 2050 (PAS) is a guidebook on how to assess the life cycle of GHG emissions of goods and services. (PAS 2050, iv)PAS is owned by the Department for Business, Innovation and Skills (BIS, UK). Co-sponsors have been Defra (the Department for Environment, Food and Rural Affairs, UK) and DECC (the Deparment of Energy and Cilmate Change, UK).(PAS 2050, iii)

PAS has two kinds of quantification of the emissions: one a cradle-to-grave and the other cradle-to-gate. Cradle-to-grave includes all the emissions from the full life cycle and cradle-to-gate includes only to the emissions before the product transfer to another party. (PAS 2050, 8) PAS has five steps to calculate the carbon footprint. The first step is to build the process map of the life cycle of the product starting with the raw material and ending with the disposal. The next step is boundaries and prioritization. The third step is collecting the data about the materials and activities in every phase of the life cycle. The fourth step is the calculation itself. The last step is checking the uncertainty of the analysis. (Guide to PAS 2050, 10) In the calculation phase all known materials, energy and output are multiplied with their emission factor. At the end, the GHG emissions are converted to CO_2eq by the GWP factor. (Guide to PAS 2050, 20) An emission factor is an amount of greenhouse gases emitted per unit, for example kg greenhouse gas per kWh energy used. At the end, these are summed up to get the total carbon footprint. (Guide to PAS 2050, 16)

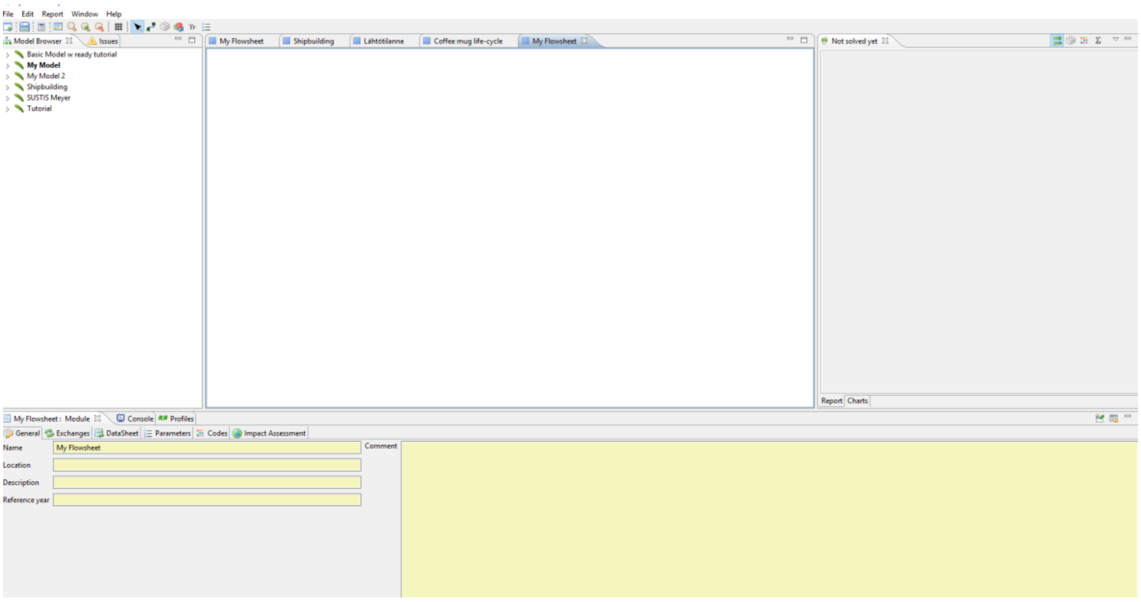
According to the Finnish Standards Association [SFS] and standard ISO 14067, the carbon footprint study has four phases. These are the goal and scope definition, the life cycle inventory [LCI], the life cycle impact assessment [LCIA] and the life cycle interpretation. The product system is divided into life cycle stages: the acquisition of raw material, design, production, transportation/delivery, use and disposal. (SFS, EN ISO 14067, 6.1) The goal is to calculate what the product CO_2eq is when quantifying all significant GHG emissions and removals over the product's life cycle or certain area of it. The scope of the study means defining the study area, system boundaries, quality requirements, a time boundary etc. (SFS, EN ISO 14067, 6.3) LCI is a phase where data is collected and it consists of the quantification of the inputs and outputs of the life cycle. (SFS, EN ISO 14067, 6.4) In the LCIA phase, the emitted GHG impact is calculated. Calculation is done by multiplying the mass of GHG by its GWP given by the Intergovernmental Panel on Climate Change (later IPCC). (SFS, EN ISO 14067, 6.5) The result is CO_2eq, which is the unit for comparing different GHG warming impacts. (SFS, EN ISO 14067, 3.1.2.2) Last, there is the interpretation, which means the inspection of the study: finding the significant issues based on the results, evaluating the consistency, assessing the uncertainties etc. (SFS, EN ISO 14067, 6.6)

4.3.1 Calculator

At the beginning of the study, calculators of different kinds were studied to find the one that would be used in this study. Some of the LCA calculators are free of charge and some are subject to a charge. One of the free calculators studied was Y-Hiilari offered by the Finnish Environment Institute. The calculator is based on the Corporate Accounting and Reporting standard of the GHG protocol. Y-Hiilari works in an Excel program and according to the standards it includes scopes 1 and 2. This calculator was not chosen due to the lack of material examination as in this study it is one of the areas of study. Instead, the chosen calculator is Sulca made by the Technical Research Centre of Finland (later VTT). One of the reasons Sulca why was chosen was that it takes into account the materials. (Y-hiilari, Yrityksen hiilijalanjälkilaskurin ohje)

5 THE CALCULATION TOOL SULCA

Sulca is designed by VTT. The program is the former KCL-ECO which was created in 1993. Since 2010, the 4.1 version has been updated to 4.2, and new models 5.0 and 5.1 were created. In this research, version 5.1 was used. Sulca has about 100 customers in Europe, North America and in Asia. With Sulca 5 it is possible to do life cycle assessment, carbon footprint calculation, life cycle inventory calculations, impact assessment modelling, as well as energy and material flow analyses. The results can be presented with different charts and graphs. The program is not connected to a specific field of industry. It has been used with machineries and carriers, the chemical industry, the forest industry, the media etc. (VTT Sulca elinkaarilaskentaohjelma ja sen käyttö, 2014) The software desktop consists of a model browser, a flowsheet editor, a selection view and a report view, which can be seen in Picture 2. The model browser section is on the left side of the desktop. It is like library for the processes, units and variables and imported processes. The LCA process is built up into the flowsheet editor, which is in the middle of the desktop. The LCA process is composed of many processes. For example this work is composed of the materials manufacture processes, the shipbuilding process itself, waste processes etc. The processes can be downloaded from a general database or the user can create the process herself. The selection view on the bottom of the desktop shows the inputs and outputs of the process and activity descriptions. Here one can add and delete variables, parameters, equations etc. In this work, for example, the steel manufacturing process, which is created by the user, has a variable of one tonne of steel and a variable of how much one tonne of steel produces CO_2. The report view on the right side of the desktop shows the results of that calculation, for example the emissions and energy consumption.



Picture 2. Desktop of Sulca.

VTT Specialist Katri Bohm says that all the life cycle programs work in a very similar way. Each life cycle program also shares the same problems and challenges. The calculation works with linear formulas such as plus, minus, multiplication. When there is a more complicated formula, it needs more work and imagination or parametrization of the formulas. There are some challenges that are not only challenges in Sulca but also in other LCA programs, tells Bohm. Between databases the terms and vocabulary varies. For example, carbon dioxide can be named “CO2, fossil”, or “carbon dioxide,fossil” etc. All these signify the same emission. However, when the name is not the same they will not sum up automatically. The user has the responsibility in the calculation and the data it feeds and uses. The user must know what has to be taken into account. One of the good qualities of Sulca is that it does not limit the calculation target example the forestry industry. In principle, everything is possible with Sulca. (Katri Bohm 2019)

In this study, most of the problems with the Sulca program occurred with the database. This study used a free ELCD database. Like Bohm said, the terms and vocabulary vary between databases. It was important to check that the terms of carbon dioxide of downloaded processes are the same so that they will be summed up. Downloading specified processes was hard because the names of the processes in the file were just mixed numbers and letters. That meant that the whole ELCD file had to be downloaded to Sulca to see what the processes were. The database can consist of over 500 different processes and thousands of variables. Databases do not include all processes – in this study, for example, there was no process for paint available and the emission factor of paint was unknown. Therefore the material paint had to be left out.

The Sulca program was chosen for this study because it is possible to take into account the materials.

6 RESEARCH

6.1 The research strategy

This thesis is an empirical study. Empirical study means that the thesis is based on concrete observations about the study target by analyzing and measuring it. The study method is a quantitative study. It includes different categorizations, comparisons and results that are explained with numbers. (Koppa 2019) The study concentrates on one particular ship and its shipbuilding process. There is a critical point of view due to the fact that calculating a carbon footprint it is far from unambiguous. The critical point of view is also needed due to all the estimations that have been made. The study is based on several estimations. The detailed information of countless pieces of materials, or tens of thousands of different pieces of equipment provided of thousands of suppliers was not available in an easily usable form. Grouping into larger entities needed to be done. This study may present the areas with the biggest CO_2 emissions. Most of the information was collected from experts interviews conducted by phone or email. The data was collected between 1st November 2018 and 30th April 2019.

The target of this work was to calculate as large a part as possible of the study subject. The research question was the following: How much CO_2 is emitted into the atmosphere when building a cruise ship? To answer the question, we need to know the major materials of the cruise ship and where they come from. The second research question was the following: How much is the energy consumption in the shipyard and how much is the output waste of building a cruise ship?

PAS 2050 has a guidebook on how to implement the standard in use. Section two, "Product footprint calculations", has been adopted as a model for this work. It consists of five steps: building a process map, checking boundaries and prioritization, collecting data, calculating the footprint and checking uncertainty. (Guide to PAS 2050, 3) The process map in this work consists of the materials, manufacturing the materials, transportation to the shipyard, energy used in shipyard and the waste which is produced in shipyard. There were small sketches of the process map at the very beginning of the work but the real process map was developed during the research and was built with the Sulca software. A general process map can be seen in the Result section Picture 4 and a more detailed process map can be seen in Appendix 1 at the end of the thesis. The boundary phase has been in operation until the end of this study. First, eight major materials were included but in the end the number was decreased to seven as there was no emission factor available for the paint. When collecting data, more boundaries arose such as not including raw material production. Some of the data was collected from the manufacturer itself and some data came from a general database**.** All factors of uncertainty are explained in this work.

6.2 Materials

The cruise ship lightweight is approximately 0.4 * GT so the example ship lightweight is 0.4*150 000=60 000 ton. The lightweight measures the actual weight of the ship without fuel, passengers, cargo and water,representing the materials and equipment the ship consists of and thus the origins for the carbon footprint. Gross Tonnage represent the volume of the ship, not weight. It is calculated from an internal volume (V) of the ship with a formula $GT=V*(0.2+0.02*\log(V))$. Gross Tonnage is a common way to present ship sizes. There was not enough time to take into account all the materials so within the scope of this study major materials are included in the calculation. The selection was affected by the amount of the materials and the availability of data. The materials chosen present 80 % of the ship total lightweight. These were 1) steel structures (66.4 %), 2) staterooms (9.3 %), 3) insulations (1.6 %), 4) cables (1.5 %), 5) windows (0.8 %), 6) fitted carpet (0.4 %) and 7) air-conditioning ducts (<0.1 %).

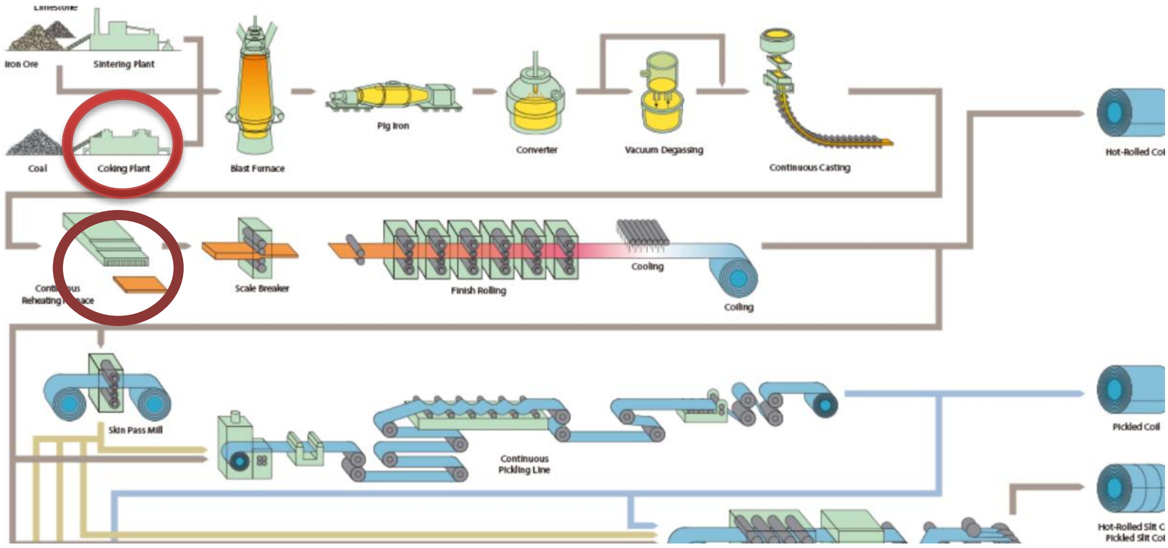
6.2.1 Steel structures

In this study, the collected steel structures were 24 900 tonnes. The weight was taken from a bigger cruise ship and scaled down to this 150 000 GT cruise ship. (Pettersson 2019) The steel structure weight was 66.4 % of the collected materials. The materials that are included in the calculation are steel sheets and steel profiles shown in Table 1. In this work, the steel structure materials come from SSAB Raahe and the manufacturing data is derived from them.

Table 1. Steel structures consist of steel sheets and steel profiles.

Steel structures	Weight (t)
Steel sheet	20 000
Steel profile	4 900
Total	**24 900**

SSAB Raahe has calculated CO_2 emission amount according to the official emissions trading. The calculation includes the production process from the coking plant to the point where the product is a steel slab. (Paldanius 2019) In Picture 3, the steel production process is illustrated and the red circles show where the calculation starts and where it ends. The emissions trading includes the liquid gas and the LNG used in rolling. (Pahkala 2019) Inner transportations are not included. The number was calculated per steel tonne, which is the weight of a steel slab. The official emissions trading number is 1599kg/tonne of steel in 2017 and that was used in this calculation. The official emissions trading value includes recycled steel coming from outside the production. (Paldanius 2019)



Picture 3. Steel production process. (source, My Sullys, 2019)

99.9 % of the steel is transported by train to Turku shipyard. (Turta, 2019) In this calculation, the mode of transport used is train and the distance used is 575 kilometers from Raahe to Turku.

6.2.2 Staterooms

There are 1 700 staterooms in this 150 000 GT cruise ship. The amount of staterooms was taken from a bigger cruise ship and scaled down to this 150 000 GT cruise ship. (Kärkäs 2019). The LCA calculation by VTT was used in the stateroom calculation. The calculation made by VTT is made with the Sulca program, which is the same program that was used in this study. VTT has made LCA calculation to one of the Piikkiö Works cabins. The VTT cabin calculation takes into account the panels of the cabin, textiles and furniture, and other items such as bathroom floor elements, piping and doors. It also takes into account the backing materials, support structures and the electricity that is used when manufacturing and assembling the cabin, as well as fuels, the amount of waste and the amount of missing data.

Cabin transportation from Piikkiö Works to the Turku Shipyard was taken into account in the calculations. The lorry used in the calculations weighs over 32 tonnes and it belongs to EURO5 emissions standard. Used distance is 30 km.

6.2.3 Insulations

The compiled insulation amount in this study weights 608 tonnes. The insulations in this calculation include two kinds of glass wool from Isover, Saint-Gobain, and stone wool from Rockwool and from Paroc. The amounts of these insulation materials can be found in Table 2. The amounts of insulations are taken from a bigger cruise ship and scaled down to a 150 000 GT cruise ship. (Puustinen 2019)

Table 2. Insulation amounts of the cruise ship.

Insulations	Area (m2)
ISOVER, glass wool 1	139 000
ISOVER, glass wool 2	73 000
Rockwool, stone wool 1	12 000
Paroc, stone wool 2	45 000
TOTAL	269 000

Glass wool manufacturing data comes from Saint-Gobain. The company has done Environmental Product Declaration (later EPD) for their products. The EPD is in accordance with ISO 14025, ISO 21930 and EN 15804. There are two products of glass wool from Saint-Gobain and for both of them Saint-Gobain gave EPD reports. The other EPD report was not exactly the same product as the one used in this study but it was similar. The density of the products is 30 kg/m^3. Saint-Gobain added that the insulation products for Meyer are reinforced with aluminum or fiberglass and there is no estimation how much this affects the results. (Kaiser 2019) Both EPD reports have the product CO_2eq amount that is used in the calculations. The calculations of both products take into account the production stage which consists of raw materials, transportation and the insulation manufacturing itself. (EPD ISOVER 2016)

Stone wool data comes partly from Rockwool and partly from Paroc. Rockwool has made a sustainability report in 2017 in which they have calculated the amount of CO_2 per ton of stone wool. In this study, the Rockwool product density is 40kg/m3. Paroc have done an EPD for all of their products and they have calculated the amount of CO_2eq for 1 m^2 of stone wool. In this study, the Paroc insulation density is 35 kg/m3. The Paroc EPD has taken into account the production stage, raw material production, transportation to manufacturer, product manufacturing, production of packaging materials, waste management, water treatment and end-of-life of residues. (EPD Paroc 2014) Table 3 shows the LCA values of the products. The value is kg CO_2eq of one square meter of the product. These values are used in the calculations.

Table 3. The LCA calculation data of the insulation products.

Product	LCA data
ISOVER, glass wool 1	3,3 kgCO_2eq/m2
ISOVER, glass wool 2	2,3 kgCO_2eq/m2
Rockwool, stone wool	2,5 kgCO_2eq/m2
Paroc, stone wool	1,5 kgCO_2eq/m2

Transportation for ISOVER glass wool 1 is taken into account in the calculations. Transportation includes shipping from Travemunde, Germany, to Helsinki, Finland. The shipping distance is 1400 km. From Helsinki the insulation goes first to Hyvinkää and from there to Turku. The distance of this transportation is 394 km and the lorry that is used in the calculation is over 32 tonnes and it belong to the EURO 5 emissions standard. Glass wool 2 is made in Finland in Forssa. Transportation for glass wool 2 is from Forssa to Hyvinkää and from there to Turku. The distance for this transportation is 268 km and lorry that is used in the calculation is over 32 tonnes and it belongs to the EURO5 emissions standard. (ISOVER expert 2019)

Stone wool from Rockwool is shipped From Denmark to Turku. The distance between Denmark and Turku is 1 300 km and from Turku to the shipyard 10 km by lorry. The lorry is 32 tonnes and it belongs to the EURO5. Transporatation of stone wool from Paroc is not taken into account in the calculations. (Rockwool expert 2019)

6.2.4 Cables

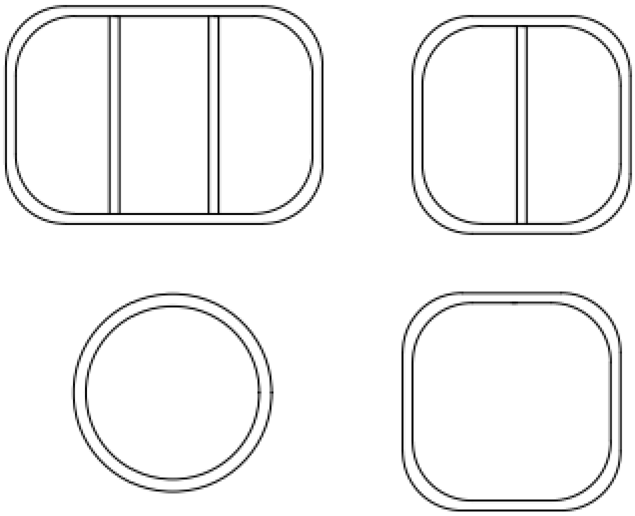
In this study the compiled amount of cables is 578 tonnes. The amount of cables was scaled down from a bigger cruise ship to the size of 150 000 GT. Approximately 2/3 of the cables are from Helkama and 1/3 are from other manufactures. (Hihnala 2018) The cable manufacturing data comes from Helkama.

Helkama Bica is specialized in marine and offshore cables, which are halogen-free and meet the safety requirements on board. These cables do not emit toxic burning fumes or thick smoke. There are no corrosive gases emitted. (Helkama Bica 2019)

Helkama provided data about oil consumption and electricity consumption. The data used for oil is heavy fuel oil from a general database. This data includes activities from cradle to transporation to the end user. For electricity medium voltage data from general database is used. This data is Finnish electricity from year 2015. The cable process takes into account the copper of the cables and the rest of the material is halogen free compound. Polyvinychloride material is used in the calculation instead of the halogen free compound. This is due to the unavailable data of halogen free compound. Copper and polyvinychloride are derived from a general database. Used recycled copper is also included into the calculations.

6.2.5 Windows

The windows in this study consist of the welded windows for the hull, glazings of the cruise ship,balcony doors and balcony balustrades of the cabins. There are many different types and sizes of welded windows, but in this study only four of them are calculated and the calculations are used for all the welded windows. These four types of windows are triple windows, two-piece windows, one-pice windows and circle windows. Picture 4 presents an example of these welded windows. One of the manufactures for these windows is Bohamet SA. In general, these windows consist of steel and glass. The amounts of the materials come from Bohamet. Table 4 shows the total amount of these components. Glass data that is used in the calculation is from a general database and the steel data includes only the emission factor of steel. The emissions factor used for this steel is 1830 kgCO_2/t calculated by the World Steel Association in 2017. The calculation does not take into account the manufacturing of windows.



Picture 4. Four types of welded windows.

Table 4. Components of the welded windows and their total amount.

Material	Amount (t)
steel	38
glass	14
Total	52

The glazings that are included in this study consist of two unites. Together these glazings have approximately 15 tonnes of glass and 25 tonnes of steel. (Ylinen, 2019) The material data, steel and glass, is the same as in the welded windows.

The glass of the balcony doors and balcony balustrades is calculated in this study. 1 413 balconies are calculated in this study. The weight of the glass of balcony doors is 129 tonnes and the weight of the glass of balustrades is 78 tonnes. The balcony door model and the balustrade model is from Meyer but the weight of the glass type is taken from the lasiverkko.fi website. Used glass process in the calculation is the same as in welded windows and glazings.

6.2.6 Fitted carpet

In this study the amount of fitted carpet is 60 000m^2. This was taken from a bigger cruise ship and scaled down to the size of a 150 000 GT cruise ship. Half of the carpet is Axminster and the other half is Colortec. Both of them are a mix of wool (80 %) and nylon (20 %). The bottom material is different in these carpets. The wool comes to the carpet manufacturers from England and New Zealand. Nylon and polypropylene come most likely from China. In the previous projects the carpets suppliers were from China, South Africa and Denmark. In this study, two of previous suppliers were chosen. (Rein 2018)

The Colortec carpet supplier comes from Denmark. From this supplier, the latest climate report of the Colortec carpet was taken between 1st May 2017 and 30th April 2018. The average emission factor of Colortec carpets from this period is 0,57 kg CO_2/m^2. The analyzis is made based on the international standard, Greenhouse Gas Protocol Initiative. (Juhl 2018)

The transportation from the manufacturer to Turku is done by trucks and ships. The total kilometer amount is 1043 km, 663 km by trucks and 380 km by ships. In Table 5, the transportation is more accurately explained. (Juhl 2018) The truck used in the calculation is a lorry of 32 tonnes which belongs to the EURO 5 emission standard.

Table 5. Colortec carpet transportation from Denmark to Finland.

From	To	Mode of transport	Distance (km)
Herning, Denmark	Frederikshavn, Denmark	Truck	192
Frederikshavn, Denmark	Gøteborg, Sweden	Ship	94
Gøteborg, Sweden	Stockholm, Sweden	Truck	471
Stockholm, Sweden	Turku, Finland	Ship	286

The other carpet material is Axminster and one of the suppliers can be from South Africa or from China. The data that is used in this work comes from the supplier from China. This material is also 80 % wool and 20 % nylon. In the calculation the transportation of Axminster is by ship from China to Finland, 24 700 kilometers. In the calculation, both of these carpets use the average emission factor of Colortec carpet which was the 0,57 kg CO_2/m^2.

6.2.7 Air-conditioning ducts

Most of the components in the air-conditioning ducts are galvanized steel. The calculation data of ducts includes the emissions factor of galvanized steel. The emissions factor used is 1,1kgCO_2/kg galvanized steel. In this study the weight of the components of air-conditioning ducts is 11 tonnes. The weight of the ducts is scaled down from a bigger cruise ship. These components are access doors, rectangle ducts, installations collars, clip plates and different connectors. (Mansikkala 2019)

6.3 Energy consumption in the shipyard

The energy consumption of shipbuilding is taken from the annual energy consumption of the shipyard. There was no information available on the energy consumption of the building of one ship due to the fact that the shipyard builds more than one ship at a time. When one ship is in an outfitting phase the other can be in production of a steel phase. The estimated energy consumption for the building of one ship is calculated from the energy consumption per GT. The energy consumption per GT was calculated from a three-year period, 2018, 2017 and 2016. First, it was estimated how many GT was produced in that one year and then the energy consumption of the year was divided with that number. Then all these years' energy consumptions per GT were compared with each other to see whether there was a lot of variation between them. The conclusion was that there was not much variation between the years. After that, the average value of energy consumption per GT between these years was calculated. These values, which are also used in the calculation, are 0,21 MWh/GT for district heating and 0,26 MWh/GT for electricity. The data for electricity and district heat are taken from a general database.

6.4 Output

Output contains the waste and leftover materials that come from the shipyard. The amount of the output is estimated and the numbers come from an existing project. The outfitting department of the shipyard has done a calculation of how many kilograms of waste is produced per worker per a thousand hours. The shipyard has estimated how many man-hours the outfitting phase of a cruise ship is going to take and that way calculated the amount of waste. The amount of waste of these estimations is scaled down for the size of the ship in this study. Table 6 shows the amount of waste produced building the 150 000 GT cruise ship and what types of waste it includes. Lassila & Tikanoja (later L&T) handles the mixed waste and sorts it at their own station. The metal waste is calculated from new buildings between 2014 and 2016. The amount is scaled down for the size of the ship of this study. (Linke 2019)

Table 6. Amount of waste of 150 000 GT cruise ship.

Waste	Weight (t)
Mixed waste	3 300
Landfill	360
Metal	11 000
Total	**14 660**

There are two different tables on the transportation. Table 7 shows the transportation of two kinds of metal waste. The table shows the type of the metal waste, the amount of waste, where the waste goes, what the distance is and what the mode of transport is. The distances have been taken from Google maps. The shipyard address is Telakkakatu 1, Turku.

Table 7. Transportation of two kinds of metal waste from shipyard to continued handling.

Metal waste	Amount (t)	Drive	Distance (km)	Mode of transport
Steel scrap	4 900	Shipyard-Raahe	567	Train
Production scrap	4 700	Shipyard-Tarvasjoki	43	Truck

Table 8 has the same calculations. The table shows the amount of the waste, where the waste is transported, distance in kilometers and the mode of transport. Mixed waste and waste to landfill goes to L&T. The sorting station is located in Vaskikatu 13, Turku. Most of the time mixed waste and waste to landfill are collected together in the shipyard and then L&T makes the sorting. In cases where a lot of landfill waste is produced, it is collected separately. For example, before the ship launching, the dry dock will be cleaned from the waste that goes to the landfill. (Linke 2019)

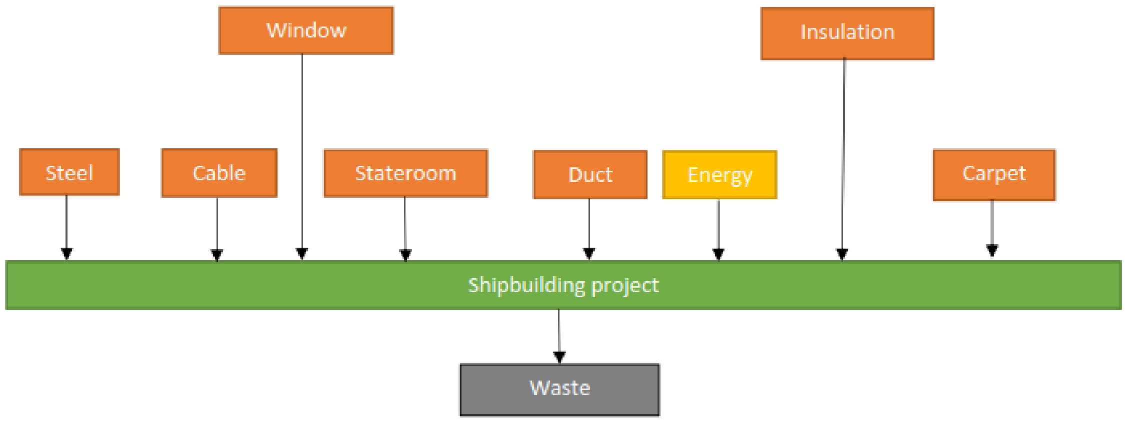
The waste calculation in the study includes only the transportation of the waste.

Table 8. Transportation of mixed waste and landfill waste.

	Amount (t)	Drive	Distance (km)	Mode of transport
Mixed waste	3 300	Shipyard-L&T	16	Truck
Landfill	360	Shipyard-L&T	16	Truck

7 RESULTS

The research question was how much CO_2 was emitted into the atmosphere when building a cruise ship. The seven largest materials of the ship, the energy consumption of the shipyard and the waste of the shipyard were the boundaries of the study. Picture 5 is a simplified picture of the process flow of the study. Orange processes are the seven materials that have been calculated. The yellow process is the energy consumption in the shipyard. The green process is the shipbuilding project itself where all the material and energy flows go. The grey process is the waste that is produced in the shipyard.



Picture 5. Process flow of the study.

Appendix 1 in the end shows a picture of the real process flow which is taken from the calculation program Sulca. The different processes are shown in more detail in the picture. Appendix 2 in the end shows a table of the processes and what the inputs of the processes were.

It was assumed in the very beginning of the thesis that these 7 materials would cover 80-90 % of total weight of the size of 150 000 GT cruise ship. In the end, the collected weight of the materials covered only 50 % of the size of 150 000 GT cruise ship. This is due the missing data of studied materials. In order to get close to the 80 % of the total weight, the calculated percentage of these seven materials and percentage of unknown materials were multiplied with 60 000 tonnes, which is the lightweight of the 150 000 GT cruise ship. That way the weight of the calculated materials is 80 % of the size of 150 000 GT cruise ship and the unknow material is 20 %, which is not included in the carbon footprint calculation. Table 9 shows the weight of collected material and percentages and what the weights were after scaling. These scaled values are used in the carbon footprint calculation.

Table 9. Compiled weight of the materials and scaled weight of the materials.

Material	Weight (t)	%	Scaled weight
Steel structures	24 900	66.4	**39 861**
Stateroom	3 485	9.3	**5 579**
Insulation	608	1.6	**972**
Cable	578	1.5	**925**
Window	261	0.8	**418**
Fitted carpet	138	0.4	**221**
Duct	11	<0.1	**18**
Unknown	7 500	20	**12 006**
Total	37 481	100	**60 000**

The total carbon footprint of 80 % of the calculated weight of the size of 150 000 GT cruise ship is 101 097 t CO_2eq. According to the value given by Meyer Energy Efficiency specialist, the fuel emissions of the 150 000 GT cruise ship during 340 operation days, almost a year long cruise, are approximately the same as the calculated carbon footprint. Figure 1 shows how the CO_2 emissions were divided between the factors.

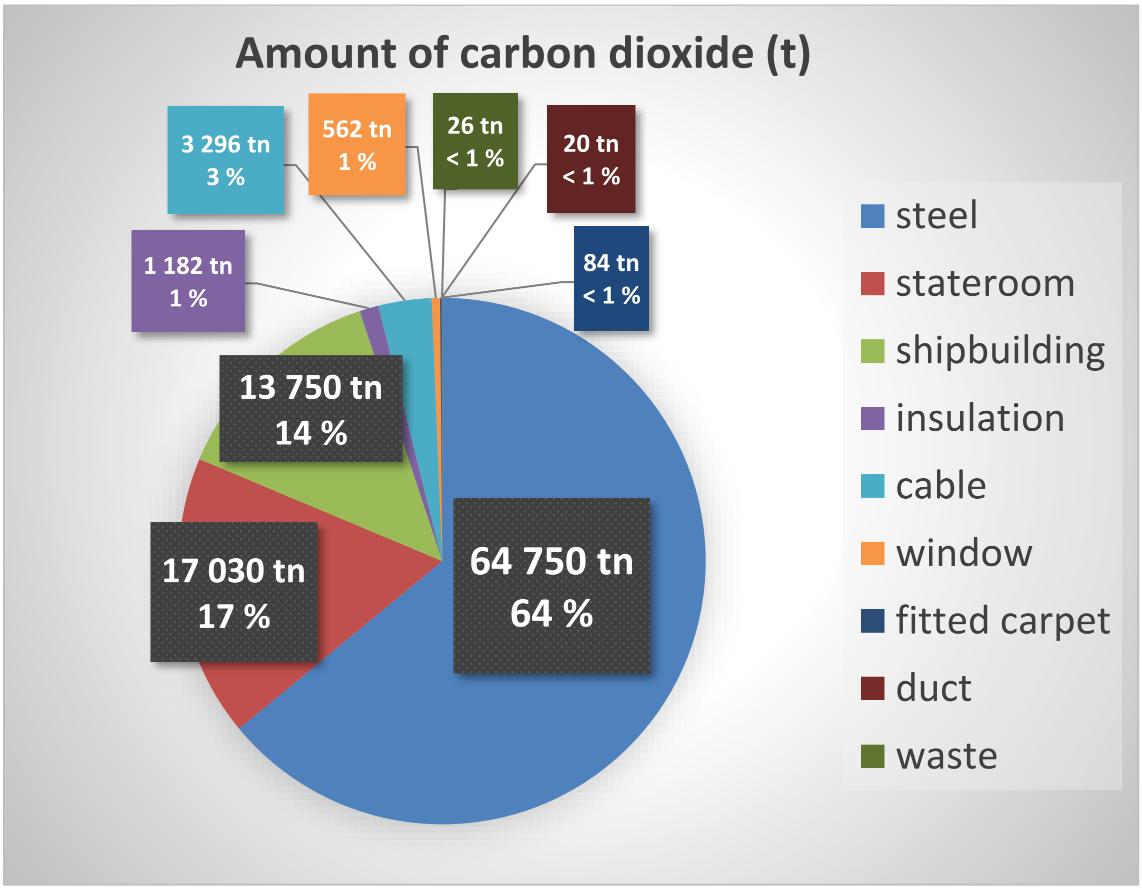


Figure 1. Amount of carbon dioxide between the factors.

The figure shows the amount of CO_2 and what the percentage between the factors is. The blue sector represents the amount of CO_2 from the steel structures. The emissions percentage of total emissions of the steel structures is 64 %. It was predicted that steel would be the biggest source of emissions in this study because steel weight is over half of the total cruise ship lightweight. The next biggest source of emissions is the stateroom, which is presented with a brown sector. Stateroom emissions make up 17 % of the total emissions. The green sector in the figure represents the shipbuilding which is the third biggest source of emissions. Its percentage is 14 %. The fourth biggest source of emissions is cables, represented with the light blue sector. The percentage of cable emissions is 3 %. The fifth biggest source of emission is insulation with the violet sector. The percentage is 1 %. The sixth biggest source of emissions is cable with percentage of 1%. For the rest of the materials, the fitted carpet, the duct, the waste, percentages are so little that the figure shows < 1 % for each of them. Appendix 3 in the end shows calculated results for every process, taken from the Sulca program. Appendix 4 in the end shows the same figure as Figure 1 but it is downloaded from the Sulca program.

7.1 Discussion

The study has a lot of estimations and lots of data is missing. First of all, the calculated weights of the materials were scaled down straight from the percentage to the size of 150 000 GT cruise ship. The percentages are inaccurate due to the missing data. The steel structures emissions factor which came from SSAB Raahe does not include the whole steel production process. The stateroom process was calculated only with cabins of one kind although cruise ships have cabins of a different kind. The stateroom emissions factor was taken from a calculation made by VTT which was very meticulously calculated in comparison to these other factors. 1/3 of the cables were unknown which is why the weight of the cables and amount of copper were estimated with an average value from the 2/3 of known cables. The EPD of insulations were not all the exact same products as the ones in the study. This means that the emissions factors used are not necessarily the exact same ones with the products in the study. The air-conditioning duct process includes only the material of galvanized steel and its emission factor. Most of the air-conditioning components are galvanized steel but the rest of the materials were unknown so it was assumed that the total amount of ducts is galvanized steel. The windows include also other materials apart from steel and glass but those were not included in the calculation. Windows included also stainless steel but it was mixed with the steel amount. The manufacturing process of the windows was not included in the calculations. Glazing took into account only two units, which is very little compared to how much glazing there is in the cruise ship. The waste process takes into account only the transportation of it. Transportation from suppliers to the shipyard are included for only some of the materials. These materials are steel, stateroom, three of the insulation products and fitted carpet.

In this study, 20 % of the total lightweight of the 150 000 GT cruise ship was unknown material. This was estimated from the percentages of material weights which were given by the Meyer weight estimation group. It is assumed that this 20 % includes engines, propellers, machines and lots of interior design materials such as textiles and lamps. These unknown materials might have big environmental impacts. If these materials would be included to the calculation it might change the results significantly.

8 CONCLUSION

The goal of the study was to calculate the carbon footprint of 150 000 GT cruise ship. 80 % of the size of 150 000 GT cruise ship was managed to calculate. To achieve the 80 %, it needed seven major materials of the ship and in the end scaling the percentage of weight to the lightweight of 60 000 tonnes. According to this study results, the biggest emission factors and major materials go almost hand in hand. Steel structure was the largest emission factor and also the weight of steel structure was over half of the size of 150 000 GT cruise ship. The carbon footprint of 80 % of the size of 150 000 GT cruise ship was 101 097 t CO2eq. To reach that amount the 150 000 GT cruise ship must operate for 340 days, almost for a year. When comparing it with the cruise ships' operating life which can be over 60 years, example MS Athena cruise ship, the shipbuilding carbon footprint looks small. Must remember that this carbon footprint is only an indicative figure.

This carbon footprint can not be compared with other carbon footprint calculations of shipbuildings because of all the uncertainties it has. If the calculations has the same factors and percentages are the same, comparing might be possible. Uncertainty of the study is a result of different factors. The biggest uncertainty factor was the missing data of studied materials. In addition to this the used emission factors in this calculation have taken into account different life cycle stages.

This topic is very interesting and new in the world. For the future development, studies of this kind could be focusing on specific area of building a cruise ship so that the results would be more accurate. For example, focusing on the shipyards emissions or focusing on the emissions of one material, could give more accurate results. Studies of this kind could give possibility to compare the results of different factors and that way see what the biggest emission source is and then focusing on decreasing that.

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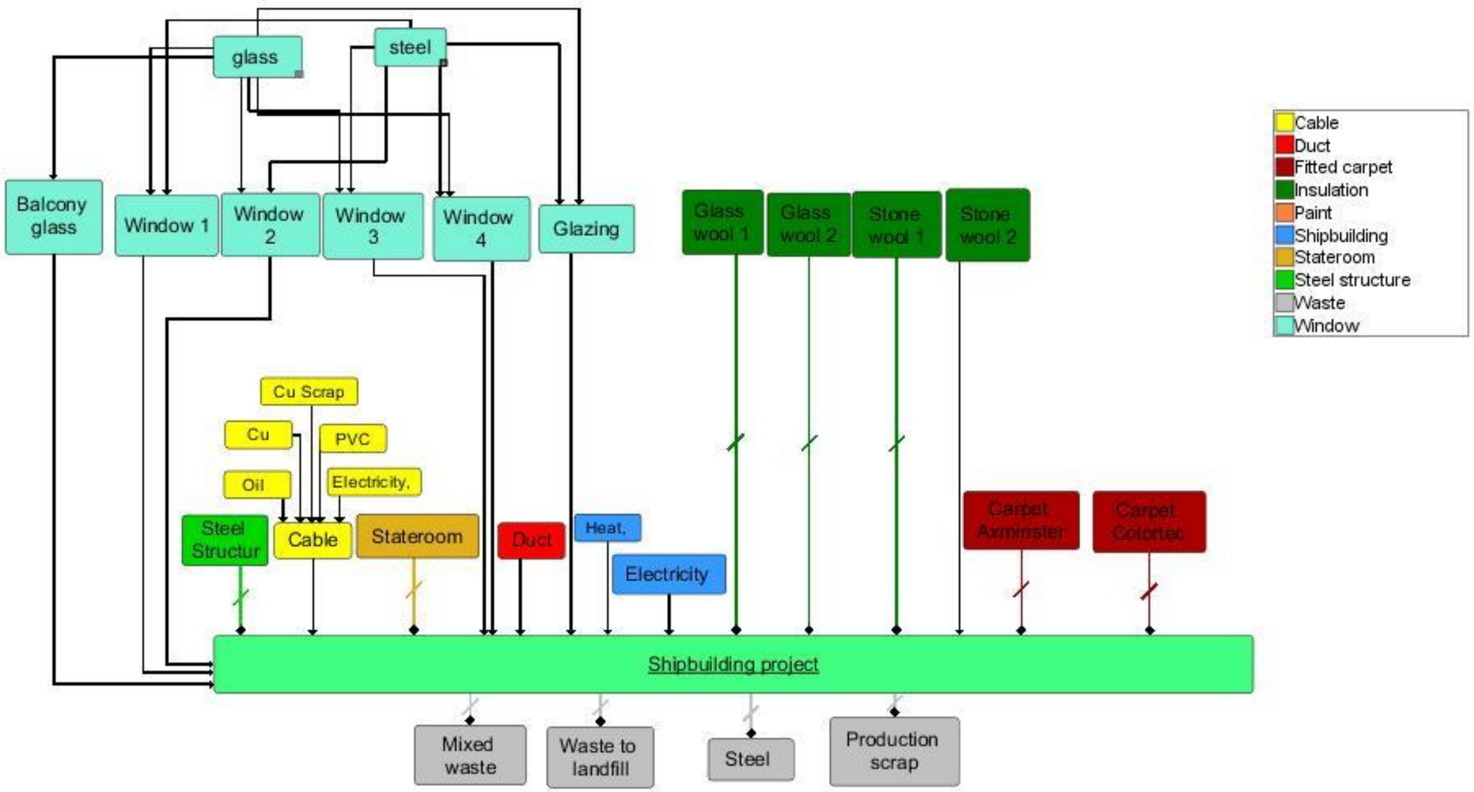
Process flow



Process flow shows the calculated processes. On the right side is a table with colour codes. Windows are the four window types that were calculated. Blue processes are the energy consumptions in the shipyard. Arrows which have colour on it and cross line means that there is transportation included. Cu scrap is the used recycled copper and Cu is raw copper.

Data table

Description	Material	Weight (t)	Input dataset
Steel strucure	steel	39 821	SSAB Raahe official emission trade 2018
Cable	copper	462	ELCD database, 2000
	polyvinylcholoride	462	ELCD database
	oil	19	ELCD database (EPER)
Stateroom	cabin	5 573	VTT calculation 2017
Duct	galvanized steel	18	ILMARI database 2013
Windows	glass	33	ELCD database
	steel	79	World Steel Association 2017
Glazing	glass	23	ELCD database
	steel	38	World Steel Association 2017
Balcony glass	glass	247	ELCD database
Glass wool 1	glass wool	327	ISOVER EPD, Ultimate
Glass wool 2	glass wool	325	ISOVER EPD, KL/KT Multi-Pack
Stone wool 1	stone wool	69	Rockwool Sustainability Report 2015
Stone wool 2	stone wool	250	Paroc EPD, with density <70kg/m^3
Carpet Colortec	Colortec carpet	111	Hammer Carpet, Denmark 2018
Carpet Axminster	Axminster carpet	111	Hammer Carpet, Denmark 2018

Description	MWh	Input dataset
Electricity	39 000	ELCD database, FIN 2015, 1 kWh
District heat	31 500	ELCD database, heat

Data table shows the processes, the input materials of the process, the amount of the input and what data is used.

Calculated results

label	output
carbon dioxide, fossil	4977 [kg]
Oil	4977 [kg] 100,00%
Carbon dioxide, fossil	8,862e+07 [kg]
Carpet Axminster	2,261e+04 [kg] 0,03%
Carpet Axminster -> Shipbui...	564,7 [kg] 0,00%
Carpet Colortec	2,261e+04 [kg] 0,03%
Carpet Colortec -> Shipbuild...	6476 [kg] 0,01%
Cu	1,827e+05 [kg] 0,21%
Cu Scrap	3127 [kg] 0,00%
Duct	1,980e+04 [kg] 0,02%
Electricity	2,840e+05 [kg] 0,32%
Electricity (cable)	4542 [kg] 0,01%
glass	2,708e+05 [kg] 0,31%
Glass wool 1	7,354e+05 [kg] 0,83%
Glass wool 1 -> Shipbuilding...	8919 [kg] 0,01%
Glass wool 2	2,671e+05 [kg] 0,30%
Glass wool 2 -> Shipbuilding...	5972 [kg] 0,01%
Heat	5,175e+06 [kg] 5,84%
Shipbuilding project -> Mixe...	1,987e+04 [kg] 0,02%
Shipbuilding project -> Prod...	7,606e+04 [kg] 0,09%
Shipbuilding project -> Steel...	5,092e+04 [kg] 0,06%
Shipbuilding project -> Wast...	2168 [kg] 0,00%
Stateroom	1,702e+07 [kg] 19,2...
Stateroom -> Shipbuilding p...	1,116e+04 [kg] 0,01%
steel (windows)	1,887e+05 [kg] 0,21%
Steel Structure	6,367e+07 [kg] 71,8...
Steel Structure -> Shipbuildi...	4,138e+05 [kg] 0,47%
Stone wool 1	4,830e+04 [kg] 0,05%
Stone wool 1 -> Shipbuildin...	65,86 [kg] 0,00%
Stone wool 2	1,060e+05 [kg] 0,12%
Carbon dioxide, fossil	9,672e+06 [kg]
Carpet Axminster -> Shipbui...	2,749e+04 [kg] 0,28%
Carpet Colortec -> Shipbuild...	1546 [kg] 0,02%
Cu	9,308e+05 [kg] 9,62%
Cu Scrap	2,357e+04 [kg] 0,24%
Electricity	7,490e+06 [kg] 77,4...
Electricity (cable)	1,198e+05 [kg] 1,24%
glass	5,997e+04 [kg] 0,62%
Glass wool 1 -> Shipbuilding...	6170 [kg] 0,06%
Glass wool 2 -> Shipbuilding...	1053 [kg] 0,01%
Heat	3,708e+05 [kg] 3,83%
Shipbuilding project -> Mixe...	3740 [kg] 0,04%
Shipbuilding project -> Prod...	1,432e+04 [kg] 0,15%
Shipbuilding project -> Steel...	6,786e+04 [kg] 0,70%
Shipbuilding project -> Wast...	408,0 [kg] 0,00%
Stateroom -> Shipbuilding p...	1969 [kg] 0,02%
Steel Structure -> Shipbuildi...	5,515e+05 [kg] 5,70%
Stone wool 1 -> Shipbuildin...	912,9 [kg] 0,01%

Carbon dioxide, fossil	1,660e+06 [kg]
Carpet Axminster -> Shipbui...	1694 [kg] 0,10%
Carpet Colortec -> Shipbuild...	754,0 [kg] 0,05%
Cu	1,016e+06 [kg] 61,2...
Cu Scrap	2,060e+04 [kg] 1,24%
Electricity	3,786e+05 [kg] 22,8...
Electricity (cable)	6055 [kg] 0,36%
glass	4,235e+04 [kg] 2,55%
Glass wool 1 -> Shipbuilding...	1279 [kg] 0,08%
Glass wool 2 -> Shipbuilding...	673,1 [kg] 0,04%
Heat	5,037e+04 [kg] 3,03%
Shipbuilding project -> Mixe...	2780 [kg] 0,17%
Shipbuilding project -> Prod...	1,064e+04 [kg] 0,64%
Shipbuilding project -> Steel...	1,384e+04 [kg] 0,83%
Shipbuilding project -> Wast...	303,3 [kg] 0,02%
Stateroom -> Shipbuilding p...	1258 [kg] 0,08%
Steel Structure -> Shipbuildi...	1,124e+05 [kg] 6,77%
Stone wool 1 -> Shipbuildin...	61,07 [kg] 0,00%
Carbon dioxide, fossil	9,829e+05 [kg]
PVC	9,829e+05 [kg] 100,...
Carbon dioxide, fossil	14,12 [kg]
Carpet Axminster -> Shipbui...	0,004359 [kg] 0,03%
Carpet Colortec -> Shipbuild...	0,0004903 [kg] 0,00%
Cu	8,070 [kg] 57,16%
Cu Scrap	0,04592 [kg] 0,33%
Electricity	4,421 [kg] 31,31%
Electricity (cable)	0,07070 [kg] 0,50%
glass	0,03221 [kg] 0,23%
Glass wool 1 -> Shipbuilding...	0,001313 [kg] 0,01%
Glass wool 2 -> Shipbuilding...	0,0003934 [kg] 0,00%
Heat	0,002110 [kg] 0,01%
Shipbuilding project -> Mixe...	0,001573 [kg] 0,01%
Shipbuilding project -> Prod...	0,006023 [kg] 0,04%
Shipbuilding project -> Steel...	0,1601 [kg] 1,13%
Shipbuilding project -> Wast...	0,0001717 [kg] 0,00%
Stateroom -> Shipbuilding p...	0,0007354 [kg] 0,01%
Steel Structure -> Shipbuildi...	1,301 [kg] 9,22%
Stone wool 1 -> Shipbuildin...	0,0001465 [kg] 0,00%

This table is taken from Sulca program. On the left side is the calculated process and on the right side is the carbon dioxide output in kilograms. Processes, with the arrow mark, mean transportation. Reason why there is multiple times the same process name but different output is because the process may include multiple carbon dioxide variables in different categories.

Sources of carbon dioxide