Master's degree thesis

LOG950 Logistics

An evaluation of alternative carbon-footprint minimizing production localizations of a new plant for the manufacturing of sustainable lithium-ion batteries for the car industry

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ABSTRACT

Unprecedented change is required to reduce the risk and effect of climate change, extreme heat, droughts, floods and more. In response to the rising concerns of the transport sector as catalyst for GHG emissions the electrification of vehicles powered by renewable energy was identified as a trustworthy initiative and the key guarantor for sustainability and reduction of GHG (Bonilla and Merino, 2010). Thus, Electric vehicles have emerged as a worthwhile substitute means of transportation, driven by energy security concerns, pressures to mitigate climate change, and soaring energy demand. The battery will remain the key component for the adoption of EVs because it expresses their cost, range and safety. Researches in the area of sustainable lithium-ion battery technology are producing opportunities for EVs to compete or replace their gasoline equivalents. However, one of the major challenges remains the location choice for a sustainable lithium-ion battery plant.

This master thesis seeks to evaluate the alternative carbon-footprint minimizing production localizations of a new plant for the manufacturing of sustainable lithium-ion batteries for the car industry among Germany, Norway, and Poland in Europe. It starts by identifying how to audit the carbon emission of a supply chain and proceed specifically to evaluate and quantify CO_2 emissions related to the energy source used in manufacturing the battery cells at the alternative locations, CO_2 emissions related to the inbound logistics at the alternative locations, and CO_2 emissions related to the outbound logistics at the alternative locations. A list of other factors affecting plant location choice was also highlighted. This study was done by the use of primary and secondary data with a combination of EcoTransit standard emission factor and a quantitative research method conducted through a comparative case study research strategy.

The study found Norway to be the best alternative to establish a sustainable EV lithium-ion battery plant. It had the lowest yearly CO_2 emission based on the same production capacity at the alternative locations. The study also revealed that the main advantage of Norway was the use of renewable energy in the cell manufacturing process that accounts for more than 98% of the total yearly CO_2 emissions in the production and distribution process. Germany has a localization advantage when it comes to emissions related to inbound and outbound logistics while Poland has no competitive advantage in terms of CO_2 emission reduction but has advantage over other factors such as lower labor cost.

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LIST OF ABBREVIATIONS

ABC:	Activity-based costing
AR:	Assessment Report
CCF:	Corporate Carbon Footprint
CDP :	Carbon Disclosure Project
CDLI:	Disclosure Leadership Index
CH_4:	Methane
CO_2eq:	Carbon dioxide equivalent
CO_2:	Carbon dioxide
EEA:	European Environment Agency
EMA:	Environmental Management Accounting concept
E**U:**	European Union
EV:	Electric Vehicle
EVBs:	Electric Vehicles Batteries
GHG:	Green House Gas
OEM:	Original Equipment Manufacturer
OECD:	Organization for Economic Co-operation and Development
ICLEI:	International Council for Local Environmental Initiatives
INDCs :	Intended Nationally Determined Contributions
IPCC:	Intergovernmental Panel on Climate Change
IRRCi:	Investor Responsibility Research Center Institute for Corporate Responsibility
LCA:	Life Cycle Assessment
Li-ion:	Lithium-ion
LIBs:	Lithium-ion Batteries
N_2O:	Nitrous oxide
SBTi:	Science-Based Targets initiative
PCF:	Product Carbon Footprint
UNO:	United Nations Organization
UNGC:	United Nations Global Compact
UNFCCC:	United Nations Framework Convention on Climate Change
WCED:	World Commission on Environment and Development
WBCSD:	World Business Council for Sustainable Development

WRI:	World Resources Institute (WRI)
WWF:	Worldwide Fund for nature

1.0 INTRODUCTION

1.1 Chapter introduction

This chapter introduces the thesis. It starts by laying down the background of the study, which includes the interest behind the study and the benefit of evaluating alternative production localizations of a new plant for the manufacturing of carbon-footprint minimizing sustainable lithium-ion batteries for the car industry in Europe. The research objectives have helped in the development of pertinent research question in the field of sustainable logistics.

1.2 Background of the study

Unprecedented change is required to cut down the risk and effect of climate change, extreme heat, droughts, floods and more. The effects of global warming has caused the international community, governments, civil societies and advocacy groups to take majors to reduce the emissions of Green House Gas (GHG). These actions are supported by UN Sustainable Development Goals on climate change and adopted by Organisation for Economic Co-operation and Development (OECD) and European Union countries amongst many. According to the UN, Sustainability is “meeting our own needs without compromising the ability of future generations to meet their own needs”. However, despite the initiative put so far to reduce the world’s carbon footprint, much is still required if the results must be actualised. This is justified by Intergovernmental Panel on Climate Change (IPCC) 2018 report which indicates that “Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate”. Even so, owing to the cumulative demand for vehicles and the continuous dependence on fossil fuel as a main source of energy has augmented the emission of GHG, making the transport sector the fastest-growing segment contribution to CO_2 emission (Kawamoto et al, 2019). Nevertheless, the effort to reduce GHG in the transportation sector is a global challenge (Gota et al, 2019) taking into consideration fuel depletion, unstable oil prices, and reliance on political oil-producing countries.

In response to the growing concerns of the transport sector as catalyst for GHG emissions the electrification of vehicles driven by renewable energy has been identified as a trustworthy initiative and the key guarantor for sustainability and reduction of GHG (Steinberg et al, 2017). This revolution brought a change in the supply chain in terms of technology, the raw material (electrified engine), integration and collaboration amongst partners. One of those innovations or discovery in the transport chain that has been identified as major catalysts for GHG saving is Electric lithium-ion battery. It is prominent that battery electric vehicles and plug-in hybrid electric vehicles may change the transport sector and considerably decrease oil consumption (Shi et al, 2019). Lithium-ion (Li-ion) and nickel-metal hydride (NiMH) batteries are the two dominant kinds of batteries used in electric vehicles, besides there are other favourable substitute battery technologies for electric vehicles such as metal-air and sodium batteries but these technologies are still under development and can therefore not be competitive now (Miao et al 2019). Presently, Li-ion batteries possess strong performance benefits over the alternative battery technologies, and it is significantly used in electric (Ding et al, 2019).

In the battery company, Sustainability problems extent the whole technology life cycle for energy storing systems like lithium-ion batteries (LIBs). It runs from battery plant localization, extraction of raw material, manufacturing of battery, use of EV, and end of life management of LIBs. To be sustainable in this type of company will mean to adopt efforts that will minimize CO_2 emission throughout the manufacturing and distribution process of the EV battery.

Nevertheless, with the advancing economics of EVs and a regulatory drive throughout different European countries, it is projected that by 2040 about 70% of all vehicles sold in Europe across diverse segments (trucks, vans, buses, and passenger cars) will be electric (Eddy et al, 2019). Similarly, it is projected that 1,200 gigawatt-hours per year of EV battery plants would be required in Europe by 2040. This amount is equivalent to 80 Giga plants with an average size of 15 gigawatt-hours per year, couple to that is the fact that several European administrations have announced their intention to block the sales of Internal Combustion Engine vehicles by 2030 or 2040 (Eddy et al, 2019). Resultantly, amongst many factors, the choice of localizing a battery plant can be very fundamental in contributing the reductions emission, besides favoring operational efficiency and productivity. The problem that centers around locating a plant is captured by the fact that European battery makers and car constructors run the danger of working at a competitive disadvantage to car manufacturers that are nearer and better able to safeguard battery supply as the demand for EVs increases. In addition, the rising production of electric vehicles without secured local battery capability might lead to high emissions from inbound logistics when the plant is located far from supplies and emissions from outbound logistics when the plant is located far from the market. Another pertinent risk for locating a li-ion battery plant is the growing demand for Electric Vehicle, which is already putting pressure on a scarce materials supply, raising supply risks. For instance, prices of lithium have tripled since 2015 and it is projected that the manufacturing of global cobalt will possibly double by 2025 to satisfy worldwide EV demand (Eddy et al, 2019).

Despite the euphoria that surrounds the revolution of the electric battery as a solution to saving GHG emission, a wide range of issues must be taken into consideration in other to establish a sustainable EV battery manufacturing plant, beginning with the location choice. Questions such as what is the primary source of energy (fossil fuel or renewable) used at a specific location? What are the technology, structure and logistical settings at certain location? What can we say about possibilities of accessing the raw materials and the cost? Is this site good-looking for professional staff? How is the taxation system and labour cost? What about the political atmosphere and policies in that location? How firmly researched the responses to such questions, the better the choice of location will be. This master's project will therefore try to answer some of these questions to come out with data in favour of the most suitable carbon footprint minimizing location among Germany, Norway and Poland.

1.3 Significance of the study

This Master thesis is expected to help EV battery manufacturers. The study sheds light on the best least CO_2 emission ways through which EV battery manufacturers can localize their manufacturing plant in other to sustainably optimize their upstream and downstream operations. Customers of these manufacturers will ask for documented sustainability in battery manufacturing, and it is therefore crucial that the choice of location is optimal with respect to minimizing CO_2-emissions. Furthermore, the conclusions of this study can serve as a steppingstone for future researchers on related topics by suggesting areas that need further attention. This thesis will also add value to the existing literation in the area of sustainable logistics.

1.4 Research objectives and questions

1.4.1 Research Objectives

The objectives of this research are classified into general and specific objectives.

General Objective

The main objective of this study is to evaluate alternative carbon-footprint minimizing production localizations of a new plant for the manufacturing of sustainable lithium-ion batteries for the car industry in Europe (Germany, Norway, and Poland). This objective will be achieved by using existing inbound/outbound data and standard emission factors from general model like EcoTransit to calculate the CO_2 emissions at alternative locations with a combination of quantitative method and comparative case study research strategy to determine the best location in terms of less CO_2 emission.

Specific Objectives

The specific objectives of the study are the following:

i. To find out how to audit the carbon emission of a Supply Chain.

ii. To identify and quantify the CO2 emission during the production of battery cells at the alternative locations.
iii. To identify and quantify the CO2 emission involved in upstream and downstream logistics at the alternative locations.
iv. To identify other relevant factors in the location choice decision at alternative locations.

1.4.2 Relevant Research Questions

It is very important for the researchers to come out with the research problem first followed by the research questions. These research questions will help the researchers to determine which research methodology to use in his work. In our study, the main research question is to find out "What is the best location among Germany, Norway and Poland to establish a green EV battery manufacturing plant" in Europe. These countries were selected because of the advantages each of them have in the manufacturing sector in terms of market size of EV used, EV manufacture, and the fact that they use different source of energy in their manufacturing sector. Therefore, from the main research problem, the following four research questions along with their explanation summarizes the concise questions which we will try to answer in other to get a solution to our research problem:

RQ1: How could the carbon emission of a supply chain be audited?

RQ2: Which is the likely CO_2-emission related to the energy source used in manufacturing at the alternative locations

RQ3: Which are the likely CO_2-emissions related to the inbound logistics at the alternative locations?

RQ4: Which are the likely CO_2-emissions related to the outbound logistics at the alternative locations?

RQ5: Which other factors than CO_2-emissions might be relevant for the choice of location?

2.0 LITERATURE REVIEW

2.1 Chapter Introduction

For research to be in a proper scholar context, it is very important to bring out relevant literature in the domain of the study. More importantly, a good theoretical framework will provide the foundation for arguments pertaining to the research questions. Our main literature will focus on sustainability, location choice, carbon auditing of supply chains, and battery technology. Meanwhile, the carbon auditing framework will be used to evaluate the GHG emissions of upstream and downstream logistics at alternative locations.

2.2 Sustainability in the supply chain

Sustainability is gaining significant courtesy from the media (Thogersen, 2006) and it has made its way into countless boardroom agendas over the previous decade, primarily due to stakeholder pressure (Eesley and Lenox, 2006). Supply chain management plays a critical role in achieving long-term success. Globalization, as well as cumulative shifts in consumer values, tastes, and desires, has had a significant impact on competition, as businesses are increasingly adapting their market strategies to meet customer needs. Nonetheless, unlike Resource base theory (Barney, 1991), which views a firm's resources and capabilities as the basis for competitiveness, Harts (1995) Natural Resource base theory examines competitiveness embedded in competences that allow economic activity in a sustainable setting. This viewpoint was backed up by Johnsen and Macquet (2012), who saw a sustainable supply chain as a source of competition that considers environmental, social, and economic concerns while procuring, producing, and distributing products to meet not only consumer values, but also economic, environmental, and societal values. When designing goods, sourcing raw materials, selecting a source of energy, manufacturing processes, and distribution capacities, a sustainable supply chain should understand the economic, environmental, and social implications to resolve their impact in the supply chain (Ibid: 10)

Procurement has long been regarded as the catalyst for value creation in the supply chain, as it lowers costs, improves company operations, and enhances customer service. However, in recent years, the conflict has centred on determining the best long-term procurement approach. As a result, procurement professionals pay little attention to long-term economic, social, and environmental considerations while standardizing specifications in order to reduce the number of suppliers and lower unit costs (Foerstl et al., 2015). Green procurement, on the other hand, has been used to base both purchasing decisions and contract allocations on environmental requirements, as well as other criteria including price, quality, and distribution (International Council for Local Environmental Initiatives ICLEI 2000). This shift in emphasis to a more strategic approach has resulted in a procurement strategy that requires procurement operations to capture long-term supply chain results.

Another well-known supply chain principle that has been used to command competition is value chain management (Porter, 1985), which entails controlling all of a company's critical activities and operations in order to provide products and services to consumers that add value or fulfil their needs. Sustainability has also been recognized as a magnificent choice for consumer values, in addition to consistency, low prices, and timely delivery. The environmental value chain analysis is one of the methods that has been used to drive supply chain sustainability. This includes instilling a culture of sustainability in key internal operations such as eco-friendly architecture, renewable energy, green transportation, recycled packaging, and upcycling, among others. Similarly, the Braungart and McDonough (2011) cradle to cradle model, which seeks to ensure that goods stay in a continuous circuit with no waste starting with the design, is critical in promoting sustainability.

Furthermore, looking downstream, reverse logistics is a logistics term that promotes sustainability. Few empirical studies have examined the effects of reverse logistics on sustainability (Aitken and Harrison, 2013), even though it has the potential to provide competitive advantages and generate new values (Jayaraman and Luo, 2007). Since reverse logistics is gaining popularity, most people still think about it in terms of recycling, which aims to handle waste rather than a circular perspective, which aims to eliminate waste from processes by upcycling, reuse, repairs, and remanufacture.

2.2.1 Definition of Sustainability by Brundtland Commission and beyond

The Club of Rome, an international think tank, published a study titled "Limits to Development" in 1972, which popularized the idea of sustainability. The momentum continued to build in 1980, when the World Conservation Union, in collaboration with the World Wildlife Foundation and the United Nations Environmental Programme, worked to make sustainability a global objective. In 1987, the World Commission on Environment and Development published "Our Common Future," a report that defined the term "sustainable development." The report is commonly referred to as the "Brundtland Report" after the commission's chairman, former Norwegian Prime Minister Gro Harlem Brundtland. This commission came up with the well-known definition: “Sustainable development is development that meets current needs without jeopardizing future generations' ability to meet their own needs” (WCED 1987, 43). As shown in figure 2.1, Carter and Rogers (2008) describe sustainability as the act of combining environmental, social, and economic responsibilities.

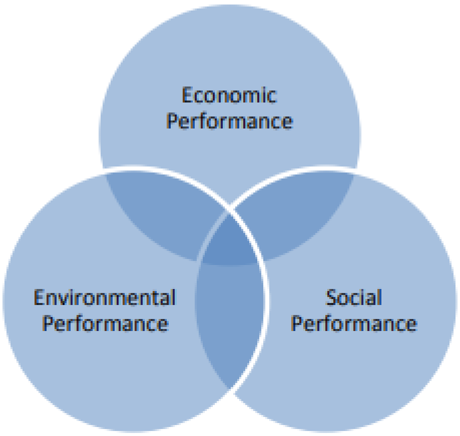


Figure 2. 1 The three building blocks of sustainability (Carter & Rogers, 2008)

The seventeen sustainable development goals proclaimed by the UN are the following:

- No Poverty
- Zero Hunger
- Good health and well-being
- Quality education
- Gender equality
- Clean water and sanitation
- Affordable and clean energy
- Decent work and economic growth
- Industry innovation and infrastructure
- Reduced inequalities
- Sustainable cities and communities
- Responsible consumption and production
- Climate action
- Life below water
- Life on land
- Peace justice and strong institutions.
- Partnerships for goals.

Most organizations and agencies have adopted this concept, but some scholars have criticized the Brundtland definition because it is too closely linked to growth and focuses less on human needs than on the separation of other life concerns. Environmentalists are not the only ones who believe in sustainability. Most theories of sustainability often include questions about economic growth and social equity. As a result, fiscal, environmental, and social sustainability are the three pillars of long-term viability.

2.2.2 The Climate Problem

Climate change, sustainability, and the creation of a circular economy are some of the most pressing issues facing the world today. Climate change can be described as human activity that alters the composition of the global environment and causes natural climate to be inconsistent and is observed over a long period of time (UNO, 1992). Just at this time the average temperature of the planet has increased since the arrival of the Industrial Revolution, with 2016 being the third consecutive hottest year on record.

The majority of scientists believe that atmospheric GHGs, especially methane (CH4), nitrous oxide (N2O), and carbon dioxide (CO2), have fueled global warming. Similarly, CO_2 emissions (CO_2eq) were chosen as the unit for calculating GHG, with each gas's 100-year global warming potential being indexed to that of CO_2. Burning, on the other hand, is the primary cause of GHG pollution. The combustion of fossil fuels such as gas, coal, and oil, on the other hand, is the primary source of GHG pollution. Other sources include farming practices such as forest clearing. These behaviors increase the amount of greenhouse gases (GHGs) in the atmosphere, raising temperatures. As a result, increased GHG levels increase the amount of radiation trapped by the atmosphere and diverted down toward the earth. This rise in GHG concentrations is expected to have a wide range of consequences, including:

- Growing sea levels
- Varying weather patterns and severe weather
- Tension on water and food
- Security risks and Political.
- Human health risks
- Influence on ecosystems and wildlife

Figure 2.2 shows the share of CO_2 emission by country. China, USA, India, Russia, and Japan have the highest shares of emission.

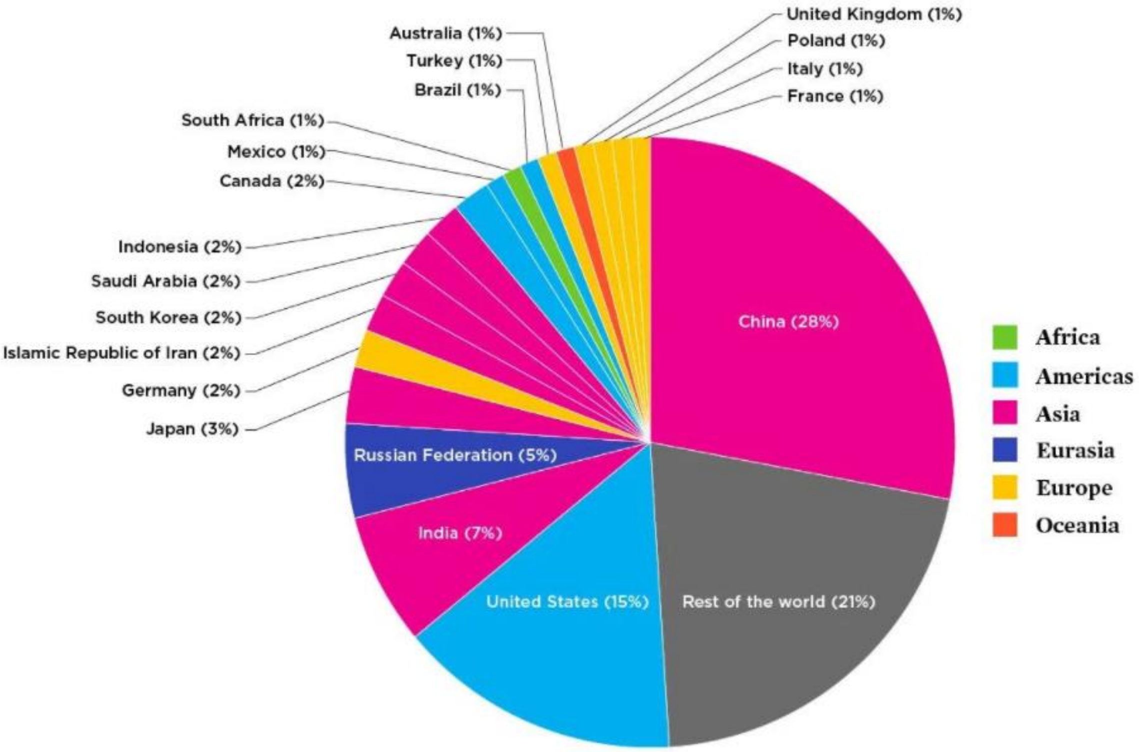


Figure 2. 2 Share of CO_2 Emission by Country (Countries colour coded by continent)

Source: Union of concerned Scientist 2020. Earth Systems Science Data 11,1783-1838, 2019

It is worth remembering that 97% of climate scientists, along with more than 200 countries, believe that human actions are to blame for climate change. These countries include the United States, the United Kingdom, Canada, China, France, Germany, India, Italy, Japan, and Russia. Some observers, on the other hand, claim that climate change is not a product of human activity. This party attributes the current rise in temperature to factors such as solar cycles and volcanic activity. Others argue that there is a lack of scientific consensus or that global temperature has decreased.

2.2.3 Actions to meet these challenges

Furthermore, due to forecasts of uncertainty on how GHG emissions would develop and the resulting changes in global temperature, the United Nations Environmental Program and the World Meteorological Organization responded to this challenge in 1988 by forming the Intergovernmental Panel on Climate Change (IPCC) to plan based on available science data, analyses of all aspects of climate change and its consequences. The scientists were selected for participation by their own governments and come from a total of 195 countries. According to the Intergovernmental Panel on Climate Change (IPCC) 2018 study, global warming is likely to hit 1.5 degrees Celsius between 2030 and 2052 if current trends continue. Thus result to take actions as follows:

i. Improving the efficacy with which energy is utilized
ii. Using renewable energy to decarbonize the world’s energy system
iii. Changing land use and management

2.2.4 Emission Related to Transport/Logistics

Transport demand per capita in developed and emerging economies is considerably lower than in the Organization for Economic Cooperation, and the Paris Climate Agreement's important goal is to keep global average temperature rise below 2 degrees Celsius while promoting measures to keep it below 1.5 degrees Celsius. They argue that countries reduce their carbon emissions. They demand that countries provide carbon reduction goals, known as "intended nationally defined contributions" (INDCs), prior to the Paris conference in order to achieve greenhouse gas emissions neutrality in the second half of this century. A series of mandatory provisions for monitoring, evaluation, and public reporting of progress toward a country's emissions-reduction goal are included in the Paris Agreement. Each country's commitments to reduce emissions were outlined in these targets.

OECD countries, however, are expected to increase their GHG emissions at a much faster pace in the coming decades due to rising incomes and infrastructure growth. According to section 8 of the IPCC fifth assessment report, the global transportation sector emitted 7.0 $GtCO_2eq$ of direct GHG emissions in 2010, including non-CO_2 gases, accounting for roughly 23% of total energy-related CO_2 emissions of 6.7 $GtCO_2$ (Section 8.1, IPCC AR5). Despite actions and policies such as more fuel-efficient cars, GHG emissions have continued to rise since the Fourth Assessment Report (AR4) (Section 8.1, 8.3, IPCC AR5). As a result, if aggressive and long-term mitigation policies are not implemented, transportation emissions will rise faster than emissions from other energy end-use sectors, reaching about 12 Gt CO_2eq/y.

According to the European Environment Agency, greenhouse gas emissions in the EU rose in 2018 and 2019, defying the EU's overall trend of decreasing emissions. Even with the measures currently planned in the Member States, the EEA National forecasts indicate that transportation emissions in 2030 will remain above 1990 levels. The transportation industry, which includes aviation and shipping, continues to be the largest contributor to transportation pollution. Nonetheless, additional action is required, particularly on the road. As a result, reducing the carbon intensity of fuels (CO_2eq/MJ) by substituting natural gas, bio-methane, or biofuels, electricity, or hydrogen generated from low GHG sources is critical. According to the International Energy Agency's (IEA) Energy Technology Perspectives survey, by 2070, global transportation (measured in passenger kilometers) would have doubled, car ownership rates will have increased by 60%, and demand for passenger and freight aviation will have tripled (IEA 2020). The combination of these factors will increase CO_2 emissions in the transportation sector, but significant technological innovations, such as the shift to lower-carbon energy sources and the use of electric vehicles, will mitigate this. The data in Fig. 2.3 is from the International Energy Agency and indicates direct GHG emissions from the transportation sector (IEA). It is represented here by mode of transport and shows a global increase in emissions from 5.0 $GtCO_2eq$/year in 2000 to 7.0 $GtCO_2eq$/year in 2010, and then to 8.0 $GtCO_2eq$/year in 2018 and lower emissions forecasted till 2070 (IEA, 2012a; JRC/PBL, 2013 and IEA 2020). Indirect emissions from fuel processing, automotive manufacturing, infrastructure building, and other sources are not taken into account.

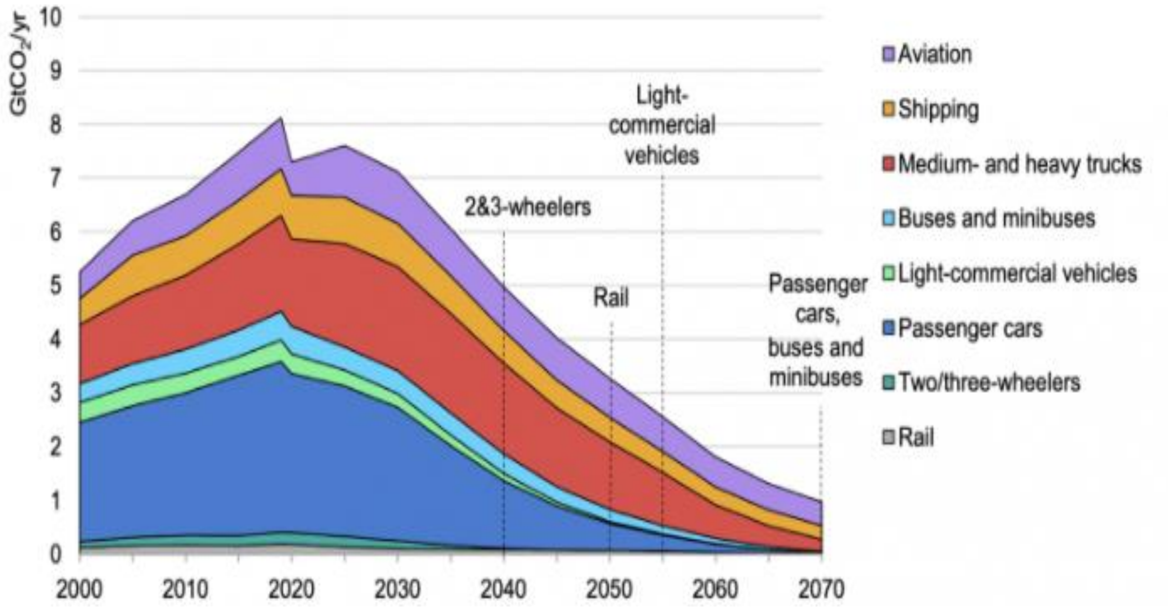


Figure 2. 3 Global GHG emissions growth for the transport sector by mode in the sustainable development scenario, 2000-2070 (IEA 2020.)

2.2.5 Lithium-Ion Batteries

To begin, the first LIBs were sold in 1991, and despite the fact that there are several different li-ion technical choices; this paper uses the Lithium Nickel Manganese Cobalt (NMC) technology. Since battery chemistries are at the heart of producers' issues, they are inextricably linked to raw materials and supplies. The Cathode makeup is the most significant feature that distinguishes Li-ion battery manufacturing technology. All types of batteries use lithium ions as charge carriers between the anode and the cathode, with graphite as the anode in the most advanced. The chemistry used in cathode prototypes serves as the basis for all cathode manufacturing techniques. There are five major innovations, each with its own set of advantages and disadvantages. Lithium nickel manganese cobalt (NMC), the technology we used in this paper, comes in a variety of varieties, including NMC 111 (which is based on an equal number of the three component atoms and is the simplest), NMC 532/622 (which is less expensive than NMC 111 due to a lower cobalt content but has a higher energy density), and the most recent and revolutionary NMC 811. The advantages of NMC include its high efficiency and low cost, as well as the fact that it can be used in other battery applications. Second, lithium cobalt oxide (LCO) has excellent performance and is relatively stable, and it is widely used in portable electronics. Because of its high cobalt content, this chemistry is relatively costly and therefore not used in EV applications. Third, Lithium nickel cobalt aluminum (NCA) improved nickel content by lowering the cost of cobalt in the LCO cathode, making it ideal for EVs and portable electronics with high energy density and low cost. Fourth, unlike other cathode chemistries, lithium iron phosphate (LFP) is intrinsically sound and stable. Because of its high power density, it's a good option for electric tools, e-buses, and EVs. Similarly, it is not covered by many intellectual property laws. Finally, Lithium manganese oxide (LMO) has a high level of reliability and is inexpensive. In comparison to other rival technologies, LMO has a disadvantage in terms of cell longevity. It has been used in electric vehicles, such as the Nissan Leaf. The global distribution of electric vehicles by battery chemistry is depicted in figure 2.4 below.

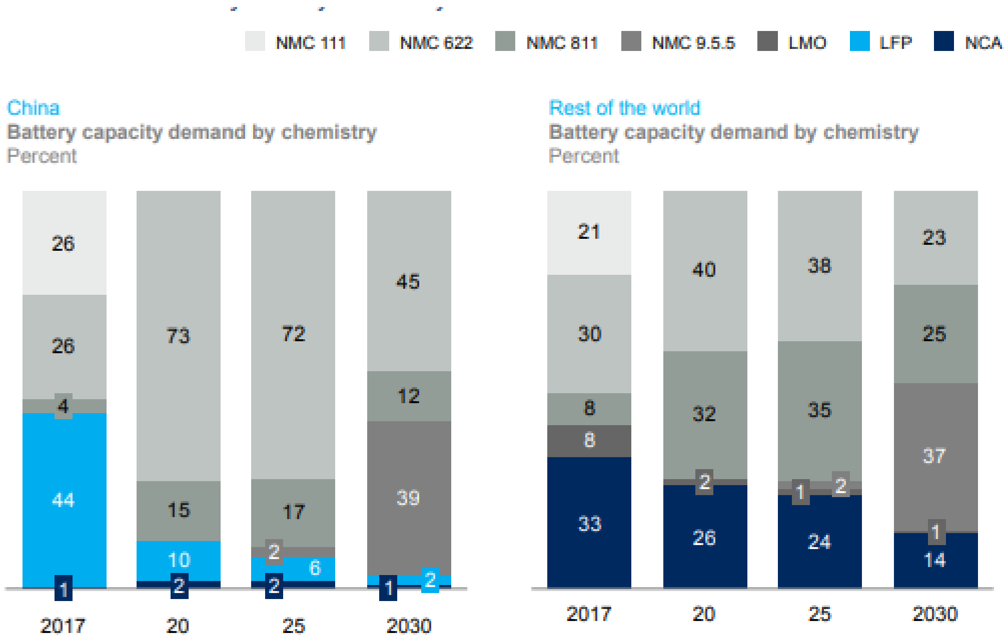


Figure 2. 4 **Distribution of EV by battery chemistry**
Source: Mckinsey Basic Material Institute Raw Materials Demand Model

Since LIB is also an active raw material for laptops and mobile phones, its market share has skyrocketed (Matteson & Williams, 2015). In 2014, more than 1500 million mobile phones with LIBs were sold, up from 300 million in 2000 (Heelan et al., 2016). In 2017, overall demand for LIB cells was 100 to 125 GWh (Avicenne, 2018), with electromobility accounting for 57-69 GWh and stationary applications accounting for 1.5-5 GWh. In 2017, the LIB demand in the portable/mobile device sector was estimated to be between 45 and 50 GWh. There are statistical inconsistencies associated with the source and market analysis in question, as well as variations in calculating product-specific unit sales and average battery sizes. Over the last few years, the LIB market has grown at a rate of 25% per year on average. The global LIB demand by segment in GWh and market share is shown respectively in Figure 2.5 and figure 2.6 below. Small-scale pouch, prismatic, and cylindrical cells up to size 18650 are available on the 3C market. The demand in this section is not considered in the subsequent studies. In electro mobile and stationary applications, only LIB is in demand. There are large-scale pouches, prismatic cells, and cylindrical cells with a diameter of 21700 used.

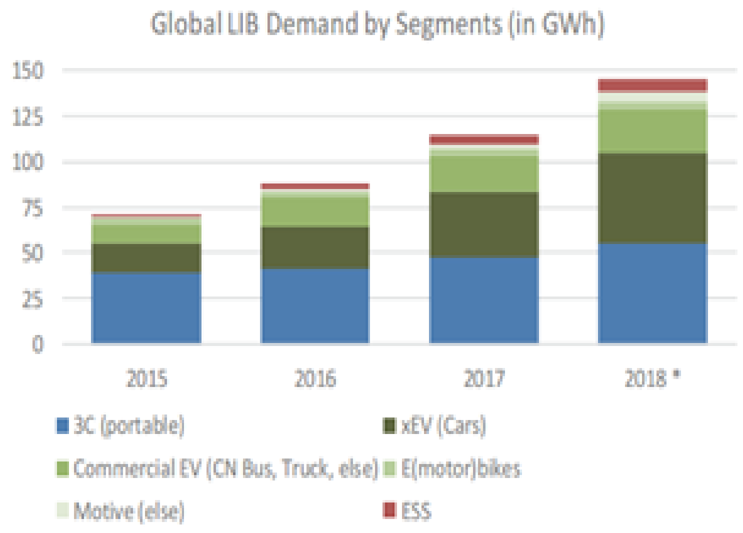


Figure 2. 5 Global LIB demand by segment (in GWh)
Source: Fraunhofer ISI (Thielmann 2017 based on various market studies market studies 2013-2017, Avicenne 2018, Takeshita 2018, Yole 2018, etc).

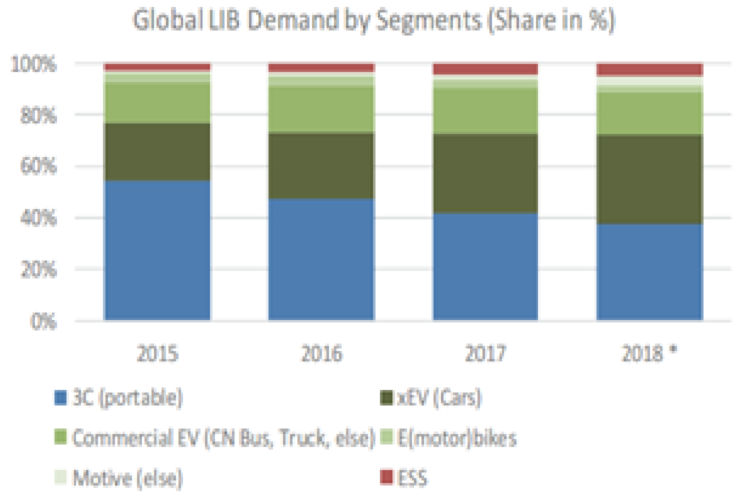


Figure 2. 6 Global LIB demand by segment (Share in %)
Source: Fraunhofer ISI (Thielmann 2017 based on various market studies market studies 2013-2017, Avicenne 2018, Takeshita 2018, Yole 2018, etc).

Generally, the useful life of a LIB in gadgets other than EVs is somewhere in the range of two and ten years (Peiro et al., 2013). The most used batteries innovation for electric vehicle battery EVB today are the LIBs innovation (Pelletier et al., 2016; Yazdanie et al., 2016). EVs are power-driven by auxiliary batteries. Auxiliary batteries are battery-powered while essential batteries are not battery-powered (Peiro et al., 2013). EVs are heavier than inside ignition motor vehicles, the principal contrast here being the heaviness of the battery (Palencia et al., 2012). As the market for EVs is developing at a quick rate and innovation headways for batteries are being made with brief time frame spans, EVBs are additionally seeing a decline in their value (Pelletier et al., 2016). The worth of EVBs in the complete creation cost of EVs can be identified with this lessening as followed. Hein, Kleindorfer and Spinler (2012) revealed that batteries represent around 66% of the complete creation expenses of EVs. After three years, in 2015, Matteson and Williams (2015) expressed that battery much of the time represents up to half of the complete expense of creation. Finally, in 2018, Klör et al. (2018) communicated that EVBs represent between 20-40% of the absolute expense of assembling an EV. Matteson and Williams (2015) contend that LIBs are over the top expensive to deliver because of the absence of economies of scale along with high material expenses. Among the distinctive EVBs as of now accessible available, the most well-known ones are nickel-metal-hydride batteries, sodium-nickel-chloride batteries, lead-corrosive batteries and LIBs (Pelletier et al., 2016). When compared to the other competing type on the market, LIBs have various advantages. We may mention, for example, how LIBs weigh half as much as other battery types and can be 20 percent to half as small while providing a similar limit. Furthermore, LIBs have several times the voltage of other battery types (Peiro et al., 2013). Their combined qualities have an unrivaled combination that makes them ideal for electric vehicles (Ellingsen, Hung, and Strmman, 2017). The attributes of LIBs, according to Ramakrishnan et al. (2014) and Pelletier et al. (2016), have a generally long support existence while also being a naturally legitimate alternative (Ordoez, Gago, and Girard, 2016). LIBs have a high energy thickness, which results in a wide stockpiling cap (Ellingsen et al., 2017; Heelan et al., 2016; Notter et al., 2010; Ramakrishnan et al., 2014; Xiao, Li, and Xu, 2017), high explicit energy and force (Pelletier et al., 2016), and low memory effect (Notter et al (Notter et al., 2010).

There have not been many mentions of LIBs' disadvantages. While LIBs need less maintenance, they are significantly more costly when they are needed (Ramakrishnan et al. 2014). Furthermore, cold weather has a negative impact on LIBs, which has a negative impact on EV results (Jaguemont, Boulon, & Dubé, 2016). The overall useful life of a LIB can be influenced by how it is used and maintained. Which is directly linked to the vehicle’s driving range (Hein et al., 2012)?

Although it is difficult to pinpoint what causes EVBs to age, driving habits, extreme temperatures, and charging rates are all known to play a role (Klör et al., 2018; Pelletier et al., 2016). Furthermore, as power fades, other features such as acceleration and quick charging capabilities become less available (Klör et al., 2018). The battery loses energy as a result of high speed, rapid acceleration, carrying heavy loads, and ascending slopes (Pelletier et al). (2016). The EVB finally enters the reverse logistics (RL) flow as a result of all these variables. The charging rate and depth of discharge are two other factors that affect the LIBs' useful life (Shokrzadeh & Bibeau 2016). Furthermore, when the total capacity of the battery has been degraded to below 80% (Hein et al., 2012; Klör et al., 2018; Pelletier et al., 2016; Yazdanie et al., 2016), or when the vehicle has been run for about 100.000 km (Klör et al., 2018) to 150.000 km (Yazdanie et al., 2016). According to research, LIBs have a good chance of improving dramatically in terms of driving range and specific energy in the future by further evolving existing technologies. Also, depending on how the EV is used and stored, it may take up to fifteen years for the LIB EOL to be reached after purchase (Peiro et al. 2013).

Even though LIB chemistry varies, the assemblage in the battery pack is nearly identical. Battery packs, according to Klör et al (2018), are modular, meaning that the cells that provide electric power are assembled into modules (Pelletier et al., 2016). After that, the modules are inserted into the battery pack. A thermal management system and a battery casing are also included in the battery pack (Klör et al. 2018), and EVBs have a battery management system (BMS) that controls consistency and protection inside the battery. An anode, cathode, separator, and electrolyte are also needed for any LIB (Heelan et al., 2016; Ordoez et al., 2016). LIBs usually contain 5-20% cobalt, 5-10% nickel, 5-7% lithium, 7% plastics, and 15% organic chemical products (Ordoez et al., 2016). According to Heelan et al. (2016), the cathode is the most inconsistent and variable component. They say, for example, that lithium cobalt oxide was used in the very first electric vehicles (LiCoO2). In 2008, more than 60% of all EVs had this configuration; by 2012, that figure had dropped to about 37%, and it is projected to fall even further (Heelan et al. 2016). Further, they clarify that cobalt as of late has been supplanted with nickel-manganese-cobalt (NMC) because of its powerful thickness. Today, this piece is habitually changed to amplify the ideal qualities of the battery. Yazdanie et al. (2016) express that right now, the piece and the advances utilized in LIBs do not altogether influence the absolute ozone depleting substance emanations from EVs; it is fairly the essential fuel source e.g., the utilization of sustainable power that has an effect in generally outflows. However, according to Dunn et al. (2012), one of the key reasons why recycling and repurposing become problematic is that LIBs are not limited to a particular collection of materials. They also note that different compositions and associated performance characteristics are another reason why LIBs have issues that need to be addressed in their EOL. Furthermore, the authors conclude that recovering and recycling metals like cobalt, lithium, and manganese could be both profitable and environmentally beneficial.

In summary, there are three major process phases in the manufacture of a lithium-ion battery cell:

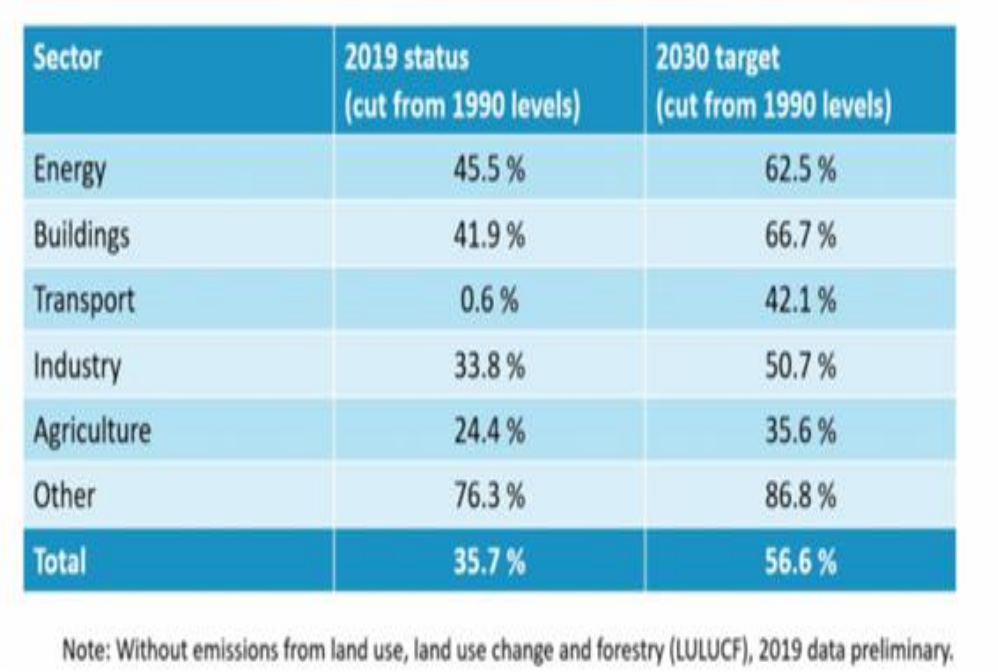
1) **Electrode manufacturing**
2) **Cell assembly**
3) **Cell finishing**.

The electrode manufacturing and cell finishing processes are not affected by the cell form, but there is a distinction to be made between pouch cells, cylindrical cells, and prismatic cells during cell assembly. The smallest unit of any lithium-ion cell, regardless of the form, consists of two electrodes and a separator that separates the electrodes from one another. The ion-conductive electrolyte fills the pores of the electrodes as well as the cell's remaining vacuum.

2.3 Carbon Auditing

Governments and international organizations have been setting greenhouse gas (GHG) emission targets for the next 10 to 30 years in recent years. The Norwegian climate change act aims to cut GHG emissions by 40% by 2030 compared to 1990, and to turn Norway into a low-emission society by 2050. A low-emission society is one in which greenhouse gas emissions have been reduced to avoid the negative effects of global warming, as defined in Article 2 1.a) of the Paris Agreement of December 2015, based on the best available scientific knowledge, global emission trends, and national circumstances. By 2050, the EU wants to be carbon neutral. That is an economy that emits no greenhouse gases at all. This goal is central to the European Green Deal and aligns with the EU's Paris Agreement pledge to global climate action. Companies all over the world are taking steps to minimize GHG emissions as a result of climate change, as is their value chain. Table 2.1 depicts Germany's 2030 GHG emission targets by sector.

Table 2. 1 Germany’s 2030 sector targets for GHG emission reduction & 2019 status



Sector	2019 status (cut from 1990 levels)	2030 target (cut from 1990 levels)
Energy	45.5 %	62.5 %
Buildings	41.9 %	66.7 %
Transport	0.6 %	42.1 %
Industry	33.8 %	50.7 %
Agriculture	24.4 %	35.6 %
Other	76.3 %	86.8 %
Total	**35.7 %**	**56.6 %**

Note: Without emissions from land use, land use change and forestry (LULUCF), 2019 data preliminary.

Carbon accounting tends to be a universal umbrella approach that covers all types of greenhouse gas and carbon accounting. The main greenhouse gas (GHG) is carbon dioxide (CO_2). The majority of what we eat and use in our everyday lives results in CO_2 pollution, either directly or indirectly. CO_2 is a greenhouse gas (GHG) that contributes to global warming and climate change.CO_2 concentrations in the atmosphere are rising at an alarming pace. Carbon dioxide (CO_2) and other greenhouse gases (GHGs) emissions have exacerbated global warming and climate change risks to our environment. In the following ways, the resulting issues directly harm our climate, health, culture, and economy: To begin with, there have been boring weather events with higher land and ocean temperatures, as well as an intensification of the hydrologic cycle, resulting in a greater incidence of severe weather such as hurricanes, typhoons, droughts, and floods. Second, global warming has had a negative impact on eco-systems and biodiversity. This is because, as the temperature of the oceans and atmosphere rises, the ecosystems of many plants and animals that have evolved will be destroyed. Temperatures can also contribute to an increase in the prevalence and spread of diseases. Also, as sea levels rise as a result of increasing ocean temperatures, glaciers and ice sheets across the world melt, putting 70% of the world's population at risk of flooding. Furthermore, as ice melts, the Earth's surface becomes less reflective, raising surface temperatures. Ice sheets melting may result in the release of deposits of greenhouse gases.

As a result, there has been a substantial increase in global awareness, and there is a pressing need to minimize GHG emissions on a global scale. Many countries are working to develop policies and protocols to monitor GHGs on an international level in order to address environmental problems. Similarly, several governments have established carbon reduction targets. Various GHG control mechanisms, such as carbon trading, pollution trading, carbon offset, clean growth mechanism, and so on, have also been developed to promote global emissions reduction. Similarly, an increasing number of businesses and corporate organizations have emphasized the importance and benefits of mitigating climate change. Regulatory uncertainties and competitive risks are two imminent threats to these businesses. Global and foreign policy instruments aimed at reducing carbon emissions pose regulatory risks. For example, the European Union has set a goal of reducing carbon emissions by more than 80% by 2020 compared to the 1990s.Regulatory uncertainties and competitive risks are two imminent threats to these businesses. Global and foreign policy instruments aimed at reducing carbon emissions pose regulatory risks. A comprehensive carbon-constrained competition that seeks to distinguish services and products in terms of carbon emissions and efficiency could result in competitive risks (Busch and Shrivastava, 2011). Nonetheless, the greatest complexity and difficulty in business society is determining how much each organization can reduce its emissions. Surprisingly, trying to resolve this conundrum resulted in the creation of the principle of carbon auditing (also known as Carbon Accounting, Carbon Footprint, Carbon or Greenhouse Inventory)

The business mantra "if you can't quantify it, you can't handle it" has inspired civil and cooperative society stakeholders to create the idea of carbon auditing as a method to measure and manage the global climate effects of GHG emissions. Through their roles as innovators, carbon emitters, and manufacturers, collaboration and business organizations have inevitably been identified as key players in carbon accounting and reporting (Hoffman, 2005). Nonetheless, product analysis and life cycle evaluation along the supply chain from upstream to downstream have been recognized as a key technique for capturing greenhouse gas emissions among the various techniques used by companies to calculate and report their carbon footprint from energy loops within product categories and business operations such as procurement, transportation, production, distribution, and storage. Figure 2.7 depicts a product's carbon footprint (either a good or a service), a single company's carbon footprint, and a supply chain's carbon footprint. The carbon auditing of a supply chain or a product is more difficult than the auditing of a single company since the carbon auditing of a supply chain or a product involves multiple players in the upstream and downstream. One of the most difficult aspects of carbon auditing is identifying the boundaries of the structure that will be carbon foot printed.

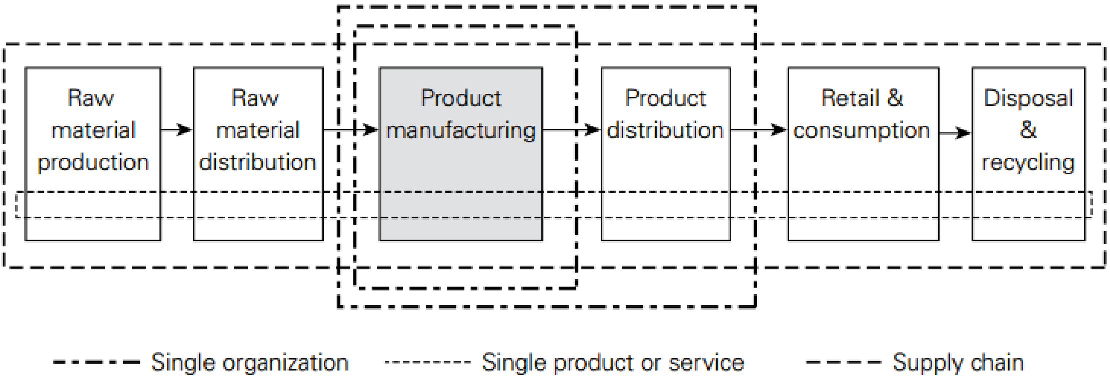


Figure 2. 7 Types of carbon footprint

Source: Based on Carbon trust (2006)

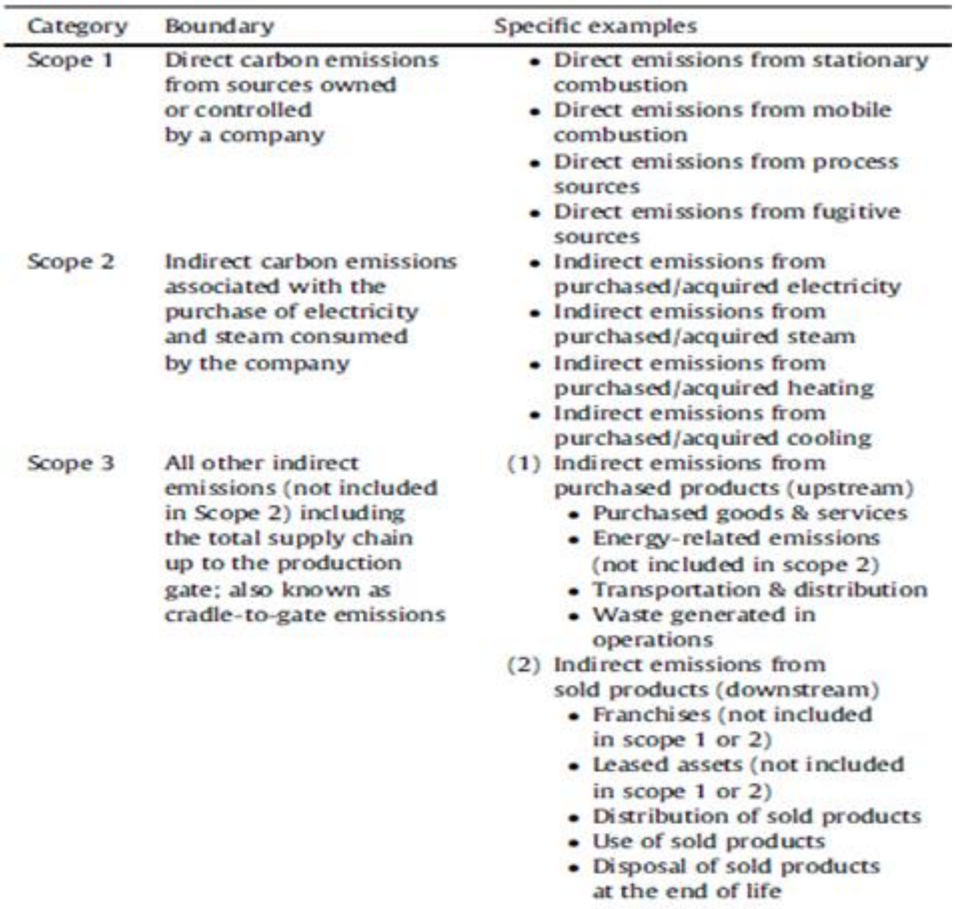
The report commissioned by the Investor Responsibility Research Center Institute for Corporate Responsibility (IRRCi), on Carbon Risks and Opportunities in the S&P 500 (Trucost,2009), found that more than 80% of businesses face carbon risks due to pollution in their supply chain. Gunasekaran and Spalanzani wrote in the press that a lack of adequate data and high monitoring costs are stumbling blocks to implementing green and sustainable supply chain management. Nonetheless, some leading organizations could follow several approaches and tools, such as a life cycle assessment (LCA), carbon footprint analysis, and environmental sustainability accounting, to address these obstacles (Matos and Hall, 2007). However, there is still a dearth of theoretical and empirical studies in the field of supply chain carbon auditing, especially for developing frameworks and measurement approaches for carbon footprint efficiency. Meanwhile, before diving into supply chain carbon auditing, it is critical to consider the current state of the carbon auditing concept, what it entails, and how it is evolved over time.

To begin with, in recent years, the word "carbon auditing" has become commonly used by academic writers and business consultants. Carbon auditing is a method used to calculate the amount of greenhouse gas emissions associated with a company's Corporate Carbon Footprint (CCF) or the life cycle of operation of a Service or Product Carbon Footprint (PCF) to figure out what role it plays in climate change (Fullana et al., 2008). The Supply Chain Solution Center substantiated this explanation, describing carbon auditing as "the process of companies quantifying their GHG emissions, recognizing their climate effect, and setting targets to reduce their emissions." Carbon auditing, according to Wiedemann and Minx (2008), is "a calculation of the cumulative amount of CO_2 emissions generated directly or indirectly by an operation or accumulated over the life stages of a product." The fact that most government economies now need their businesses to measure their emissions correctly and reliably demonstrates this. The European Emissions Trading Scheme, for example, requires that industries that rely heavily on fossil fuels, such as chemicals, steel, power generation, and cement, register their carbon footprint (McKinnon and Halldórsson 2010). Companies in other industries are now routinely measuring and reporting figures of their carbon emissions as part of their cooperative social obligation. Similarly, the Carbon Disclosure Project is an international initiative that promotes annual carbon emissions tracking and reporting. Carbon auditing or accounting has been sponsored by both of these programs. It is classified as greenhouse gas inventory in some organizations. In their report, Wiedmann and Minx (2008) confirmed that there is no widely accepted concept of carbon auditing, defining it as a calculation of the cumulative amount of carbon dioxide emissions produced by operation or accumulated over the life stages of a product, both directly and indirectly. The scope of carbon auditing within the supply chain was defined by this term, which included all direct activities related to on-site or internal emissions (downstream) and indirect activities related to off-site or external emissions (upstream). This has also exposed the importance of correctly selecting balancing boundaries in greenhouse gas emissions accounting and reporting to include both direct and indirect emissions so that businesses can account for emissions from manufacturing processes, oil, and raw material sourcing. The GHG Protocol Initiative (WRI/ WRCSD 2004) captures this concept of specifying the spectrum for corporate accounting and reporting of CO_2 and greenhouse gas emissions, which identifies three scopes of greenhouse gas emissions as follows:

- **Scope 1:** Emissions resulting from the company's direct operations, such as fuel combustion in facilities and automobiles owned or regulated by the company.
- **Scope 2:** Emissions resulting from the generation of purchased energy used by your business, such as steam, heating, and cooling.
- **Scope 3:** All other indirect sources of emissions in your company's supply chain, such as imported raw materials, distribution, and transportation, employee commuting, product usage, and end-of-life care.

Contrary to the popular belief that carbon accounting should be treated as a separate business activity, there is a clear need to incorporate carbon accounting issues into various functional fields in order to achieve both corporate and climate policy objectives (Csutora and Harangozo 2017). Carbon auditing is a growing field of business economics that encompasses a broad range of activities such as greenhouse gas emissions assessment, estimation, tracking, reporting, and auditing at the organizational, operation, product, and supply chain levels. Accepting an inventory of a company's total greenhouse gas emissions, its equipment, and its goods can be used to measure carbon output (Lee, 2011). Setting organizational boundaries to calculate and report carbon emissions is essential for managing carbon output in a supply chain (Lee, 2011). For example, Archel et al. (2008) reviewed 57 sustainability papers that were said to be "in line" with the GRI database and discovered that they lacked boundary setting and boundary transparency at an organizational and operational stage. Their findings have revealed that companies use sustainability reports to avoid accounting obligations and refuse to disclose the direct and indirect carbon impacts of their activities. As a result, it is important to use the right balancing boundaries when planning for and measuring carbon emissions, and to consider both direct and indirect emissions, as seen in table 2.2.

Table 2. 2 Carbon Emission Reporting Boundary **(Adapted from Lee 2011)**



Category	Boundary	Specific examples
Scope 1	Direct carbon emissions from sources owned or controlled by a company	• Direct emissions from stationary combustion • Direct emissions from mobile combustion • Direct emissions from process sources • Direct emissions from fugitive sources
Scope 2	Indirect carbon emissions associated with the purchase of electricity and steam consumed by the company	• Indirect emissions from purchased/acquired electricity • Indirect emissions from purchased/acquired steam • Indirect emissions from purchased/acquired heating • Indirect emissions from purchased/acquired cooling
Scope 3	All other indirect emissions (not included in Scope 2) including the total supply chain up to the production gate; also known as cradle-to-gate emissions	(1) Indirect emissions from purchased products (upstream) • Purchased goods & services • Energy-related emissions (not included in scope 2) • Transportation & distribution • Waste generated in operations (2) Indirect emissions from sold products (downstream) • Franchises (not included in scope 1 or 2) • Leased assets (not included in scope 1 or 2) • Distribution of sold products • Use of sold products • Disposal of sold products at the end of life

Furthermore, the release of greenhouse gas data by International Climate Policy Markers sparked Carbon Auditing and the need for monitoring and controlling carbon emissions from various socio-economic spheres. This can be traced back to the 1997 Kyoto Protocol, an international treaty that supplemented the 1992 United Nations Framework Convention on Climate Change (UNFCCC) by requiring party states to minimize greenhouse gas emissions, based on scientific consensus that global warming is accelerating at an alarming pace and that man-made greenhouse gas emissions are primarily to blame. The UNFCCC's goal of reducing the onset of global warming by reducing greenhouse gas concentrations in the atmosphere to a degree that prevents harmful anthropogenic interference with the climate system was adopted by the Kyoto Protocol, which went into effect in 2005. Carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride are the six greenhouse gases covered by the Kyoto Protocol (SF6). As a result of this framework, the concept of corporate greenhouse gas accounting and reporting was born. Aside from that, the Carbon Disclosure Project (CDP) is another organization that promotes greenhouse gas emissions accounting and monitoring. The Carbon Disclosure Project (CDP) is a non-profit organization that manages the global disclosure framework for investors, businesses, cities, states, and regions. CDP was seen as the gold standard in environmental reporting, with the richest and most detailed dataset on corporate and city action. CDP is based on the Global Reporting Initiative's (GRI) definition of environmental disclosure, which was introduced in 2002 and focuses on individual businesses rather than nations. CDP now accounts for about a quarter of all global greenhouse gas emissions. The Intergovernmental Panel on Climate Change (IPCC) is another organization that has made significant contributions to carbon auditing and monitoring. IPCC is a United Nations intergovernmental body established in 1988 that produces detailed Assessment Reports on the state of science, technological, and socioeconomic information on climate change, its effects and potential threats, and options for slowing climate change. Human health and well-being are motivations for the initiative of carbon auditing to account, monitor, and control greenhouse gas emissions, which follows the IPCC Report on Global Warming in 2018, which notes that reducing global warming to 1.5 degrees Celsius would minimize difficult impacts on ecosystems. Similarly, a study from the IPCC that funded the creativity of carbon auditing and accounting among collaborating and civil society stakeholders depicts that reducing global net human-caused carbon dioxide (CO2) emissions by 45 percent by 2030 and achieving "net zero" about 2050 would ensure a healthy climate. This scheme included the sale of carbon credits as well as a restriction mechanism in which businesses are limited in the amount of CO2 they can emit. Similarly, the International Standard Organization ISO 14090 developed standards, criteria, and guidelines for adaptation to climate change. Other factors that motivate the quantification of carbon emissions, and hence the birth of carbon auditing, are the need to help organizations quantify climate change impacts and put strategies in place for successful adaptation. These tools aided organizations in identifying and managing threats, as well as seizing any opportunities presented by climate change. Meanwhile, it is critical to discuss the Criteria developed for calculating and reporting carbon emissions, as well as the organizations involved in developing such standards, after giving credence to the frameworks that motivated the creation of carbon auditing.

To begin, the Greenhouse Gas Protocol (GHG Protocol) is the most used international accounting tool for understanding, quantifying, and managing greenhouse gas emissions by government and business leaders. The World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) recognized the need for an international standard for corporate GHG accounting and reporting in the late 1990s, and the GHG Protocol was founded. The GHG Protocol is a long-term collaboration between the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), which began in 1997 with an official agreement to establish an NGO-business relationship to discuss uniform GHG accounting procedures. Furthermore, the first version of the Corporate Standard was released in 2001 and has since been updated with supplementary guidance that explains how businesses should calculate and account for emissions from electricity and other energy purchases, as well as emissions from their value chains. In addition, the GHG Protocol developed a set of measurement methods to help businesses calculate their greenhouse gas emissions and assess the benefits of climate change mitigation programs. Overall, the GHG Protocol is about collaborating with governments, companies, and environmental organizations all over the world to develop a new generation of reliable and successful climate change initiatives. From the International Standards Organization to the Climate Registry, it provides the accounting basis for almost every GHG standard and program in the world. It serves as the accounting basis for thousands of GHG inventories prepared by individual entities, as well as virtually every GHG standard and program in the world, from the International Standards Organization to the Climate Registry. The GHG Protocol also provides developing countries with a globally negotiated management mechanism to assist their businesses in competing in the global marketplace and their governments in making informed climate change decisions. In 2016, for example, 92 percent of Fortune 500 businesses responded to the Carbon Disclosure Project (CDP) by reporting their carbon emissions directly or indirectly through a program focused on the GHG Protocol. GHG Protocol Corporate Accounting and Reporting Standard, which specifies a step-by-step checklist for organizations to use in quantifying and reporting their GHG emissions, and GHG Protocol Project Quantification Standard, which is a guide for quantifying reductions from GHG mitigation programs. The GHG Protocol developed another framework for managing the value chain, the GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, as a supplementary standard that focuses on Scope 3 emissions.

The Science-Based Targets initiative is another organization that helps businesses gain a competitive edge in the transition to a low-carbon economy (SBTi). By 2020, science-based goal setting will be ordinary business practice, and companies will play a major role in reducing global greenhouse gas emissions, according to the overall message. It began as a partnership between the Carbon Disclosure Project (CDP), the United Nations Global Compact (UNGC), the World Resources Institute (WRI), and a few of the major Business Coalition Commitments. With the help of a professional advisory committee, SBTi was able to define and encourage best practices in science-based target scenery. It also planned to provide tools, seminars, and advice to help businesses overcome obstacles to adoption while independently evaluating and approving their goals. It also wanted to highlight companies that set science-based targets through events, media, and case studies to highlight how science-based goal setting improves creativity, reduces regulatory uncertainty, strengthens investor trust, and boosts profitability and competitiveness. Through incorporating science-based goal setting into the CDP survey and scoring, science-based target setting has become an appealing aspect of companies' annual reporting practices and the data infrastructure for institutional investors. The Science Based Targets initiative also promotes the integration of science-based target-setting into existing climate leadership networks such as UN Caring for Climate, WWF Climate Savers, and others. In addition, CAIT climate data includes science-based goals. In order to achieve a low-carbon economy, science-based goals must be embedded as a fundamental component of sustainable management activities.

2.3.1 Critical Elements and Challenges of Cooperate Carbon Accounting

Before we delve into the critical elements and challenges of corporate carbon accounting, which will be the focus of this segment, it's important to remember that carbon accounting was first discussed by the Environmental Management Accounting definition (EMA).The Environmental Management Agency (EMA) is one of the sustainability principles that has gained praise from the press and civil society for accounting for how the organization's business behavior impacts the environment, as well as the environmental effect on cooperation. Carbon Accounting has evolved from a topical field in EMA to a practical area, despite the global nature of this concept's approach to environmental concerns such as recycling energy, power, and carbon footprint (Csutora and Harangozo 2017). Since much attention was paid to climate and, therefore, carbon emission issues during the second period of environmental management accounting, where Greenhouse gas emissions were no longer considered as one form of flying emissions but rather as a separate topical concern within environmental accounting, this became a special focus field for sustainability researchers and business practitioners. As a result, the field of carbon accounting was born. When the definition of carbon accounting is expanded to include a broader range of GHGs, however, the term "carbon accounting" becomes somewhat misleading, as other non-carbon dependent GHGs (such as N2O and SF6) are included as well (Downie and Stubbs 2013). In this regard, the terms greenhouse gas accounting or even global warming accounting might be more useful (Svensson and Wagner 2011). Meanwhile, following carbon accounting as a separate research area, it was realized that ambitious efforts to combat climate change would fail if businesses do not dramatically reduce their carbon emissions (Csutora and Harangozo 2017). As a result, Corporate Carbon Accounting was developed to capture emissions from the perspective of businesses. Nonetheless, in order to minimize company pollution, it is becoming increasingly important to include the entire supply chain and product life cycle in carbon accounting, which includes emissions from both direct and indirect sources from business processes and manufactured goods. Even though Corporate Carbon Accounting has been identified as a potential solution for reducing greenhouse gas emissions, analysts and scholars have identified its strengths and weaknesses.

To begin, the option of where to set system boundaries is the first issue in carbon accounting (Harangozo et al. 2015). In recent years, the issues of identifying boundaries and allocating resources and pollution have sparked a lot of debate. This could occur between organizations, operations, or goods, necessitating a reorganization of carbon management responsibilities. Even though the Greenhouse Gas Protocol (GHG), the most commonly used international standard for carbon accounting, tackled the issue of determining the scope while accounting for carbon, businesses have struggled to define the scope. Indirect emissions from scope three, for example, account for a significant percentage of organizational emissions (Downie and Stubbs 2012), but they are usually undervalued by businesses. Similarly, Matthews et al. (2008) said that only 26% of greenhouse gas emissions in the United States are protected by scopes one and two. According to Huang et al. (2009), indirect GHG emissions from supply chains can account for up to 75% of a company's total GHG emissions. Furthermore, Matthews et al. (2008) believe that scope three is too wide, and instead suggest scope three for indirect emissions from manufacturing, and scope four for indirect emissions from delivery, usage, and end-of-life. Lenzen and Murray (2010) supported this component of Scope 4, emphasizing the importance of considering downstream consequences in corporate carbon footprint accounts as well. As a result, if Scope three emissions are ignored, the most cost-effective carbon reduction strategies will be missed (Matthews et al. 2008). However, if businesses are encouraged to choose more environmentally friendly alternatives in their manufacturing processes and to incorporate mitigation targets into their organizational strategies by accounting for and disclosing indirect emissions, carbon emissions can be managed more effectively (Ascui and Lovell 2012)

Furthermore, as carbon accounting and reporting has grown in popularity, there has been a need to standardize carbon accounting approaches and tools in order to capture the key interest of Corporate Carbon Accounting. Companies used to be more interested in approximating their overall carbon footprint by basing their estimates on total energy usage, but as their auditing capabilities have improved, they have developed the ability to quantify emissions at a more disaggregated level, such as by business unit, facility, operation, and activity. This disaggregated carbon emissions monitoring have been compared to activity-based costing (ABC), in which cost is exchanged for carbon. The term "cost-to-serve" has been replaced with "carbon-to-serve" to account for the CO_2e emissions associated with individual customer supply (Braithwaite and Knivett, 2008). Similarly, even though several approaches have been proposed in various pieces of literature, Life-Cycle Assessment (LCA) is commonly used by business organizations. LCA is a Bottom-Up methodology that evaluates and accounts for all GHG emissions associated with the extraction of raw materials, manufacturing or distribution, transportation, use, and end-of-life management of products or services. LCA may be performed for a good, service, initiative, or organization, and its core requirements are derived from ISO 14044 and ISO 14040. It also accounts for all pollution associated with goods and services, regardless of which economic activities or sectors are responsible for them. Even though this strategy has been shown to produce accurate emissions results, the complexity of certain operations, such as car manufacturing, which requires a thousand processes, makes it exceedingly difficult to account for emissions from all of these processes (Muller and Schebek 2013). Furthermore, due to a lack of evidence, a large portion of the emissions can be overlooked (Lenzen 2000). In addition to the LCA as a Bottom-Up Approach, the Top-Up Approach (Mózner 2015) can be used to cover carbon emissions across long supply chains. However, the system's limits are not well defined (Ozawa-Meida et al. 2013). Nonetheless, evidence suggests that the bottom-up, process-based LCA approach is superior for downstream emissions, while the top-down method is superior for upstream emissions (Bilec et al. 2006). The hybrid approach, on the other hand, was discovered to overcome the drawbacks and weaknesses of data sources in both the Bottom-Up and Top-Down methods (Crawford 2008). Both physical and monetary units, as well as process-based and input-output-based data, were covered by the hybrid approach (Suh 2003). For example, the Hybrid was used in a variety of Australian industry sectors and yielded a variety of results, according to Lenzen (2002). Ozawa Meida, et al. (2013) used it to investigate carbon emissions in British universities for scopes 1, 2, and 3, and found it to be worthwhile. Although the hybrid method uses the input-output approach for upstream estimation and the bottom-up approach for downstream estimation, the bottom-up LCA approach is more accurate and the device boundaries are better established, while the top-down approach can produce data even if process-based data is lacking, and it does so at a significantly lower cost. Furthermore, carbon footprint (CFP) is a method of accounting for carbon or GHG emissions that are generated directly or indirectly by an organization's operations or arise during the life cycle of the organization's goods or services (Townsend and Barrett, 2015). It estimates the cumulative amount of greenhouse gas emissions that are produced over the life stages of a product (Galli et al. 2012) or directly and indirectly generated by operation. It is also expressed in physical units like g, kg, or t of CO_2 (Vázquez-Rowe et al. 2013).

Carbon reporting is another important part of corporate carbon accounting. Carbon reporting is the process of disclosing the findings of carbon accounting to a variety of stakeholders of varying perspectives and interests. Many voluntary mechanisms and schemes have been proposed in the last two decades that can be used to disclose a company's carbon emissions to investors or other stakeholders. Regardless of the establishment of programs, businesses attempting to monitor greenhouse gas emissions have found a lack of accountability and comparability. The Disclosure Project is one of those systems that has remained exemplary in carbon reporting (CDP). CDP serves as an activist coalition that offers a tool for institutional investors and other stakeholders to evaluate their investments. In 2015, for example, 827 institutional investors, including pension funds, banks, asset managers, and insurance firms, signed the CDP, representing more than US$ 100 trillion in assets under management (CDP, 2016). Even though the CDP rates companies based on the Disclosure Leadership Index (CDLI), the percentage of companies publishing high-quality information has not increased significantly over time (Matisoff et al. 2013). As a result, the CDP, in collaboration with the Global Reporting Initiative, uses the GHG Protocol as a carbon accounting source. Investors have used voluntary carbon transparency as corporate social responsibility to meet the needs of various stakeholders (FuHo, 2014). Voluntary disclosure can be a valuable mechanism for communicating environmental goals and milestones, but it lacks sufficient incentive, and goals are often missed (Pellegrino, Lodhia 2012). However, given the low interest in voluntary reporting among businesses, mandatory reporting could make more sense. For example, the UK's Department for Environment, Food, and Rural Affairs (DEFRA) issued a directive in 2013 requiring all publicly traded companies to disclose their Scope one and Scope two emissions (DEFRA 2013) in order to reduce carbon emissions by four million tons by 2021. (Carbon Trust 2016). Sullivan and Gouldson (2012) pose concerns about, first, the existence of large shares of indirect emissions along the supply chain, second, one-size-fits-all approaches that ignore the characteristics of individual companies, and finally, data accuracy and comparability, especially if the reporting companies are not motivated to report. However, in addition to CDP, GHG Protocol, and GRI reporting system standards, additional international standards with unique focus areas have been established, such as British Standard PAS 2050 for carbon labeling, ISO 14067 for product carbon footprints, and ISO 14064 for GHG reporting.

Additionally, product-level carbon auditing and labeling is an alternative aspect of cooperative carbon accounting that is gaining traction. There has been considerable support for encouraging carbon auditing of supply chains at the commodity level in order to generate carbon awareness and provide customers with the information they need to consider CO_2e emissions when making purchasing decisions. Even though few companies have carbon audited their supply chains at the product level, and industrial experience is limited, carbon labeling each product with an estimate of the total amount of CO_2e produced through its supply chain, from raw material source to final point of sale or usage, is still a useful idea. The study of the possible behavioral response to carbon labeling is still in its early stages (McKinnon and Halldórsson 2010). The aim of product level auditing and labeling is to allow market forces to shift demand for goods with low CO_2e emissions during development and distribution. This would give businesses a key role in decarbonizing individual consumption, encouraging competition among businesses to create more environmentally sustainable goods and services, as well as a mass movement toward green consumption. Similarly, one of the most important components of this corporate agenda is informing customers about the quantities of CO_2e embedded in products and services. This data will allow them to differentiate goods based on their carbon content and determine how much CO_2e they could save by moving to lower carbon alternatives. Despite the potential benefits of commodity carbon footprint printing for the world, (McKinnon and Halldórsson 2010) described crucial problems for logistics and supply chain management, which he attempted to address in his paper. Like how precise does the carbon calculation for a particular SKU have to be to satisfy product labeling criteria, given that government regulations mandate the accuracy of nutritional information on food labels and energy ratings for electrical usage? Even though most carbon labeling of consumer goods occurs in the United Kingdom, there is no equivalent set of laws governing carbon labeling in the United States. Even though most carbon labeling of consumer goods in the UK has been done so far with the help of the Carbon Trust, it is unclear to what degree company estimates are independently audited. Despite this, (McKinnon and Halldórsson 2010) concluded that product-level carbon auditing and labeling is a "wasteful diversion", and that management time and money will be better used on other decarbonization initiatives.

Furthermore, determining the chain's end can be difficult. Determining the beginning and end points for carbon measurement within the vertical supply chain can be difficult. Carbon emissions can be traced back to raw material sources or, in the case of recycled materials, the reprocessing point if LCA was implemented as a suitable routine. Several LCAs often consider the energy used and pollution emitted during a product's actual use, as well as its subsequent recycling or disposal. Given the variability of customer travel activity, reverse logistics choices, and product consumption, including CO_2e emissions from these post-purchase events in the footprint calculation would be complicated. Most of the carbon footprint research to date has assumed that the supply chain stops at the store shelf. Even though a growing percentage of retail transactions are made online and delivered to the home, the chain is effectively extended to the point of use.

Furthermore, the transportation industry has resulted in a rapid increase in corporate emissions. Long-distance shipping using highways, railways, trucks, and, above all, airplanes has increased as a result of globalization and changing market demand, resulting in much higher CO_2 emissions. Similarly, increased international trade has resulted from the liberalization of trade among countries, trade corridors, and economic societies, which has a direct impact on carbon emissions. Furthermore, the long nature of certain supply chains, which include multiple notes and connections such as facility locations and distribution centers spread both locally and globally, necessitates products being transported from one note to another, resulting in CO2 emissions. Consider the United States, where carbon emissions have been exported as industrial manufacturing has shifted to Asia. Similarly, most multinational corporations are offshoring their facilities to take advantage of the economic and social benefits of low-cost economies, resulting in more exports and increased carbon emissions from transportation. Furthermore, the fact that sourcing managers must import globally to save money has an indirect effect on carbon emissions as the goods are transported.

2.3.2 Carbon Footprint Principles, Methodology, and Success Factors

The first step in the carbon management process is to measure and record GHG emissions. Quantifying your carbon emissions implies a consistent, accurate, and straightforward examination of the amount of carbon the company produces. You can calculate your emissions by calculating your carbon footprint, which is the total amount of greenhouse gases emitted by a company, supply chain, or product. Even if there may be supplementary gases that contribute to the organization's carbon footprint in addition to carbon dioxide (CO_2), carbon is used as a jargon for the whole greenhouse gases since it is the most prevalent. Quantifying your carbon footprint allows you to take some early steps toward adapting to a changing environment and building a more resilient business. To calculate, manage, and report GHG emissions from various activities, organizations, supply chains, and goods, a standard measurement method must be developed, allowing for comparisons of GHG emissions as well as reporting and regulatory requirements. This involves calculating the cumulative volume of carbon dioxide and other GHGs released directly and indirectly by an organism in CO_2 equivalents or CO_2e (Carbon Trust, 2006). Nonetheless, the key point of contention is determining the audited system's limits. Carbon auditing of a supply chain or a commodity, on the other hand, is more difficult than auditing a single entity because it includes other players upstream and downstream. Meanwhile, if a company's carbon footprint or a product's supply chain has been calculated, prospects for reduction can be identified and highlighted. Several guidelines have been released by various organizations to assist businesses in tracking, monitoring, and controlling their carbon footprints. Among the many, the following are the most important:

- The Greenhouse Gas Protocol: An Accounting and Reporting Standard for Corporations. WBCSD/WRI, 2004. Revised Edition.

- PAS 2050: Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services (publicly available specification) (British Standards Institution, 2011a).
- Greenhouse Gases – Carbon Footprint of Products, International Standard Organization (ISO) 14067, 2013.
- International Standard Organization (ISO) 14064:1, Greenhouse Gases – Measurement with Organizational Guidelines for Quantification and Monitoring of Emissions and Removals of Greenhouse Gases (ISO 14064:1, 2006).
- General Principles for the Assessment and Labeling of Carbon Footprint of Products (Japanese Ministry of Economy, Trade, and Industry) (METI, 2009).
- Guidelines for industries or activities are also available, such as a statement from the European Chemical Industry Council exploring the possibilities for calculating CO2 emissions from transporting chemicals in Europe (McKinnon and Piecyk, 2010); and the UK Department for Transport's guidelines on measuring and reporting GHG emissions from freight transport operations (DfT, 2010).
- Companies' carbon reporting leadership at the individual consignment stage (World Economic Forum, 2010).

Even if the specifics and information in written structures and guidelines differ, the methodologies and conclusions are identical. Similarly, the same GHG auditing and reporting guidelines should be applicable to all aspects of calculating a company's carbon footprint. The principles widely employed are those adopted by WBCSD/WRI, 2004; British Standards Institution, 2011, ISO 14064–2, 2006; some of which include:

Transparency: Expectations should be stated clearly, and the report should include relevant references to the reporting standards and data sources. As a result, data on GHG emissions should be published in a scientific, impartial, and reliable manner, based on a well-defined audit trail.

Consistency: Computation methods should be used in such a way that GHG emission data can be compared over time. Any changes in methodology, data, or other factors that may affect GHG emission estimates should be transparently reported and justified.

Completeness: All GHG emission sources covered by the chosen reporting cap must be included in the carbon footprint calculations. Any restrictions should be well-founded and clearly stated in the GHG report.

Relevance: All details that internal and external operators need for decision-making must be included. A GHG emission report should consider the company's, supply chain's, or service's environmental capacity.

Accuracy: To give internal and external users confidence in the reliability and trustworthiness of the recorded information, ambiguities should be reduced as much as possible. Estimation of GHG emissions should be done in such a way that ensures optimum precision and reduces the risk of over- and under-reporting.

British Standards Institution (2011b) and WBCSD/WRI (2004) define the mechanism and methodology for carbon accounting behind the principles as shown in figure 2.6 below.

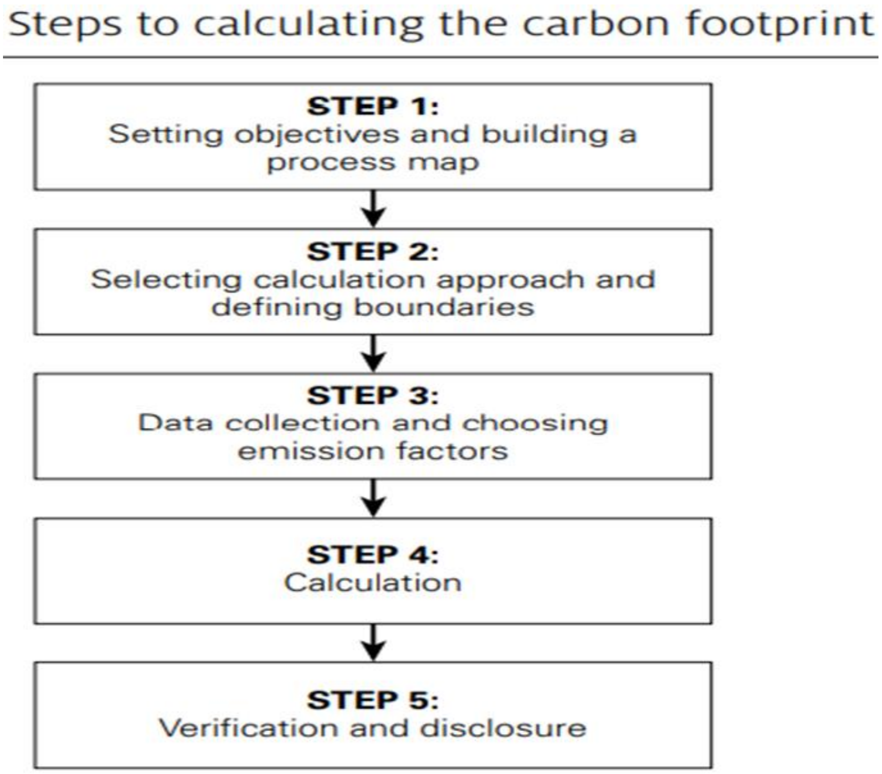


Figure 2. 8 Steps to calculate the carbon footprint

Source: (British Standards Institution, 2011 and WBCSD/WRI, 2004)

Step 1: Setting objectives and building a process map.

The most important consideration when determining environmental priorities is to ensure that they are in line with the company's strategic and financial objectives. Setting objectives would make it easier to track performance and take corrective steps to enhance the carbon management process. The carbon footprint exercise's goals aid in determining the technique to be used; for example, in order to obtain ISO 14000 series certification, the ISO rules must be followed, in addition If an organization wants to use the carbon footprint internally, it can pick and choose which rules to use, but the approach should be explained in the final report. When identifying the goals, a process map must be created to identify all resources, operations, and processes that influence carbon footprint. The most common objectives are as follows: Companies must comply with the law in order to fulfill the minimum requirements. Second, carbon measurement is often used as a means of cost-cutting and improved resource management, as efforts to minimize pollution often focus on eliminating waste, transportation, and energy use. Furthermore, since consumers are becoming more environmentally aware, carbon management may be a way to gain a competitive edge. Green certifications can have a significant impact on consumer behavior by demonstrating to the public that a company's practices are environmentally sustainable, thus promoting a green picture. Furthermore, improved attractiveness as a potential supplier may be another target for carbon management. This is because businesses are increasingly requiring their suppliers and contractors to comply with their environmental requirements and report on environmental accomplishments that can help them achieve preferred-supplier status. Carbon managers also see carbon management as a means of new product and service growth. This is since monitoring and controlling environmental impact encourages product and service creativity, which helps to protect new markets or sustain existing ones. Finally, a good environmental status can be an important factor in an employee's choice of employer, so carbon measurement should be used as a goal to hire employees.

Step 2: Selecting the calculation approach and defining boundaries.

Following the definition of the carbon footprint goals, the next step is to define the organizational boundaries. The corporation may have one or more facilities, as well as fully owned activities, joint ventures, and or subsidiaries, making it critical to define the extent of the carbon footprint estimates. This necessitates describing the company's companies and activities in order to account for and monitor GHG emissions (WBCSD/WRI, 2004). ISO 14064-1, (2006) revealed two approaches to consolidating GHG emissions within a boundary, the first of which is the control approach, in which the boundary is drawn to include all activities over which the organization has financial and/or operational control. The equity share strategy is one in which the company takes a portion of the responsibility for GHG emissions from facilities in which it owns a stake. Meanwhile, it is critical to ensure that facilities operated by several organizations adopt a similar consolidation strategy to avoid double counting of emissions. As the accounting reporting regulations represent market reality and are realistic in terms of data collection, the boundaries of the carbon footprint assessment must be set in a way that communicates with other requirements already in place. After the organizational boundaries have been defined, the operational boundaries are established. This process entails detecting GHG emissions from sources within agreed-upon organizational boundaries, categorizing them, and deciding on the scope of reporting for indirect emissions. GHG emissions can be classified into three groups or scopes, according to WBCSD/WRI (2004). To begin, there are Scope 1 emissions, which are direct GHG emissions from sources owned or regulated by the audited business, such as emissions from on-site fuel ignition, emissions from vehicles owned and controlled by the organization, and emissions from chemical reactions in manufacturing activities. Second, there are indirect GHG emissions from the production of power, heat, or steam obtained from outside sources, known as Scope 2. Finally, there are Scope 3 emissions, which are indirect GHG emissions that are a function of the audited company's activities but come from sources maintained or regulated by other organizations; for example, emissions from subcontracted activities like distribution, waste disposal, product usage, employee commuting, and commercial travel in vehicles owned and controlled by other organizations. Scope 3 has a reputation for being the most underrated, but more attention should be paid to it because its emissions are enormous as compared to Scope 1 and 2. Furthermore, they increase the company's risk exposure; they are often viewed as serious by key stakeholders such as consumers, suppliers, and investors; and, finally, there are opportunities for pollution reductions that can be exploited or affected by the company. On the other hand, during the second compliance cycle (2013–2020), the Kyoto Protocol identified six classes of gasses that should be included when measuring carbon footprint and later added nitrogen trifluoride (NF3). As a result, the Greenhouse Gas Protocol now includes the NF3 year 2013 in the documentation of

Kyoto GHG emissions. Similarly, all GHGs, including those protected by the Montreal Protocol, were included in the British PAS 2050.

Step 3: Data collection and choosing emission factors.

After determining what needs to be included in the framework of carbon footprint calculations, step three entails gathering all necessary data. A data collection strategy should be developed, based on what information is necessary, the data plan that is needed, and who owns or has access to the relevant documents. When data from outside the company is needed, it is beneficial to have nominated individuals in all organizations involved who can coordinate and handle the data collection process on the inside. Until obtaining data from supply chain stakeholders, it's a good idea to develop and communicate the project's priorities to them, in the hopes of gaining their buy-in and enthusiastic support. Either a top-down or bottom-up method may be used to obtain primary data. In the past, some understanding of the two methods was needed. Energy consumption is measured from the top down in a top-down method. Energy use data is collected at a cumulative level in a top-down approach, for example, yearly electricity consumption for the whole enterprise, while in a bottom-up approach, individual processes can be scrutinized separately and their specific energy requirements and GHG emissions determined, and the carbon footprint can be erected from these component measurements. Although the data obtained using the bottom-up method is more successful at later stages in the carbon management process, when opportunities for efficiency changes are being evaluated, the top-down approach will provide reliable overall emission estimates.
Although the data obtained using the bottom-up method is more successful at later stages in the carbon management process, when opportunities for efficiency changes are being evaluated, the top-down approach will provide reliable overall emission estimates.
Secondary data, on the other hand, represents generic emission factors for a given activity and is therefore appropriate for activities that have minor impacts on total GHG emissions and cannot be substantiated by the time, effort, and resources required to collect primary data. When collecting secondary data, it is also important to understand the source's accuracy and reliability. The preferred sources of acceptable energy-conversion and emissions elements should be approved government publications or agreed auditing standards. The emission factors for different energy sources and the global warming potential (GWP) of GHGs are two other types of secondary data that are critical to the carbon footprint estimation. For example, in the life cycle study, inventories of data on the

emissions of various gases from a wide range of manufacturing, distribution, use, and recycling/disposal activities have been collected. To ensure comparability and durability across various organizations, supply chains, and goods, formal values for these must be used.

Step 4: Calculation

The measurement of a company's or supply chain's actual carbon footprint is relatively simple. All calculations can be done with a simple spreadsheet program, but more sophisticated software packages are now available to help with carbon data management and analysis. Calculating the carbon footprint of a product can necessitate a slightly different approach. The data is combined, and GHG emissions are measured using conversion factors for various types of energy inputs and activity types. At this stage, a process map would be extremely useful. It summarizes all the processes that a product undergoes at each stage of the end-to-end supply chain. If many different goods are handled at a single location or transported in a single vehicle, a method for allocating pollutants that are common to classes of products, such as their share of warehouse energy consumption or truck fuel, should be devised. The computing requirements also provide for all by-products of processes that are not listed separately. The emission values will then be added together to determine the product's overall carbon footprint across its entire supply chain. The computing requirements also allow for any process by-products that are not separately stated. The emission values will then be added up to determine the product's overall carbon footprint across its entire supply chain. Still, saying that carbon is a good shorthand for carbon dioxide equivalent is acceptable as long as this is stated clearly and all figures are in CO_2e (Defra, 2008). Furthermore, the problem of greenhouse gas sinks must be weighed when measuring. GHG sinks are described as “physical units or processes that remove GHG from the atmosphere” (ISO 14064–1, 2006). Emission reductions from carbon storage in GHG sinks should be deducted from the overall carbon footprint using appropriate exclusion factors. PAS 2050 contains detailed guidance on how to measure the impact of carbon storage and what should be used in the assessment. Any changes in the footprint should be explicitly due to changes in the product itself or the process content in its manufacture and distribution, according to the general rule. Carbon reductions achieved by unrelated activities such as obtaining carbon credits or offsets do not satisfy the criteria (British Standards Institution, 2011b).

Step 5: Verification and disclosure

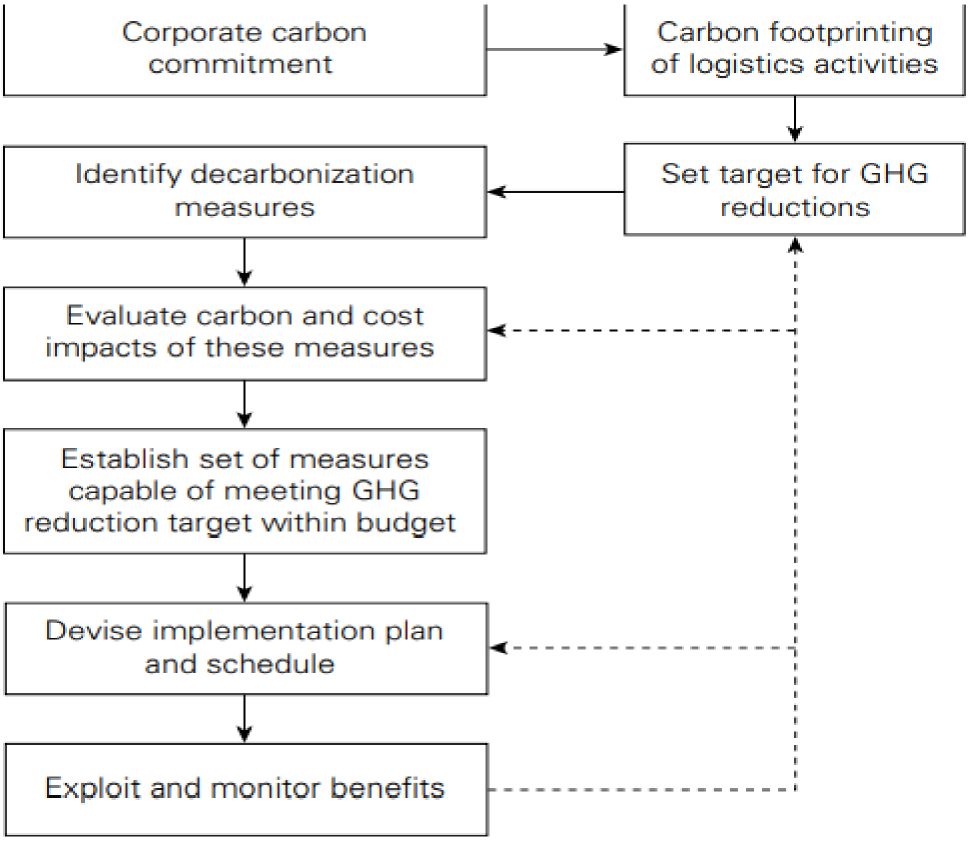
Verification reduces the risk of human error and decision-makers reaching incorrect conclusions based on inaccurate carbon footprint data. The verification target will be determined by the carbon footprint practice's main objectives. Companies should try to validate their carbon footprint estimates before publishing any GHG data to show their accuracy and reliability. If the pollution data is only going to be used internally, self-verification is usually enough. This entails requiring someone else inside the company to independently verify the collected credentials and all computations in order to detect any errors or missing data. If companies wish to make their carbon footprint data public, independent review by a third party is recommended. The verifier must be able to demonstrate that the carbon footprint data meets the precision, transparency, validity, completeness, and quality requirements. A qualification body that offers standardized certification will prescribe the highest level of validation. Outside validation services are also offered by non-certified third-party organizations. The final GHG report should provide relevant information on GHG emissions, measurement margins, process used, and estimate time. The required level of detail and scope of the study will also be determined by the target audience and the primary goal of the carbon footprint procedure. However, it should still be based on the best available information at the time of release, while still being open and honest about its shortcomings (WBCSD/WRI, 2004). Furthermore, if the carbon footprint is calculated on a regular basis, data on GHG emission trends must be included. Quantifying a carbon footprint is a challenging and time-consuming task, especially when it involves the activities of many companies in the supply chain. It should be regarded as an ongoing long-term strategy that is intended to benefit all parties involved. The following are important success story considerations for carbon footprint:

- Use simple data collection methods that incorporate uniform questions and statistics input designs that are compatible with other applications.
- Employee involvement and understanding of the environmental effects of the carbon auditing and reduction program.
- A project calendar with clearly specified goals for each phase of the carbon footprint exercise.
- Participating partners' support and a fair degree of cooperation across the supply chain.

- Support from all stakeholders and a high level of collaboration around the supply chain.

2.3.3 Corporate Decarbonization Strategy

Without providing leadership on the implementation of a Corporate Decarbonization Strategy, the carbon management process will be incomplete. As previously stated, determining one's carbon footprint should be the first step in any carbon management strategy. Nonetheless, since measuring and disclosing carbon emissions, it must proceed with the carbon decarbonization policy. As a result, McKinnon (2011) developed a seven-stage protocol for developing a decarbonization strategy, as shown in Figure 2.9 below.



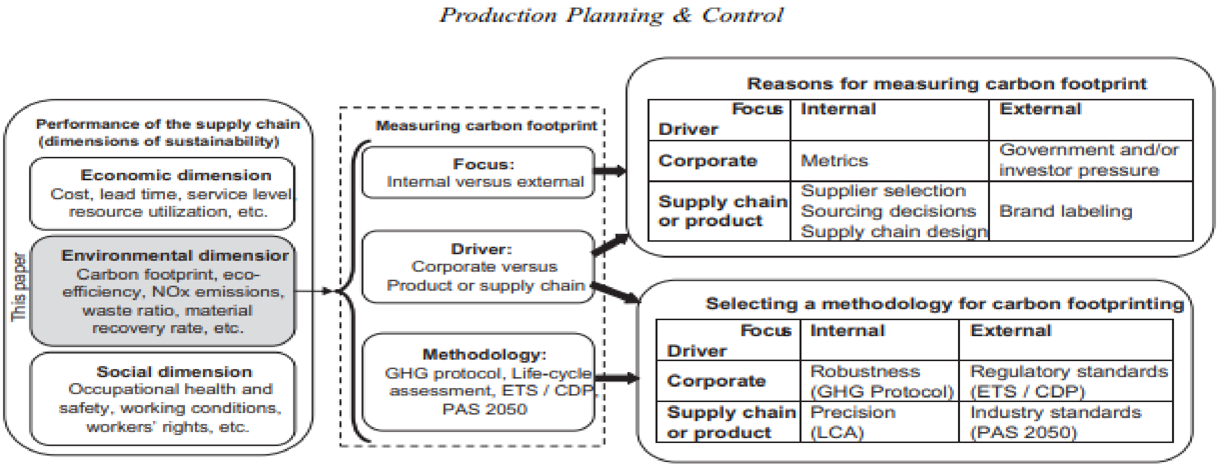
SOURCE: Adapted from McKinnon (2011)

Figure 2. 9 Corporate Decarbonization Strategy

The first step in the carbon decarbonization process is for an organization to commit to reducing GHG emissions from its logistical activities. The next step is to determine the logistics carbon footprint using a bottom-up strategy, if possible. This makes identifying the most carbon-intensive practices and behaviors much easier. When managers have assessed and comprehended the current carbon footprint and its future business-as-usual course, a GHG reduction goal can be set, perhaps based on McKinnon and Piecyk's subsequent criteria (2012). The next step in the procedure is to create a list of possible decarbonization steps that are suitable for the business. The cost and carbon implications of each measure are then assessed to determine which sequence of actions will more cost-effectively achieve the GHG reduction goal. To ensure the accuracy of this evaluation, it is critical to use reliable and unbiased data. This approach can be aided by a variety of instruments. Road freight transport operators, for example, may use the Carbon for Money Tool to see a list of decarbonization procedures for fleets and get an estimate of the costs and carbon benefits from various mediation packages. The execution strategy and plan are developed in the seventh phase of the process. Economic and environmental influences should be extensively investigated until the plan is implemented. The results are then fed back into previous stages of the process, making the decarbonization strategy improvement a never-ending and reiterative process. As a result of these feedback loops, the company gains awareness of decarbonization and its activities become more closely aligned with its operational, financial, and environmental responsibilities.

2.4 Carbon Auditing Framework

On the academic front, several recent papers (Seuring and Müller 2008) highlight the importance of environmentally sustainable or green supply chain management. Given these issues, it is critical for a company to incorporate GHG emission control and monitoring into its corporate strategy (Claver et al. 2007). Jairo (2014), on the other hand, proposes a conceptual framework for measuring and assessing the carbon footprint in supply chains that considers the complexity of collected data and contributes to the understanding and practice of green supply chain management at the corporate level while also providing robustness. This system aids decision-making by identifying methods for achieving the efficiency gains that can be achieved by reducing CO2 emissions through the supply chain. Furthermore, since businesses already play such a large role in achieving GHG reduction goals, adopting green supply networks is an essential part of industrial growth. This system combines the fundamentals of the Green House Gas (GHG) protocol with agreed personal weights that depend on the reliability and assurance of data sources. In order to contribute to the knowledge and practice of measuring and managing carbon footprint through supply chains, the conceptual framework is needed. In addition to their well-known methods for calculating supply chain costs, as seen in figure 2.10, it is critical to identify a conceptual framework that will assist businesses in competently calculating the environmental effects.



Reasons for measuring carbon footprint

Focus / Driver	Internal	External
Corporate	Metrics	Government and/or investor pressure
Supply chain or product	Supplier selection Sourcing decisions Supply chain design	Brand labeling

Selecting a methodology for carbon footprinting

Focus / Driver	Internal	External
Corporate	Robustness (GHG Protocol)	Regulatory standards (ETS / CDP)
Supply chain or product	Precision (LCA)	Industry standards (PAS 2050)

Figure 2. 10 Proposed conceptual framework for studying environmental impact in supply chains.

Source : (Jairo R. Montoya-Torres 2015)

For calculating carbon footprint in business operations, this Framework stressed the importance of both direct (on-site, internal) and indirect (off-site, external, upstream, downstream) emissions. It also encompasses low-carbon growth policies and laws; businesses all over the world must incorporate carbon footprint management into their business decisions (Hua et al. 2011). Corporate carbon footprint refers to measuring both direct and indirect emissions from an organization's operations, as well as electricity and gas consumption in manufacturing processes and fuel consumption in vehicles, while commodity or supply chain carbon footprint refers to calculating emissions from a single product's supply chain. Organizations are required to calculate their carbon footprint in order to reduce and monitor emissions, as well as to increase environmental commitment through the responsible execution of their operations. In the meantime, cost-cutting strategies, product differentiation, brand awareness, supply chain redesign, collaborative partnerships with manufacturers and innovation in the marketplace inspire product-oriented carbon footprint calculations. Furthermore, the methodology used to calculate carbon footprint is questionable. The emphasis can be internal or external, depending on the driver, which may be corporate or product supply chain. Various methodologies for calculating carbon footprint are currently available (Li, and Daskin, 2013). There is no universal agreement on which one is the best or which one should be used on an international scale (FEI 2012). The carbon footprint metric is estimated differently depending on the methodology used (Dias and Arroja 2012).

2.5 Plant Location Choice

Battery manufacturers have a wide variety of locations to choose from, so understanding their needs can be beneficial to countries that are making it a priority to attract this industry. At a high level, battery-cell manufacturers are traditionally seeking the best business case and lowest risk in a friendly political atmosphere, renewable energy, access to skilled labor, and proximity to suppliers and consumers with excellent raw material interaction. Before we look at the literature on the advantages of making li-ion batteries localized in Europe and the potential demand for EV-battery production in Europe, it is important to remember that the unprecedented shift to electro mobility and the resulting rise in Electric Vehicle production has seen high growth rates in the market for EV batteries over the last few years. The European Li-ion battery market represents a significant, but untapped potential opportunity for European battery and car manufacturers, as well as the European economy as a whole. Outside of Europe, companies supplied less than 3% of global demand for electric vehicle batteries in 2018, and European companies supplied just about 1%. (Eddy et al, 2019). Now, only three countries, all of which are in Asia, dominate the EV-battery market: China, Japan, and Korea.

Despite the fact that European battery makers and carmakers have fought to ensure adequate battery supply and investments in battery manufacturing, Europe's EV-battery situation has been a mystery because most battery manufacturers are concentrated in Asia. The resulting problems for the incumbent industry, as well as difficulties with planned investment have prompted some of Europe's homegrown battery manufacturers to relocate to China. China is home to 46 of the 70 Giga factories that have been revealed worldwide (Eddy et al, 2019) Unlike China, Europe lacks a clear industrial policy for attracting large-scale battery manufacturing. For example, Lithium Werks, a Dutch company with two plants in China, announced plans for a third on September 19 (Eddy et al, 2019). The company claims that it prefers to build factories in China because the infrastructure is better, and it is easier to obtain the required licenses.

To add to the uncertainty surrounding the localization of battery plants in Europe, some European premium OEMs have so far ruled out additional investments in cell manufacturing, focusing instead on R&D and packaging by approving long-term contracts with Asian suppliers.(2019, Ding et al.). Nissan currently operates a plant in Sunderland, United Kingdom, but has asked to be separated from it (Goodman, P. 2019). Volkswagen recently announced a €1 billion investment in a battery-cell factory in Germany, which it is establishing in partnership with SK Innovation (Casals et al 2017), It also has important supply agreements with Samsung, LG Chem, and CATL, a Chinese battery manufacturer (Ma et al, 2018). Meanwhile, in November 2019, Tesla CEO announced Giga investment in a battery-cell factory in Germany.

Furthermore, strategically positioning lithium-ion battery facilities in Europe may be a money-making opportunity, as rival car producers that are closer to battery plants are better able to ensure battery supply as demand for electric vehicles grows. Nonetheless, most automakers have decided not to produce their own batteries and have neglected to secure supplies near their European plants. Furthermore, to close the gap between estimated battery demand from EV manufacturers in Europe, which is more than five times the volume of currently confirmed projects in Europe, more battery manufacturing capacity in Europe is needed (Gersdorf et al 2017).

Another strong economic and strategic motivation for local li-ion battery production in Europe is that the battery is a single high-cost component of an EV, accounting for between 35 and 45 percent of the total cost now (Outlook, I. G. E, 2019). It is also expected to be the most difficult to obtain in the coming years as EV manufacturing and supply chains expand. Holding this critical part of the manufacturing process close to OEMs poses a considerable risk to the supply chain and represents a missed opportunity for policymakers to retain a significant portion of value development in Europe. Furthermore, as the production of electric vehicles grows without a reliable local battery supplier, the European automotive industry may become less competitive, as OEMs usually prefer to produce their products close to their target markets. Should battery manufacturers decide not to place their giga factories near projected Electric vehicle production, they might prioritize being close to the critical part of their supply chains and move their EV production closer to battery manufacturing (Dixit et al, 2019).

Furthermore, European automobile manufacturers do not seem to be interested in being involved in the production of battery cells (Eddy et al, 2019). This may be due to the fact that finding the right chemistry, setting up the manufacturing process, and putting other processes in place to manufacture battery cells that don't expose a core car OEM's knowledge and expertise is difficult. Car manufacturers, on the other hand, see value in the processing of cells into modules and battery packs. Similarly, manufacturing batteries in-house or moving to a larger base of suppliers, possibly even European suppliers, can pose risks, some of which can be attributed to individual suppliers' inability to secure enough raw materials at low enough prices to meet the necessary production levels (Olivetti et al, 2017).

Another danger that favors locating a lithium-ion battery plant in Europe is the growing demand for electric vehicles, which is already putting strain on a limited supply of materials. Lithium prices have risen since 2015, and global cobalt output in 2025 would almost certainly need to double that of 2016 to meet universal EV demand (Olivetti et al, 2017). To mitigate this danger, EV manufacturers will want to work more closely with cell manufacturers who have a strong grip on their own supply chains (Olivetti et al, 2017). As a result, European OEMs might look to a handful of Koreans, Chinese, and Japanese cell manufacturers, who outperform the market and control a large portion of their value chain, including lithium and other main metal mines in some cases. Also, sourcing from nearby battery manufacturers allows OEMs to avoid supply-chain risks such as dangerous-goods transportation concerns and working-capital problems, while also promoting co-development and troubleshooting of battery cells, packs, and electric vehicles (Olivetti et al, 2017).

Another benefit of locating a lithium-ion battery plant in Europe is that most European countries' political structures are predictable, and there is a strong obligation at all levels of government to move to a lower-carbon system, of which EVs and their batteries are important components (Gota et al 2019). Some ports are well-connected, providing excellent access to global raw-materials markets and supporting infrastructure. Similarly, Europe has some of the world's best scientific research facilities and academies, which is especially important as battery technology advances. Similarly, while European states are prohibited from providing direct financial benefits under state aid law, the European Union and individual member states provide funding to a variety of bodies and programs. Some producers in Eastern Europe are given tax cuts in specific economic zones, and electricity, labor, and land costs are still relatively low (Eddy et al, 2019). Furthermore, as the requirements for extended producer liability rise and the price of raw materials such as cobalt and lithium rises, Europe's robust recycling environment will prove to be extremely beneficial to manufacturers. Maintaining supply chains for reverse logistics and recycling often improves the supply protection of scarce resources, which are often produced in unpredictable regions. Creating a closed recycling loop could give European countries a competitive advantage in implementing a long-term battery life cycle (Eddy et al, 2019).

3.0 METHODOLOGY

3.1 Chapter Introduction

According to Kothari (2004), research methodology refers to the different stages that researchers take on when studying a problematic along with the logic after them. A research methodology is therefore a combination of the methods and the logic behind the methods used for data gathering, analysis, and its interpretation. It is paramount for the researcher to make a thorough methodological choice because the quality and success of the research rest on such choice. However, the choice of the research framework model is determined solely on the researcher and the research objectives (Omotayo & Kulantunga 2015). According to Omtayo & Kulantunga (2015), the research onion is one of the major research frameworks (process) used in research methodology. The research onion permits the researcher to carry out his research easily by following five stages. According to Nwabude (2010), the research philosophy indicates the view of carrying out the research and it thus help the researcher in choosing the appropriate research approach; The research approaches on other hand permits the researcher to explain the theory which permits him to be able to design the method to either test the hypothesis or examine the data; the methodological choice is used to come up with the strategy in the study that will affect the data collection process and; the data collection method can be used as a guideline the researcher to adopt questionnaires or interviews to gather relevant data to answer the research questions. Once the researcher as gone through out these steps, the models are eventually able to recognize the time horizon, as the last phase of the study. This chapter elaborate the general research methodology used in this study. We will begin this chapter by presenting the research philosophy, since it is very important for a researcher to be aware of the philosophical stance that underpins his study (Johnson and Clark 2006). It will be followed by a presentation of the research strategies and methods, including the analytical approach to the study.

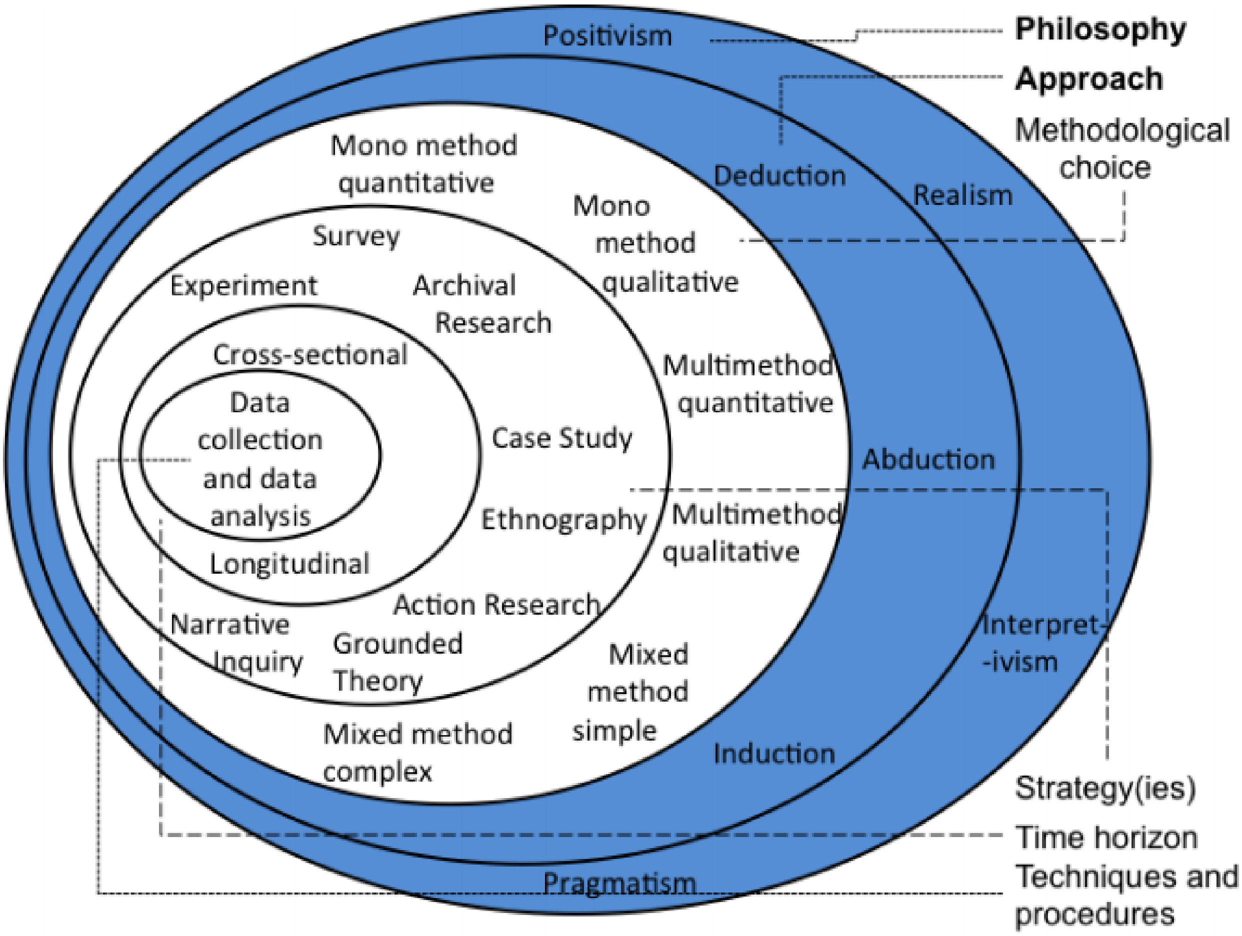


Figure 3. 1: General Research Methodology "Onion"

Source: Revised from Saunders, N, Lewis & Thornhill a (2019) Research methods for Business Students, 8th Edition, Pearson

3.2 Research Philosophy

Research philosophy is a belief about the approach in which data about a phenomenon should be collected, examined and used. To come up with their philosophical stances, researchers adopt philosophical assumptions. Philosophical position taken by researchers reflects their stance with respect to four philosophical assumptions namely ontology, epistemology, axiology and methodology (Cresswell 2007). These assumptions are interconnected and the combination of stance selected by the researcher explains his philosophical position. These four assumptions are explained thus:

Ontology: This assumption is concerned about the nature of reality. Crotty (2003) defines it as "the study of being" It is interested in "what kind of world we are investigating, with the nature of existence, with the structure of reality as such". Ontological positions are characterized by objectivism and subjectivism. Objectivism holds that objects of study happen in reality and are external to the social actors concerned with their existence. Subjectivism on the other side believes that objects of study are produced from the perception and resulting actions of the social actors concerned with their being (Saunders et al. 2012). The philosophical stance of a researcher with respect to ontology will always reflect one or more of these assumptions.

Epistemology: This hypothesis investigates how we learn. It is a way of comprehending and elucidating how we know what we know (Crotty 2003). According to Crotty (2003), epistemology also involves defining philosophical stance in order to determine what types of information are possible and how to ensure that they are both appropriate and valid. As a result, epistemology focuses on the "how" and "what" of knowledge. Researchers' epistemological positions are influenced by the responses they give to these questions.

Axiology: Axiology is concerned with the nature, types, and criteria of values and value judgments (Saunders et al. 2012). This assumption is concerned with the evaluation of the researcher's own worth at all stages of the research process. Since researchers bring values to a study, axiological position is established by the degree to which those values play a role in the study. The positivist view, for example, holds that research is conducted in a value-free manner, that the researcher is independent of the evidence, and that the researcher maintains an impartial position. Constructivism, on the other hand, argues that analysis is constrained by principles and that the researcher is a participant in the events under investigation.

Methodology: The methodological assumption is the strategy, course of action, procedure, or design that guides the selection and application of specific methods, and connects the methods' selection and application to the desired outcomes (Crotty, 2003).This explains that philosophical stand has effects on the research methods that researchers choose in their study. For example positivists tend to use quantitative methods with the aim of testing hypothesis while constructivists tend to use qualitative methods with the aim of making in-depth investigations.

3.2.1 Philosophical stance of the present study

The present study is underpinned by positivism. This philosophical position maintains that empirical data gathered through the senses is the only reliable basis for knowledge. It goes on to say that true understanding can only be presumed if all observers describe a thing in exactly the same way. Finally, it stipulates that these definitions must be consistent for all researchers or observers, implying that calculation is the royal path to understanding. Thus, the ontological assumptions of positivism are that which assumes one defined reality, fixed, quantifiable and evident, impartial, and free of social actors. If epistemological assumptions hold that true knowledge is empirical and quantifiable, and that science's purpose is to test and extend theory. The axiological assumptions presume that the study is value-free and that the researcher is impartial and independent of the evidence. Finally, the methodological assumptions presuppose the use of quantitative research techniques such as case studies, exploratory, and empirical models, all of which necessitate objective measurements and analysis. The view of this study implicitly coincides with the positivism philosophy and that is why it is the philosophical stance in the study. As can be shown, the above assumptions contribute to quantitative research that is based on empirical measurement of observable phenomena. As a result, anything that can't be calculated can't be accurately established.

3.3 Research Approach

As the philosophical position of a study determines how a researcher will develop knowledge and their belief of the nature of the study objective, the research approach focus on whether the knowledge will be raised at the start or at the end of the review process (Altinay and Paraskevas 2008). According to Saunders et al. (2019), research approach can be divided into deductive, inductive and abductive research approach. The deductive research approach starts with a theory and later conducts a study to verify the theory. On the other hand, an inductive research approach generates a theory based on the analysis of data. An abductive research is a combination of inductive and deductive approach. This last approach involves generating a new theory or modification of an existing one built on the data and the subsequent testing of the said theory using extra data. This research will us the inductive approach since our research starts with a research question and which objective is to achieved during or at the end of the study.

3.4 Research Method Choice

Mono-method qualitative, Mono-method quantitative, Multi-method quantitative, Multi-method qualitative, mixed method basic, and mixed method complex are the six methodologies that the researcher must choose from when conducting research (Saunders et al 2019). Therefore, for the purpose of this study, we will use the quantitative method based on carbon auditing framework and the Ecotransit analysis tool for CO_2 emissions calculations. This is justified by the fact that quantitative analysis is described as the process of collecting and analyzing numerical data relevant to our research focus.

3.5 Research Design

According to Saunders et al. (2019), based on the type of study question to answer, the research designs can be classified as descriptive, explanatory and exploratory research design. The descriptive design is used when the purpose of the study is to establish an accurately and systematically profile of a population, events or situations. Where the aim of the study is to discover relationships between variables, an explanatory design is used. It therefore helps to better understand a topic that was not well researched before. Lastly, exploratory design is employed when the objective of the study is to investigate a problem or clarify an understanding which is not clearly defined. The latter appears to be in line with our research focus.

3.6 Research Strategy

The research strategy serves as a link between a study's theoretical context and the data collection and analysis method chosen. The diverse research strategy that can be used within a research field depends on the aim and the queries of the research. Experimental Survey, case study, action research, grounded theory, ethnography, archival research, grounding theory and narrative inquiry are some of the strategies used in research (Saunders, Lewis, and Thornhill 2019). For our case, we will use a comparative case study strategy. This strategy does not intend to study the whole organization process but it will focus on the best location among Germany, Norway and Poland where a Sustainable EV battery manufacturing plan can be located. Also the sustainability aspect of the EV battery will be narrow to Environmental sustainability that will look into the environmental impact of EV battery production in each of the alternative locations.

3.7 Time Horizon

According to Saunders et al (2019), whether a study is like a "diary" or a "snapshot" raises significant concerns. The term "diary" denotes a longitudinal study, while "snapshot" denotes a cross-sectional study.The longitudinal means that study can be carried out at different time and new development and changes can be done at a different time frame. In our case, this is not applicable since this research is time constraint. Thus, this study we will adopt the cross sectional time horizon spanning the duration of our thesis.

3.8 Data Collection

The principal source of information for this research will be secondary data. This will be used to better understand the problem background, literature review, development of theory. The main source of secondary data is a database that contains knowledge gathered by other researchers for purposes other than the current analysis. The main ones include books; articles written in scientific journals, papers presented at conferences, library data base, web sites, carbon auditing report of EV battery manufacturers and internet sources. Documentations from industrial practice and case studies from specific companies in the selection of carbon-footprint minimizing production localizations would equally contribute to increase the richness and in-depth information to this study. Secondary data is useful and researchers can use them as important tools to better understand and explain the research problem (Ghauri and Gronhaug 2010). Secondary data has a number of benefits, including the ability to save time and money while looking for information; it is also faster than primary data. Furthermore, since this form of data already exists, the researchers would be able to collect it from the appropriate source.

The primary data use in this research comes specifically from the email exchange with one of Norway potential EV battery manufacturers, Freyr Battery AS. Through collaboration with Freyr Battery AS, we were able to harvest important data required for our study.

3.9 Analytical Approach

The use of analysis to break down a problem into the elements required to solve it is known as an analytical approach. It is important for the researcher to make the correct choice of the analytical technique to be used in his study, since it helps to obtain valid information from data and subsequently draw valid conclusions. This study's analytical component is divided into two sections. The first section is analysed with the help of a spread sheet model, developed with data obtained from the sources mentioned earlier in section 3.8 to quantify the CO_2 emissions based on the energy source used in the manufacturing process of EV battery cells at alternative locations. The second rely upon EcoTransit standard emission factors to come up with the CO_2 emissions from upstream and downstream logistics with respect to the transport mode and purchasing/distribution volumes from alternative locations. Thereafter, a comparative analysis of the CO_2 emissions at alternative locations is done to come up with the best location choice.

4.0 ANALYSIS AND FINDING

4.1 Chapter Introduction

The study's data and interpretation are presented in this chapter. The data were gathered from both primary and secondary sources, as discussed earlier in chapter three and based on the carbon auditing framework, the CO_2 emissions from the cells manufacturing process and the CO_2 emissions from the upstream and downstream logistics activities were calculated using the EcoTransit online model. Thereafter, we use a comparative case study analysis approach to determine the best option based on our main objective. The results are presented in five subheadings respectively according to the research questions to ensure that our objectives are achieved.

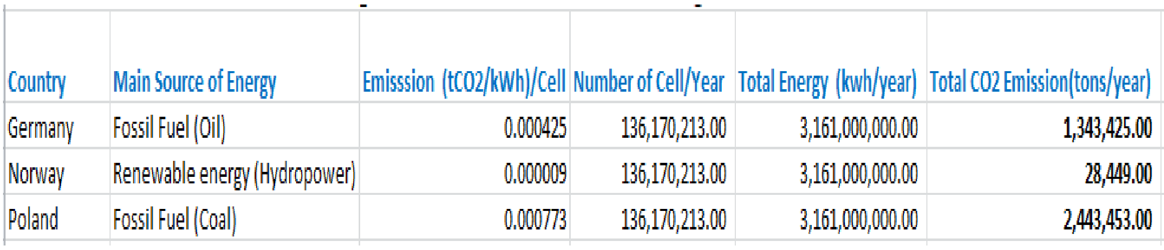
4.2 How could the carbon emission of a supply chain be audited?

“A carbon footprint is the total set of GHG emissions caused directly and indirectly by an individual, organization, event or product” (UK Carbon Trust 2008). The first step in the carbon management process is to measure and record GHG emissions. The literature review on carbon auditing and carbon auditing framework in 2.3 and 2.4 explains in detail how to audit the carbon emission of a supply chain. According to WBCSD/WRI (2004) and British Standards Institution (2011), setting priorities and creating a process map are the first steps in calculating a supply chain's carbon footprint; the next step is to choose a measurement method and determine boundaries. After defining the boundaries, we then collect data and choose the emission factors and proceed with the calculation. The last step of this process is verification and disclosure. Several guidelines, such as the Greenhouse Gas Protocol, ISO 14067, ISO 14064:1, and others, have been released to assist businesses in calculating, monitoring, and controlling their carbon footprints.

4.3 Which are the likely CO_2 emissions related to the energy source used in manufacturing at the alternative locations?

The energy source used in the production of EV battery cells accounts for the highest percentage in the EV battery production. Table 4.1 below shows the details of the CO_2 emissions in the alternative locations according to the source of energy. The data on emissions (tCO_2/kwh) based on different sources of energy at alternative locations was obtained from Freyr Battery AS. We then calculated the total yearly CO_2 emission in tons by multiplying the emissions per cell based on the energy used in kwh by the total energy in kwh used in the production of 136 170 213 cells.

Table 4. 1 CO_2 **Emission Report in the Cell Manufacturing Process at alternative locations**



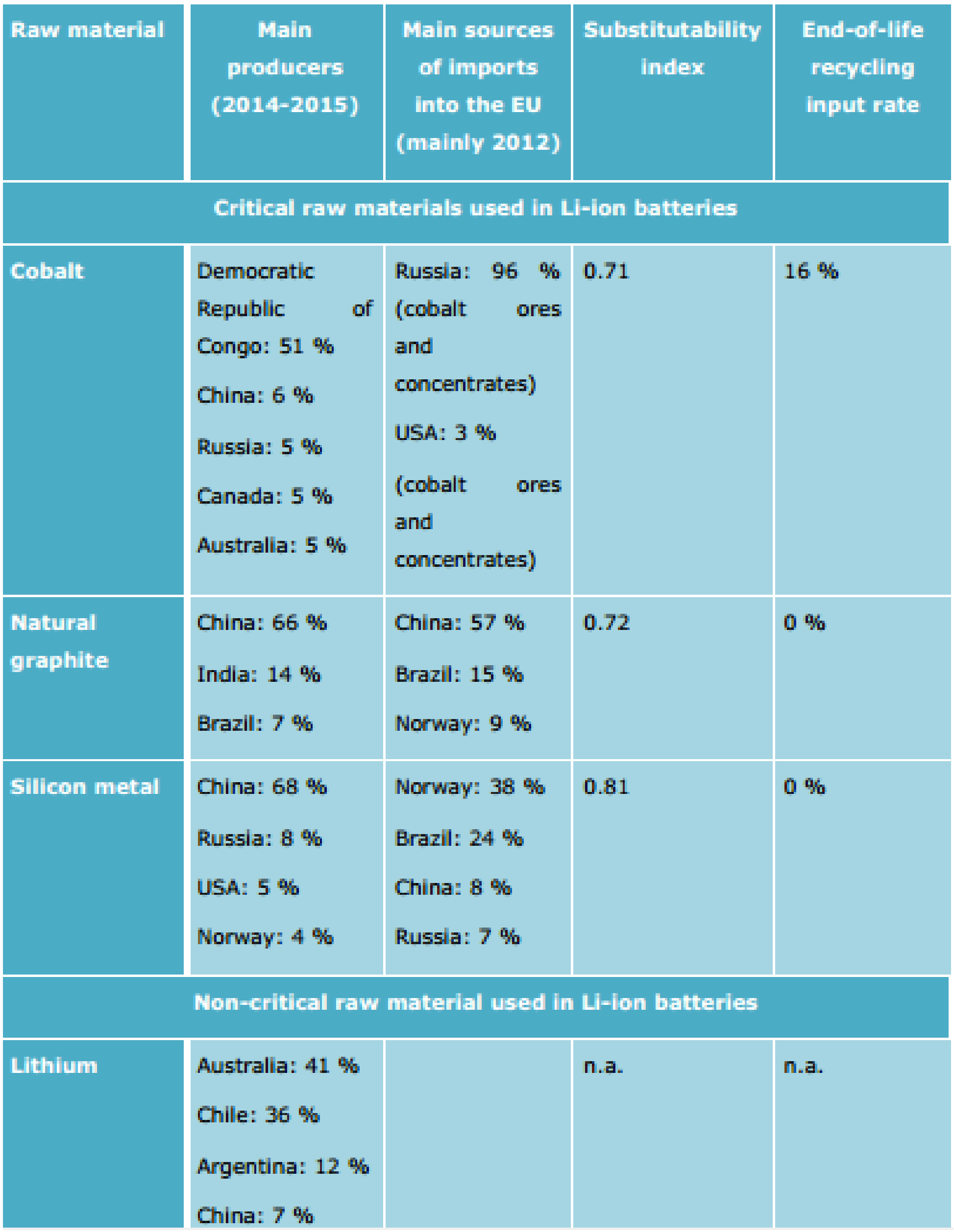
Country	Main Source of Energy	Emisssion (tCO2/kWh)/Cell	Number of Cell/Year	Total Energy (kwh/year)	Total CO2 Emission(tons/year)
Germany	Fossil Fuel (Oil)	0.000425	136,170,213.00	3,161,000,000.00	**1,343,425.00**
Norway	Renewable energy (Hydropower)	0.000009	136,170,213.00	3,161,000,000.00	**28,449.00**
Poland	Fossil Fuel (Coal)	0.000773	136,170,213.00	3,161,000,000.00	**2,443,453.00**

From the table 4.1 above, the study reveals that the main source of energy in Germany is from fossil fuel(oil) followed by renewable energy and for an annual production of 136170213 cells of EV battery, it will emit 1343425tons of CO_2/year. Poland's main source of energy is coal from fossil fuel, for the production of the same number of EV battery cells, Poland will emit 2443453tons of CO_2/year. On the other hand, the main source of energy in Norway is from Hydropower from renewable energy. For the same production capacity as the other alternative locations, Norway emits only 28499tons of CO_2/year.

4.4 Which are the likely CO_2 emissions related to the inbound logistics at the alternative locations?

The upstream/inbound logistics is very important in the EV lithium ion battery production since it is through this inbound logistics activity that we get the essential raw material for manufacturing the said battery. Before diving into the inbound CO_2 emissions at alternative locations, it is paramount to point out the main producers and main source of import of this critical material in Europe. The key manufacturers, major sources of import into the EU, substitutability index, and recycling rate of cobalt, natural graphite, silicon metal, and lithium are shown in Table 4.2. This is just an illustrative table to understand how critical the raw material for the production of sustainable EV at alternative locations is.

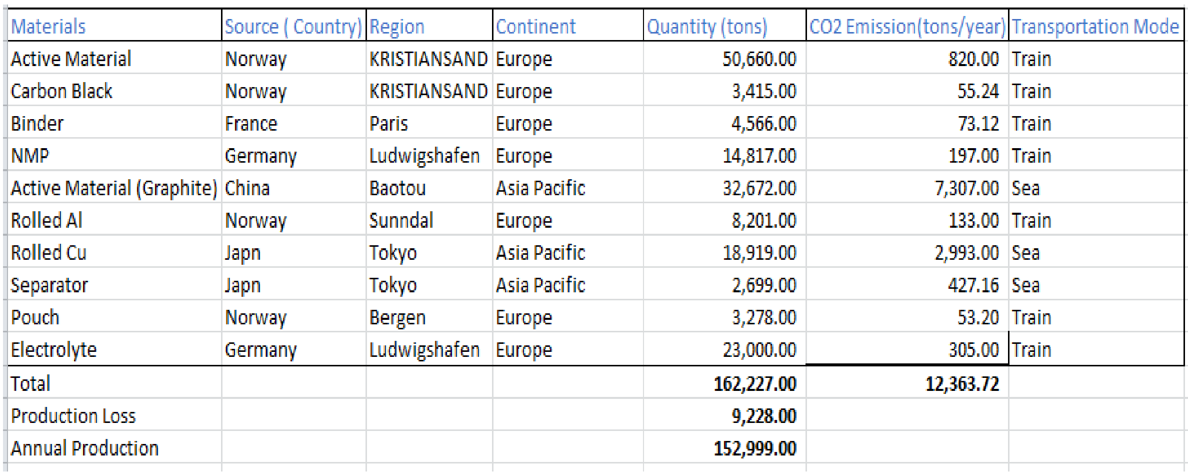
Table 4. 2 **key manufacturers, major sources of import into the EU, substitutability index, and recycling rate of cobalt, natural graphite, silicon metal, and lithium (COM(2014) 297 final)**



Raw material	Main producers (2014-2015)	Main sources of imports into the EU (mainly 2012)	Substitutability index	End-of-life recycling input rate
Critical raw materials used in Li-ion batteries				
Cobalt	Democratic Republic of Congo: 51 % China: 6 % Russia: 5 % Canada: 5 % Australia: 5 %	Russia: 96 % (cobalt ores and concentrates) USA: 3 % (cobalt ores and concentrates)	0.71	16 %
Natural graphite	China: 66 % India: 14 % Brazil: 7 %	China: 57 % Brazil: 15 % Norway: 9 %	0.72	0 %
Silicon metal	China: 68 % Russia: 8 % USA: 5 % Norway: 4 %	Norway: 38 % Brazil: 24 % China: 8 % Russia: 7 %	0.81	0 %
Non-critical raw material used in Li-ion batteries				
Lithium	Australia: 41 % Chile: 36 % Argentina: 12 % China: 7 %		n.a.	n.a.

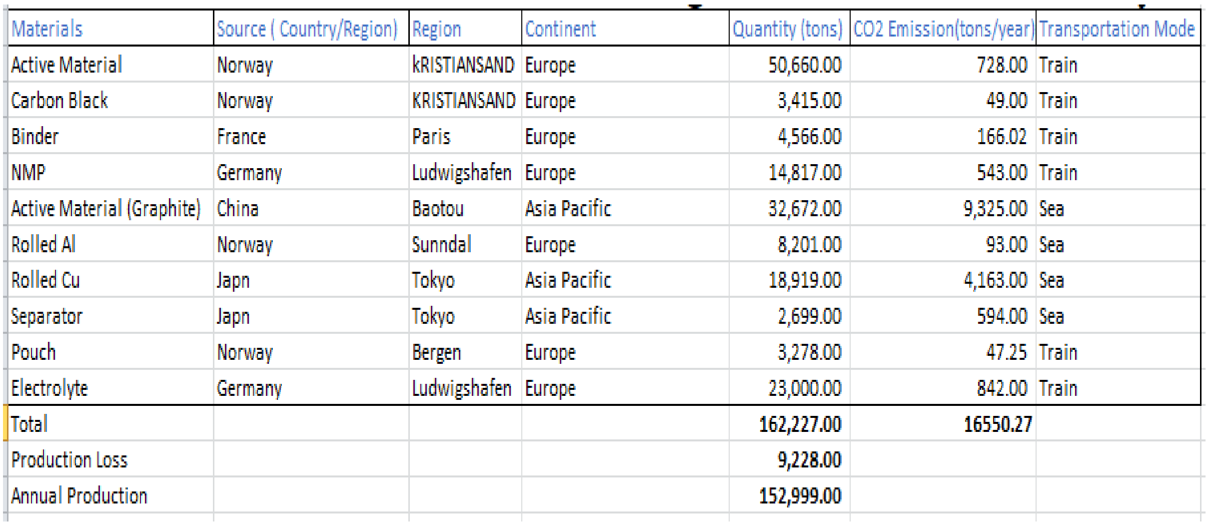
The CO_2 emissions related to inbound logistics operations at alternative locations for a production volume of 136 170 213 cells of EV batteries are depicted in tables 4.3, 4.4 and 4.5 below.

Table 4. 3 **CO_2 Emissions Related to Inbound Logistics in Berlin Germany**



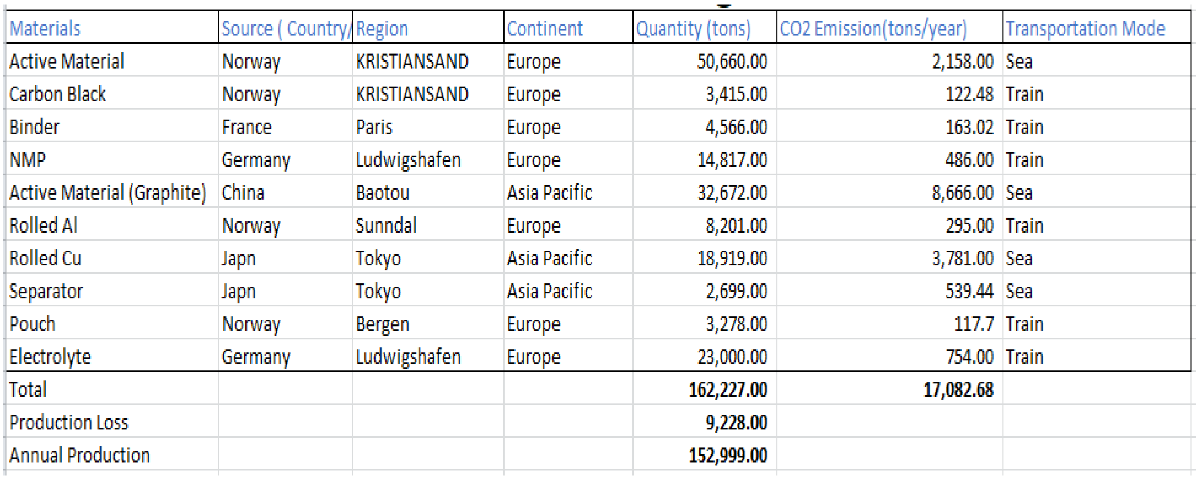
Materials	Source (Country)	Region	Continent	Quantity (tons)	CO2 Emission(tons/year)	Transportation Mode
Active Material	Norway	KRISTIANSAND	Europe	50,660.00	820.00	Train
Carbon Black	Norway	KRISTIANSAND	Europe	3,415.00	55.24	Train
Binder	France	Paris	Europe	4,566.00	73.12	Train
NMP	Germany	Ludwigshafen	Europe	14,817.00	197.00	Train
Active Material (Graphite)	China	Baotou	Asia Pacific	32,672.00	7,307.00	Sea
Rolled Al	Norway	Sunndal	Europe	8,201.00	133.00	Train
Rolled Cu	Japn	Tokyo	Asia Pacific	18,919.00	2,993.00	Sea
Separator	Japn	Tokyo	Asia Pacific	2,699.00	427.16	Sea
Pouch	Norway	Bergen	Europe	3,278.00	53.20	Train
Electrolyte	Germany	Ludwigshafen	Europe	23,000.00	305.00	Train
Total				**162,227.00**	**12,363.72**	
Production Loss				**9,228.00**		
Annual Production				**152,999.00**		

Table 4. 4 **CO2-Emissions Related to Inbound Logistics in Mo i Rana Norway**



Materials	Source (Country/Region)	Region	Continent	Quantity (tons)	CO2 Emission(tons/year)	Transportation Mode
Active Material	Norway	kRISTIANSAND	Europe	50,660.00	728.00	Train
Carbon Black	Norway	KRISTIANSAND	Europe	3,415.00	49.00	Train
Binder	France	Paris	Europe	4,566.00	166.02	Train
NMP	Germany	Ludwigshafen	Europe	14,817.00	543.00	Train
Active Material (Graphite)	China	Baotou	Asia Pacific	32,672.00	9,325.00	Sea
Rolled Al	Norway	Sunndal	Europe	8,201.00	93.00	Sea
Rolled Cu	Japn	Tokyo	Asia Pacific	18,919.00	4,163.00	Sea
Separator	Japn	Tokyo	Asia Pacific	2,699.00	594.00	Sea
Pouch	Norway	Bergen	Europe	3,278.00	47.25	Train
Electrolyte	Germany	Ludwigshafen	Europe	23,000.00	842.00	Train
Total				**162,227.00**	**16550.27**	
Production Loss				**9,228.00**		
Annual Production				**152,999.00**		

Table 4. 5 **CO2-Emissions Related to Inbound Logistics in Warsaw Poland**



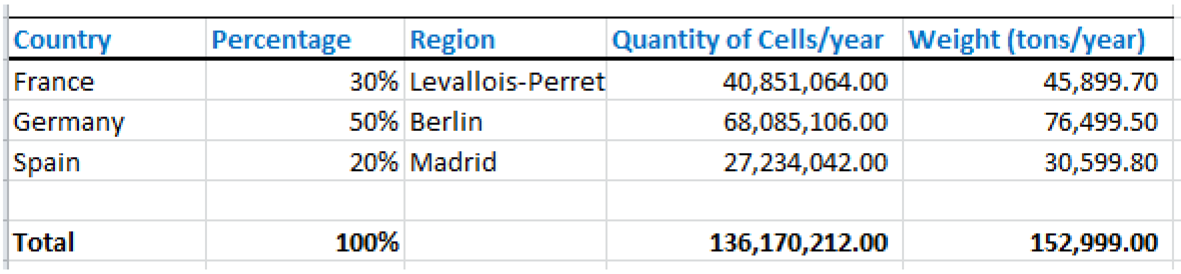
Materials	Source (Country	Region	Continent	Quantity (tons)	CO2 Emission(tons/year)	Transportation Mode
Active Material	Norway	KRISTIANSAND	Europe	50,660.00	2,158.00	Sea
Carbon Black	Norway	KRISTIANSAND	Europe	3,415.00	122.48	Train
Binder	France	Paris	Europe	4,566.00	163.02	Train
NMP	Germany	Ludwigshafen	Europe	14,817.00	486.00	Train
Active Material (Graphite)	China	Baotou	Asia Pacific	32,672.00	8,666.00	Sea
Rolled Al	Norway	Sunndal	Europe	8,201.00	295.00	Train
Rolled Cu	Japn	Tokyo	Asia Pacific	18,919.00	3,781.00	Sea
Separator	Japn	Tokyo	Asia Pacific	2,699.00	539.44	Sea
Pouch	Norway	Bergen	Europe	3,278.00	117.7	Train
Electrolyte	Germany	Ludwigshafen	Europe	23,000.00	754.00	Train
Total				**162,227.00**	**17,082.68**	
Production Loss				**9,228.00**		
Annual Production				**152,999.00**		

Table 4.3, 4.4 and 4.5 above shows the yearly CO_2 emissions from inbound logistics operations from the production center of the alternative locations. For a total yearly inbound material of 152999tons from various areas across the globe, the CO_2 emission from Germany is 12363.72 t/year, Norway is 16550.27 t/year, and Poland with the highest amount stands at is 17082.68 t/year.

4.5 Which are the likely CO_2 emissions related to the outbound logistics at the alternative locations?

Based on the research limitation, Germany, France and Spain which are major cars manufacturing nations in Europe were chosen to be the countries where the main volumes of EV batteries cells are needed in Europe. Table 4.6 below shows the data from these locations used in the calculation of CO_2 emissions related to outbound logistics operations at alternative locations.

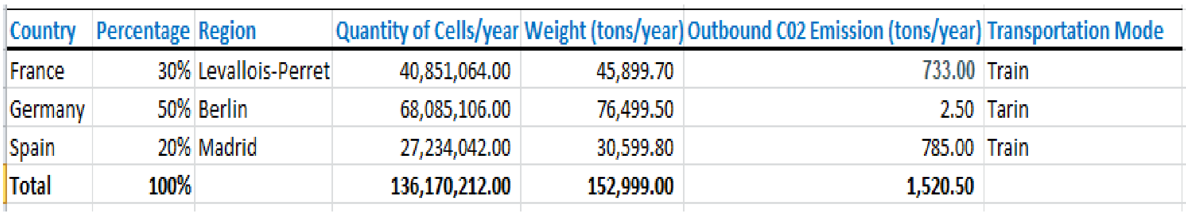
Table 4. 6 **Data Related to Outbound Logistics at the Alternative Locations**



Country	Percentage	Region	Quantity of Cells/year	Weight (tons/year)
France	30%	Levallois-Perret	40,851,064.00	45,899.70
Germany	50%	Berlin	68,085,106.00	76,499.50
Spain	20%	Madrid	27,234,042.00	30,599.80
Total	**100%**		**136,170,212.00**	**152,999.00**

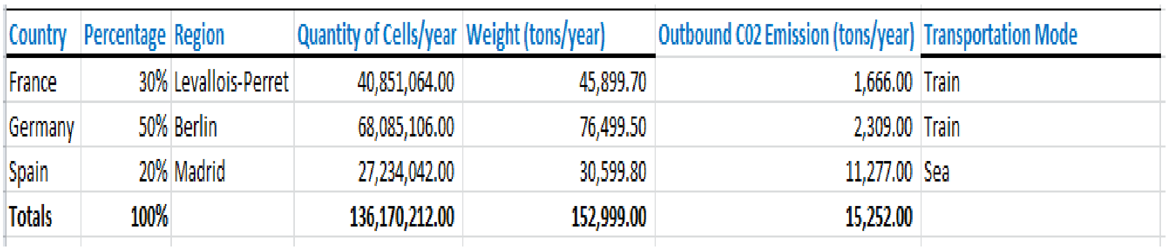
Based on the total number of cells to be produced, the respective share and weight of cells of these countries, the CO_2 emissions related to downstream logistics at alternative locations was calculated as presented in tables 4.7, 4.8 and 4.9 below.

Table 4. 7 **CO2-Emissions Related to Outbound Logistics From Berlin Germany**



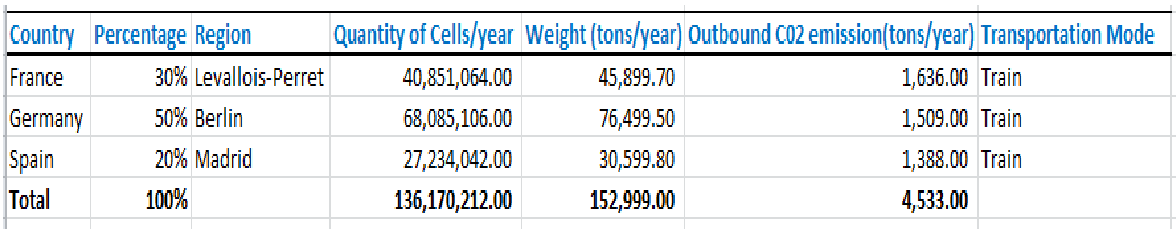
Country	Percentage	Region	Quantity of Cells/year	Weight (tons/year)	Outbound C02 Emission (tons/year)	Transportation Mode
France	30%	Levallois-Perret	40,851,064.00	45,899.70	733.00	Train
Germany	50%	Berlin	68,085,106.00	76,499.50	2.50	Tarin
Spain	20%	Madrid	27,234,042.00	30,599.80	785.00	Train
Total	**100%**		**136,170,212.00**	**152,999.00**	**1,520.50**	

Table 4. 8 **CO2-Emissions Related in Outbound Logistics from Mo i Rana Norway**



Country	Percentage	Region	Quantity of Cells/year	Weight (tons/year)	Outbound C02 Emission (tons/year)	Transportation Mode
France	30%	Levallois-Perret	40,851,064.00	45,899.70	1,666.00	Train
Germany	50%	Berlin	68,085,106.00	76,499.50	2,309.00	Train
Spain	20%	Madrid	27,234,042.00	30,599.80	11,277.00	Sea
Totals	**100%**		**136,170,212.00**	**152,999.00**	**15,252.00**	

Table 4. 9 **CO2-Emissions Related in Outbound Logistics from Warsaw Poland**



Country	Percentage	Region	Quantity of Cells/year	Weight (tons/year)	Outbound C02 emission(tons/year)	Transportation Mode
France	30%	Levallois-Perret	40,851,064.00	45,899.70	1,636.00	Train
Germany	50%	Berlin	68,085,106.00	76,499.50	1,509.00	Train
Spain	20%	Madrid	27,234,042.00	30,599.80	1,388.00	Train
Total	**100%**		**136,170,212.00**	**152,999.00**	**4,533.00**	

The three tables above depict the CO_2 emissions related to the outbound logistics operations in the alternative locations. After the production of the cells, they are transported using train and sea to the major EV battery cell markets in Europe (France, Germany and Spain). The CO_2 emissions are calculated by using the EcoTransit model. This model is the most commonly used program for calculating energy consumption, carbon emissions, air pollution, and external costs automatically around the world. After obtaining the weight of the cells and choosing the best transportation mode from each alternative location to the respective major market. The total number of cells (136170213) produced by each plant weighed a total of 152999 tons. Sharing the major market between France, Germany and Spain with respective percentages of 30%, 50% and 20%; France had a total weight of 45899.70 tons, Germany got 76499.50 tons and Spain 30599.80 tons. After applying this weights and transportation mode in the EcoTransit model, the results shows that Germany has an annual outbound logistic emission of 1520.5 tco_2/year, Poland stands with 4533 tco_2/year, and Norway with the highest has15252 tco_2/year.

4.6 Which other factors other than CO_2 emissions might be relevant for the choice of location?

Analyzing the CO_2 emissions at alternative locations to produce sustainable EV lithium ion batteries is one of the most significant environmental factors that influence a plant's location decision. Thus the source of energy (renewable energy or fossil fuel) is the most important factor here. As discussed in the literation review other factors such as political environment, access to skilled labor, nearness to suppliers and customers with excellent contact to raw materials are not to be neglected but for the purpose of this study, these factors will not be discussed in detailed because of the time constraint and the study delimitations.

4.7 Comparative Analysis of alternative locations

Going back to our main research objective which is to evaluate alternative production localizations among Germany, Norway and Poland of a new plant for the manufacturing of carbon-footprint minimizing sustainable lithium-ion batteries for the car industry, it is clear that our main localization parameter is low CO_2 emission thus, the best location of the plant should be the one with the lowest total CO_2 emissions throughout the EV battery cell production and distribution process. Figure 4.1 below illustrates the total CO_2 emissions at the alternative locations with the ranking. Norway is rank first with the lowest CO_2 emission of 60251 tons/year as a result of the use of renewable energy as its main source of energy, Germany is second on the list with a yearly CO_2 emission of 1 357 309 tons, and finally Poland is the third with a yearly CO_2 emission of 2 465 069 tons both based on the use of fossil energy as their main source of energy.

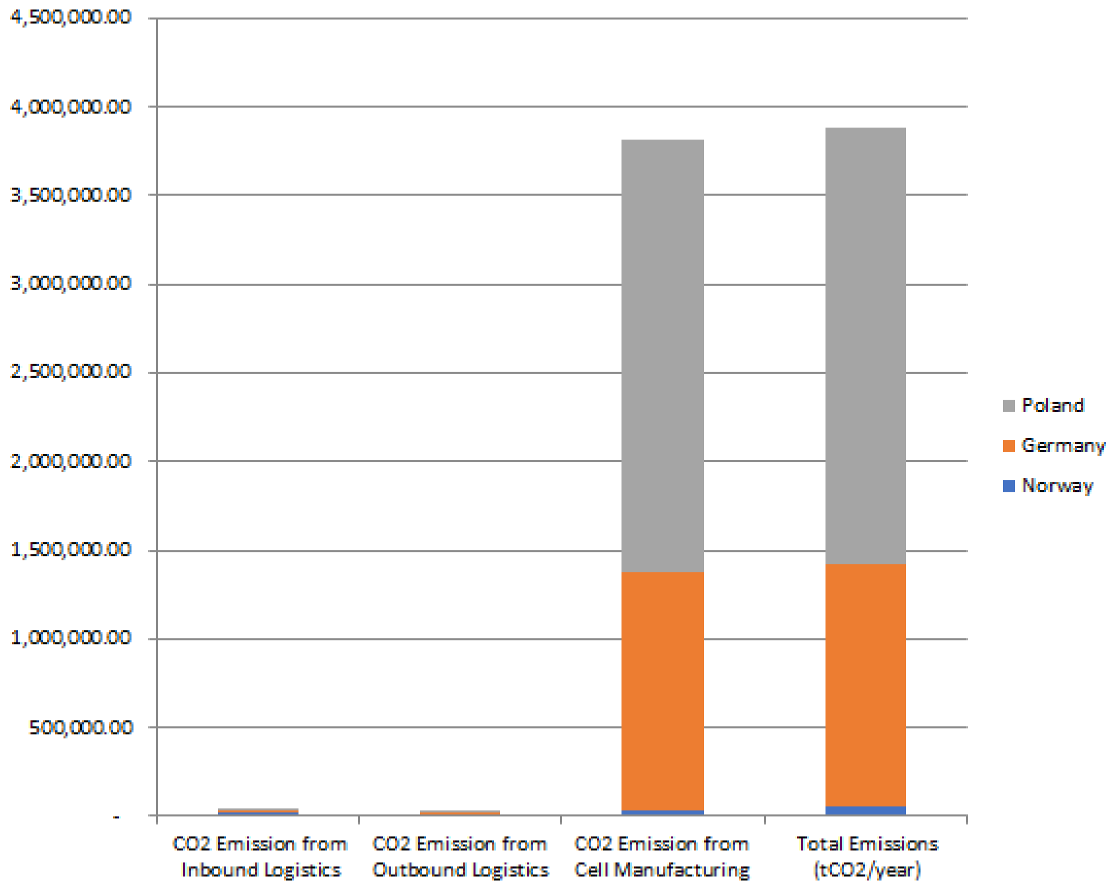


Figure 4.1 Total yearly emissions at alternative loctaions

5.0 DISCUSSION

5.1 Chapter Introduction

The main objective of this study was to evaluate alternative carbon-footprint minimizing production localizations of a new plant for the manufacturing of sustainable lithium-ion batteries for the car industry in Europe (Germany, Norway, and Poland). This study was done by using existing inbound/outbound data and standard emission factors from EcoTransit to calculate the CO_2 emissions at alternative locations with a combination of quantitative method and comparative case study research strategy to determine the best location in terms of less CO_2 emission. This chapter discusses and reflects on the results of our findings based on our research questions and brings out future perspective of greening the grids in terms of energy used, sourcing of active material and new batteries technology.

5.2 Research Questions

This section discusses and reflects on the research questions.

RQ1: How could the carbon emission of a supply chain be audited?

The details of this research question are well elaborated in the carbon auditing literature and carbon auditing framework in section 2.3 and 2.4 above.

RQ2: Which is the likely CO_2-emission related to the energy source used in manufacturing at the alternative locations

The study reveals that based on the various source of energy used in manufacturing at the alternative locations, the CO_2 emission varies. For an annual production volume of 136170213 cells of EV battery, Norway with hydropower as main source of energy emits 28499tons of CO_2/year emissions; Germany with fossil fuel as main source of energy emits 1343425tons of CO_2/year, and finally Poland with fossil fuel from coal as main source of energy emits 2443453tons of CO_2/year.

To continuously reduce this CO_2 emission, a lot is been done by most countries to switch from fossil fuel to renewable energy. We discuss below the energy situation at the alternative locations and some future perspective of transformation.

Germany

Starting with Germany, Electricity produced from renewable sources has multiplied by three in Germany over the past 10 years. Based on Germany's Energiewende targets, which include a low-carbon, environmentally sustainable, secure, and affordable energy supply, the share of power generated from renewable sources is expected to increase to 45% by 2025 and to more than 80 percent by 2050 (Sieminski, 2014). According to Fraunhofer Institute for Solar Energy Systems ISE news of January 15, 2020, Germany's anticipated development in renewable electricity comes from wind, biomass, solar, and hydropower energy which together accounted for 46.1% total electricity production in 2019 as depicted in figure 5.1 below.

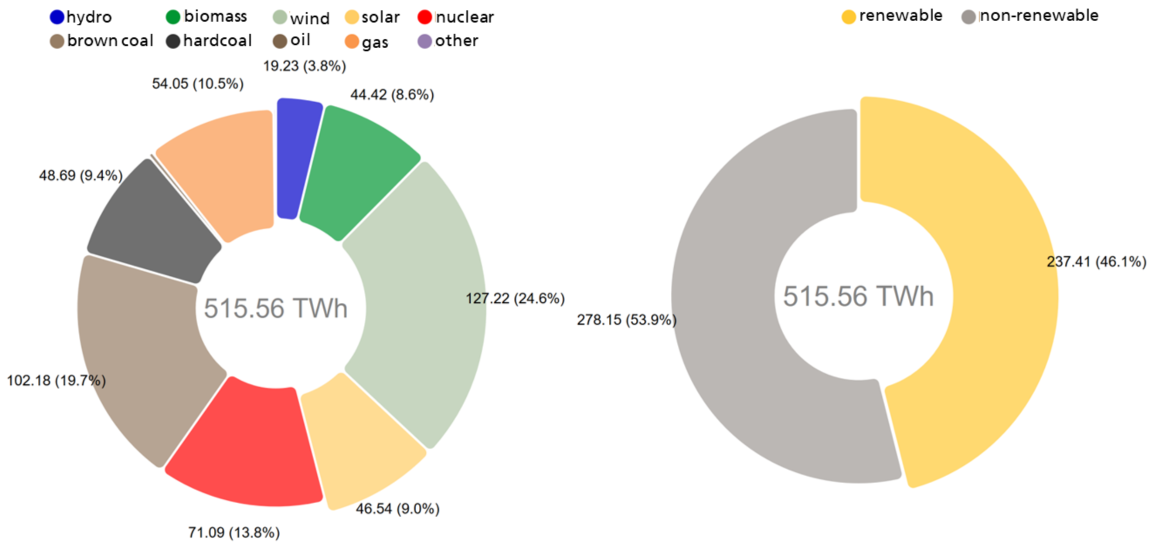


Figure 5. 1 Net Electricity Production in Germany 2019 (Fraunhofer ISE, 2020)

For the first time, overall electricity output from all renewable sources was about 237 TWh in 2019, up 7% from 2018 and surpassing fossil fuel carriers (207 TWh) (Fraunhofer ISE, 2020). The amount of electricity produced by wind in 2019 was about 127 TWh, up 15.7% from the previous year. As a result, for the first time in Germany, wind became the primary source of electricity (Fraunhofer ISE, 2020). The German government has championed for the production of renewable energy by promising a fixed, above-market price for every kilowatt-hour of energy generated by solar PV or wind and fed into the grid, a policy known as a feed-in tariff. By regulation, renewable energy sources take priority over conventional energy sources, meaning that other forms of generation must be curtailed in order to respond to fluctuations in renewable energy production. These policies have helped to double the amount of wind production in the last five years. Germany has made several improvements to its energy policies in order to promote green growth while keeping costs in check. Adjustments to the feed-in tariffs were introduced in 2014. Electricity producers will have to compete in auctions in the future as a replacement for fixed tariffs. If annual renewable growth goals are exceeded, the feed-in tariff benefits for the following year will be reduced to offset the growth.

Poland

Looking at electricity production in Poland, the transition to a low-carbon economy may pose questions for the power sector but also creates opportunities for the wider economy. Poland’s ageing power plants as well as its obligation to meet climate targets necessitate the need to supplant Poland’s ageing power plants (Foltyn et al 2021). No matter the rate at which Poland wants to achieve carbon neutrality which is in the EU green deal ambition for EU countries by 2050, lessening greenhouse gas emissions is essential for the future of the Polish economy. The domestic coal market's absurdity is that, amid constant high domestic demand for coal, output in Polish mines is dwindling, while reserves on heaps are increasing. Diversification of gas supplies and Russian imports account for less than half of Poland's blue fuel supplies (Foltyn et al 2021). Electricity production is decreasing, with lignite and hard coal generating the most electricity. In 2019, coal accounted for 73.6% of total electricity output, down from 4.8% in 2018. In 2019, Poland's electricity imports more than doubled, reaching 10.6 TWh (Foltyn et al 2021). The largest amount of electricity produced by renewable energy systems was over 25 TWh last year (Foltyn et al 2021). It is without a doubt the best in history. Nonetheless, this result is insufficient to meet EU standards.

Norway

Electricity output in Norway is overshadowed by hydropower. According to Statistics Norway (Statistisk sentralbyra, 2021), Norway’s share of hydropower in electricity production is 91.5%. Hydropower is one of the few renewable energy sources that can be stored, and generators can easily adjust output from minute to minute (Sovacool, 2017). Norway's significant reservoir capacity can be used to store and control a fluctuating supply from renewable energy sources such as wind and solar in neighboring countries, thanks to the common Nordic grid. In addition, Norway has significant untapped wind and bioenergy resources that could be useful for potential domestic and intercontinental demand. Norway and Sweden launched a joint green certificate program in 2012, which is expected to result in increased wind and hydropower capacity in Norway (Sovacool, 2017). In Norway, the average household electricity price, except taxes and grid rent, is 53.5 øre per kWh (Statistics Norway, 2021) which is a decrease of more than 37% of last three months figures. This is an indication that there is sufficient clean energy.

RQ3: Which are the likely CO_2-emissions related to the inbound logistics at the alternative locations?

The CO_2 emissions related to inbound logistics were calculated based on the materials used in the production process, the location of the materials, the weight and mode of transport of the materials to the alternative locations. As depicted in tables 4.3, 4.4 and 4.5 above, Germany got the lowest emission level, followed by Norway and lastly Poland.

Before we begin to discuss the CO_2 emissions that can be related to material component sources it is important to define the boundary and scope of our analysis according to the Greenhouse Gas Protocol, who defines CO_2 emissions related to inbound logistics as scope 3. Meanwhile, the calculations of CO_2 were limited to cell material supplies even though our analysis would not be complete without examining the sources of raw materials to the cell material suppliers. As previously stated, the cathode material's value has an effect on the cell's overall performance. Lithium nickel cobalt manganese oxide (NMC) was chosen as the state-of-the-art cathode material due to its high operating potential compared to lithium and theoretical power. In the case of cathode manufacturing, quality control starts with the raw material manufacturing point.

To begin with, the Democratic Republic of the Congo dominates cobalt mining, accounting for more than 60% of global production, with China, Russia, Canada, and Australia each having a much smaller share. As a result, cobalt is primarily obtained as a by-product of the nickel (50%) and copper (44%) mining industries (Cobalt Institute). The world's largest cobalt producers are in the Democratic Republic of Congo, where working conditions, including child labor, are not strictly controlled (Siddharth Kara, 2018). The refinement, on the other hand, is dominated by Chinese firms. The price of cobalt has risen by more than 300 percent, owing to the market's slow response to the rising demand for electric vehicles and mining companies looking to benefit from these geographically concentrated deposits.

Similarly, lithium is an oligopolistic commodity with just eight producing countries, three of which Chile, Australia, and China account for 85% of global output (Chagnes and Swiatowska, 2015). Lithium may be made from brines or hard rock, and clay-based materials are also in the works. Lithium is currently supplied by only one of these sources in each producing region, such as brines from Argentina, Chile, and Bolivia, and hard rock from Australia. China is an exception, since it uses both hard rock and brines to make its products.

In addition, nickel is a cathode active material. The proven steel industry has overshadowed the nickel sector. Nonetheless, because of the switch to Ni-rich cathode materials, demand for this metal is expected to skyrocket (Bernhart, 2019). The nickel market is generally more uneven, with mining and processing mostly carried out by the same business. Manganese is also an active ingredient in the cathode. The steel industry, which accounts for about 90% of manganese extraction, is followed by the use of primary and rechargeable Li-ion batteries (Bernhart, 2019). Manganese reserves are estimated to be about 690 million tons and are primarily found in South Africa, Australia, and India as stated by European Commission Report on Raw Materials for Battery Applications (2018). Ukrainian and Chinese companies dominate manganese refinement in spins, and the price of this commodity remains consistently low. Similarly, no major production bottlenecks from other sectors are expected. All of this leads to the fact that manganese is not a vital material in the manufacture of lithium batteries.

Graphite, on the other hand, is a state-of-the-art anode substance that can be divided into natural and synthetic varieties. Synthetic graphite is made from petroleum coke or tar pitch, while natural graphite is extracted from ore. Natural graphite is used in a variety of industries, including electrodes, refractories, lubricants, foundries, and as an active ingredient in batteries (D. ENTR, 2014). The percentage of used in batteries is comparatively poor, at 4%. (D. ENTR, 2014). According to Geological Survey of the United States of America (2016), natural graphite production is highly concentrated, with China accounting for 66% of total market value, India for 14%, and Brazil for 7%. China imports the most natural graphite into the EU (57%), followed by Brazil (15%) and Norway (9%). Natural graphite has a (very) low replaceability in some applications (substitutability index for all applications is 0.72), but it is possible to replace natural graphite with other materials in batteries with substitutability index 0.3 (D. ENTR, 2014). Natural graphite has a 0% end-of-life recycling input rate. The natural graphite market is expected to experience a strong surplus of production in 2020, with supply exceeding demand by more than 10%. (D. ENTR, 2014).

The Asian suppliers dominate the production of electrolytes for Li-ion batteries, with China accounting for up to 60% of the total market, Japan 18%, and Korea 14%. (Pillot 2015). There may be business opportunities for EU-based producers in this thriving market environment, particularly given the expected market growth. The demand for electrolytes is expected to rise from the current 62,000 tons to more than 235,000 tons in 2025, with the automotive sector accounting for roughly 33% of the market today and approximately

50% in 2025 (Pillot 2015). Similarly, Asia dominates the market for Li-ion battery separators, with Japan accounting for 48% of total production, China 17%, and Korea 10% (Pillot 2015). Evonik (DE), based in the EU, is one of the newest players in the separator materials industry (Pillot 2015). Finally, the Specialty Carbon Black market is divided into Latin America, the Middle East, Asia Pacific, Europe, North America, and Africa centered on geographic segmentation. Due to low carbon black manufacturing costs and China's rise in high volume carbon black exports, Asia Pacific is considered to have a potential share of the carbon black market in terms of yields.

RQ4: Which are the likely CO_2-emissions related to the outbound logistics at the alternative locations?

The outbound logistics CO_2 emissions at alternative locations was calculated considering France, Germany and Spain as the major car manufacturing nations in Europe. Their respective market shares were 30%, 50% and 20% of the number of EVB cells produced per year. Based on the weight of cells to be transported to a particular market and the mode of transport from the alternative location, Germany came out with the lowest yearly CO_2 emission, followed by Poland and lastly Norway. To better understand how we can reduce the level of outbound logistics emissions, it is important understand the battery technology. This outbound logistics can be affected by the battery technology where by the lower the amount of active material use, the lesser weight of the cell and thus lower CO_2 emissions. Panasonic, a major Tesla battery supplier, recently launched lithium-ion cells with a cobalt content of less than 5%, with the firm aiming for zero in the next two to three years. The company's new Ultium battery device, produced in partnership with LG, another Tesla supplier, was demonstrated by GM's CEO. Ultium is a modular battery cell construction that uses 70% less cobalt by replacing it with aluminum in the chemistry of the battery. All these inovation in battery technolgy will not only lead to the reduction of CO_2 emission during inbound and outbound logistics but it would also help to ultimately reduce the negative effects of batteries on the environment while also lowering the cost.

RQ5: Which other factors than CO_2-emissions might be relevant for the choice of location?

Other considerations such as technological infrastructure and logistical conditions, raw material availability and expense, and the location's attractiveness to well-trained and skilled personnel, the tax situation, the cost of labour, political stability and regulations were also identified as being important for the choice of location. Due to the research delimitation and time constraint, this aspect cannot be discussed in detail.

6.0 CLOSING REMARKS

6.1 Chapter Introduction

This chapter brings out the closing remarks that conclude the study by discussing the research summary, managerial implications, limitations of the study, and suggestions for further research.

6.2 Research Summary

This master thesis sought to evaluate the alternative carbon-footprint minimizing production localizations of a new plant for the manufacturing of sustainable lithium-ion batteries for the car industry among Germany, Norway, and Poland in Europe. It started by identifying how to audit the carbon emission of a supply chain and proceeded specifically to evaluate and quantify CO_2 emissions related to the energy source used in manufacturing at the alternative locations, CO_2 emissions related to the inbound logistics at the alternative locations, and CO_2 emissions related to the outbound logistics at the alternative locations. A list of other factors affecting plant location choice was also highlighted. This study was done by using primary and secondary data with a combination of EcoTransit standard emission factor and a quantitative research method conducted through a comparative case study research strategy.

The study found Norway to be the best alternative to establish a sustainable EV lithium-ion battery plant. It had the lowest yearly CO_2 emission based on the same production capacity at alternative locations. The study also revealed that the main advantage of Norway was the use of renewable energy in the cell manufacturing process that accounts for more than 98% of the total yearly CO_2 emissions. Germany has a localization advantage when it comes to emissions related to inbound and outbound logistics. Meanwhile, Poland has no competitive advantage in terms of CO_2 emission reduction but has advantage over other factors such as lower labor cost.

6.3 Managerial Implications

Base on the discussions and prove from analysis, it is easy to conclude and to make recommendations without intimidation, to corporate bodies and managers on how to attract and maintain a sustainable upstream and downstream while deciding where to locate the plant of Li-ion Battery. To begin with, regarding the mode and means of transport, it is noted that train system is the cleanest energy for the transportation of raw material in the upstream, and finish product in the downstream within Europe. Besides considering that most of the suppliers and market are in Europe is advantageous as it implies significant energy savings in terms of less CO_2 emission. Meanwhile, for suppliers out of Europe and most especially Asia it is advisable to utilize sea which is beneficial in terms of quantity distance and can be reflected in reducing CO_2 emissions. Furthermore, companies that want to take advantage of considerable reduction of CO_2 by utilizing renewable energy in the production process should locate their plant in Norway, however, the only limitation is that it is little further from the suppliers and the market and contribute slightly more CO_2 during transportation than Germany who is located quite close to the suppliers and market. Since cell manufacturing accounts for more than 98% of the energy used in the overall sustainable EV battery production and distribution process, it is therefore paramount that companies carrying out such operations be located in countries that uses renewable energy as their main source of energy in other to drastically reduce CO_2 emissions as depicted in the case of Norway above. Also Factors such as technological infrastructure and logistical conditions, raw material availability and expense, and the location's attractiveness to well-trained and skilled personnel, the tax situation, the cost of labour, political stability and regulations should not be neglected. In Europe the emissions related to upstream and downstream logistics does not account for a significant amount in the total CO_2 emission in the overall production and distribution process but it is equally important to continue to seek for ways to reduce their emissions.

6.4 Limitations of the Study

Carrying out a research work involves many challenges that the researcher may face during the process. This does not make the work to be invalid, but it has some challenges during the design process and quality of data used. The following limitations were encountered during this study:

Firstly, there was some limitation in having enough primary data from EV battery manufacturer in the alternative locations. So we generalized the data obtained for all the alternative locations.

Secondly is the time constraint. The time frame for this master thesis could not permit us to evaluate in detail other factors that might be relevant for the choice of location at alternative locations.

Thirdly, in the past, most facility choice decisions by firms were not taken based on how sustainable the plant location choice could be, but more on the company's top and bottom line. Therefore, the challenge was lack of sufficient prior research on this topic.

6.5 Suggestions for further Research

This research seeks to identify the alternative carbon-footprint minimizing production localizations of a new plant for the manufacturing of sustainable lithium-ion for the car industry in Europe could be the benchmark in other continents like south and North America since they have a conservable small li-ion battery manufacturer which could serve as the source to determine the most optimal location that will keep CO2 emission low. Also further research could be carried out to evaluate the other factors other than CO_2 emissions that might be relevant for the location choice of a sustainable EV battery plant.

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