A Comparative CO_2 Emission Analysis of a Diesel and Electric Engine

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PREFACE

This bachelor thesis has been written in cooperation with MENG and Eide Fjordbruk. The bachelor was written during the spring semester 2021 at Western Norway University of Applied Sciences, Department of Mechanical and Marine Engineering in Bergen. The thesis is written by Helene R. Moxnes, Kristoffer B. Hauge and Vermund Leite.

We would like to thank Helge Folgerø-Holm and Hans Marius Remmen from MENG and Hans Martin Eide form Eide Fjordbruk for this opportunity and their support. We would also like to thank our professor, Maneesh Singh, for guidance and support throughout the bachelor thesis. Finally we would like to show our appreciation to Corvus Energy, ABB and Scania for good, useful and up-to-date information that have been shared with us .

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ABSTRACT

To decrease the CO_2 emission and achieve FN's sustainability goals, it is a possibility to replace fossil fuel with electricity. Electric vehicles have therefore been an alternative that have become popular over the years. As the technology for electric vehicles are evolving, the technology has now been implemented in the marine industry.

This thesis presents a comparative CO_2 emission analysis between an electric and diesel engine system. Manufacturing, transportation and operation are the three phases that are included in the analysis. The recycling in the end-of-life phase will be described and discussed, but not included in the calculations. The thesis also consider where in the world the different stages take place, along with other considerations.

Companies that operate within electric motors, batteries and diesel motors have provided up-to-date information for the thesis. The information have to contributed to a more accurate calcualtion. The calcualtions of the different phases shows that total CO_2 emission from the diesel engine system is 15 times higher than the electric engine system. The conclusion of this thesis is that the CO_2 emissions from the ABB electric engine and Corvus Dolphin Energy battery system emits far less CO_2 than the Scania diesel engine through a 20-year phase.

This bachelor thesis will present step by step how much CO_2 emissions that will be generated in the different phases of the two engine systems.

SAMMENDRAG

For å redusere CO2-utslipp og oppnå FNs bærekrafts mål, er det en mulighet å erstatte fossilt drivstoff med elektrisitet. Elbiler har derfor vært et alternativ som har blitt populært de siste årene. Etter hvert som teknologien for elektriske biler utvikler seg, har teknologien nå implementert seg i den maritime industrien.

Denne oppgaven presenterer en komparativ analyse for utslipp av CO_2 mellom et elektrisk og diesel motor system. Produksjon, transport og drift er de tre stegene som er inkludert i denne analysen. Resirkulering vil bli beskrevet og diskutert, men ikke inkludert i beregningene. Denne oppgaven tar også hensyn til hvor i verden de forskjellige stegene finner sted, sammen med andre betraktninger.

Selskaper som er næringsdrivende innenfor elektriske motorer, diesel motorer og batterier har delt oppdatert informasjon til oppgaven. Informasjonen har bidratt til en mer nøyaktig kalkulasjon. Beregningene av de forskjellige fasene viser at det totale CO_2 utslippet fra diesel motoren er 15 ganger høyere enn det elektriske motorsystemet. Konklusjonen for oppgaven er at det elektriske motorsystemet fra ABB og Corvus Energy slipper ut mye mindre CO_2 enn diesel motorsystemet fra Scania, for en periode på 20 år.

Denne bacheloroppgaven vil presentere trinn for trinn hvor mye CO2-utslipp som vil genereres i de forskjellige fasene av de to motorsystemene.

Table of Contents

Nomenclature

D	= Distance [km]
$E_{Battery}$	= CO_2 emissions from battery system manufacturing [kg]
$E_{Battery\ mfg}$	= CO_2 emissions from battery manufacturing [kg CO_2e / kWh]
E_{CO2}	= Emission CO2 [kg]
$E_{el.engine}$	= CO_2 emissions from electric engine per trip [kg]
E_{factor}	= Emission factor for ship type [g CO_2 / kWh]
E_{ferry}	= CO_2e emissions per trip with ferry [kg]
E_{fuel}	= CO_2 emission per liter fuel [kg / liter]
$E_{material}$	= CO_2 emissions per ton material produced [kg CO_2 / kg material]
E_{mfg}	= CO_2 emissions from manufacturing [kg]
$E_{operation}$	= CO_2 emission from operation of vessel per trip [kg]
$E_{power\ source}$	= CO_2 emissions from power source [kg CO_2 / kWh]
E_{ship}	= CO_2 emission per trip with ship [kg]
$E_{specific.m}$	= Specific CO_2 emission from ship transport of product [kg]
$E_{specific.road}$	= Specific CO_2 emission from road transport of product [kg]
E_{trans}	= CO_2 emissions from road transport [kg]
E_{vessel}	= CO_2 emission per trip from ferry or ship [kg]
F_{cargo}	= Fuel consumption as a function of cargo and distance [liter]
$F_{consump}$	= Fuel consumption based on cargo [liter / (km*ton)]
$F_{empty\ cargo}$	= Fuel consumption empty vehicle [liter / kilometer]
$F_{max\ cargo}$	= Fuel consumption with maximum cargo [liter / kilometer]
E_{factor}	= Emission factor for ship type [g CO_2 / kWh]
$F_{specific}$	= Specific fuel consumption [g / kWh]
$F_{specific,\ propeller}$	= Specific fuel consumption, propeller curve [liter / hour]

Fuel	= Consumptions [l]
h_{op}	= Operating hours [hour]
h_{trans}	= Transportation hours [hour]
k	= CO_2 variable for fuel [kg CO_2 / liter]
$kWh_{battery}$	= Energy in battery system [kWh]
$P_{tot.}$	= Total kWh during usage phase [kWh]
w	= weight of material [kg]
w_{cargo}	= Weight of cargo on vehicle [ton]
w_{max}	= Weight of maximum cargo [ton]
$w_{product}$	= Weight of product [kg]
ρ_{fuel}	= Density of fuel [kg / liter]

1. Introduction

1.1 Background

After years with high use of fossil fuel, the atmosphere is more and more affected by human CO_2. To stop climate change, FN has set a goal of becoming climate neural by 2030. In order to achieve this goal, CO_2 consumptions must be reduced at all levels possible.

To decrease the CO_2 emission and achieve FN's sustainability goals, it is a possibility to replace fossil fuel with electricity. Electric vehicles have therefore been an alternative that have become popular over the years. As the technology for electric vehicles are evolving, the technology has now been implemented in the marine industry.

Eide Fjordbruk is a company with a goal to shape the future of aquaculture in the best possible way. As a food producer and a local family business, they recognize the importance of reducing their greenhouse gas emissions to protect the environment locally and globally. Eide works purposefully with several concrete measures to reduce both their direct climate emissions from diesel for boats and facilities, and the climate footprint of their salmon. Together with MENG they want to contribute to maritime changes buy looking at cleaner alternatives. This thesis will therefore analyze an electric and a diesel alternative for a vessel to compare the total difference in CO2 emissions.

1.2 Aim of the Thesis

The aim of the thesis is to estimate the total CO_2 emissions generated by a fully electric engine system and a diesel engine system, by including manufacturing, transport, operation, and recycling.

1.3 Research Question

The research question for this bachelor thesis is:

How much CO_2 is generated throughout the lifespan of a full electric engine system and a diesel engine system?

1.4 Scope of Work

This thesis will cover the following:

- A comparison study of an electric and diesel engine system
- Calculation of CO_2 emissions through various stages:
    - Manufacturing of engines and batteries
    - Road and maritime transport of engines and batteries
    - Calculations of CO_2 from the operational phase over a 20-year period
    - Total CO_2 emissions for the considered lifespan
- Discussion of the end-of-life phase and current recycling methods

1.5 Limitations

The thesis is written based on information provided by MENG, Eide Fjordbruk, ABB, Corvus Energy, Scania and existing relevant literature on the topic. The results from this thesis cannot be used as a standard for all fully electric and diesel systems. Other engines and batteries can have different properties that will affect the end results.

The following limitations for this thesis have been set:

- Where information is lacking, assumptions will be made to calculate CO_2 emissions.
- Emissions from construction of infrastructure and production of charging stations for the electric engine system is neglected.
- Emissions related to diesel filling stations or tanks is neglected.
- CO_2 emissions from diesel production is neglected.
- Materials that are not categorized as steel, aluminum or copper in the engines are neglected.
- Neglects CO_2 emissions when assembling gear (diesel engine)
- Emissions related to construction and assembly of other parts on the engine (such as gear) are neglected.
- Emissions from assembly of engine systems on vessel are neglected.
- All other components than engine and battery in the engine system are neglected in this thesis.
- Any stop during transportation that are not related to the engines or batteries are not considered.
- Neglects sea flow and waves when calculating the CO_2 emission for transport by sea
- Uphill and downhill slopes are disregarded for road transport.

1.6 Structure of Thesis

The thesis is divided into the following chapters:

Chapter 1: Contains the background, the aim of the thesis, the scope of work, limitations, the structure of the thesis and abbreviations.

Chapter 2: A brief introduction that contains necessary information for the thesis.

Chapter 3: Contains the methods used and approaches taken to complete the study

Chapter 4: Calculations for CO_2 emission of all the different stages.

Chapter 5: Summary of the total CO2 emission, and comparison of the full electric system and the diesel system, as well as discussion of the different systems.

Chapter 6: Conclusion

Chapter 7: Recommendation for Further work

1.7 Abbreviations

CO_2	= Carbon Dioxide
CO_2e	= CO_2 equivalent
GP	= Gross power [kW]
GWP	= Global Warming Product
Kg	= Kilogram
Km	= Kilometer
kW	= Kilowatt
kWh	= Kilowatt hour
LCA	= Life Cycle Assessment
mm	= Millimeter
NMC	= Lithium Nickel Manganese Cobalt oxide
PBE	= Passenger car unit
VDC	= Volts of direct current

2. Description of Salmon Eye and Engine Systems

2.1 Salmon Eye

Salmon Eye is a center for learning and discussion about the possibilities for a sustainable way of fish farming. The center is floating in Hardangerfjord, outside Rosendal, and will be opening in 2021 [1]. The guests will be transported to the location by a passenger vessel. The production plant Hågardsneset will be close to Salmon Eye and will be a part of the visitation center.

The fish farming industry is moving toward a greener and more sustainable way for producing seafood. Eide Fjordbruk will through Salmon Eye spread awareness and interest on the topic.

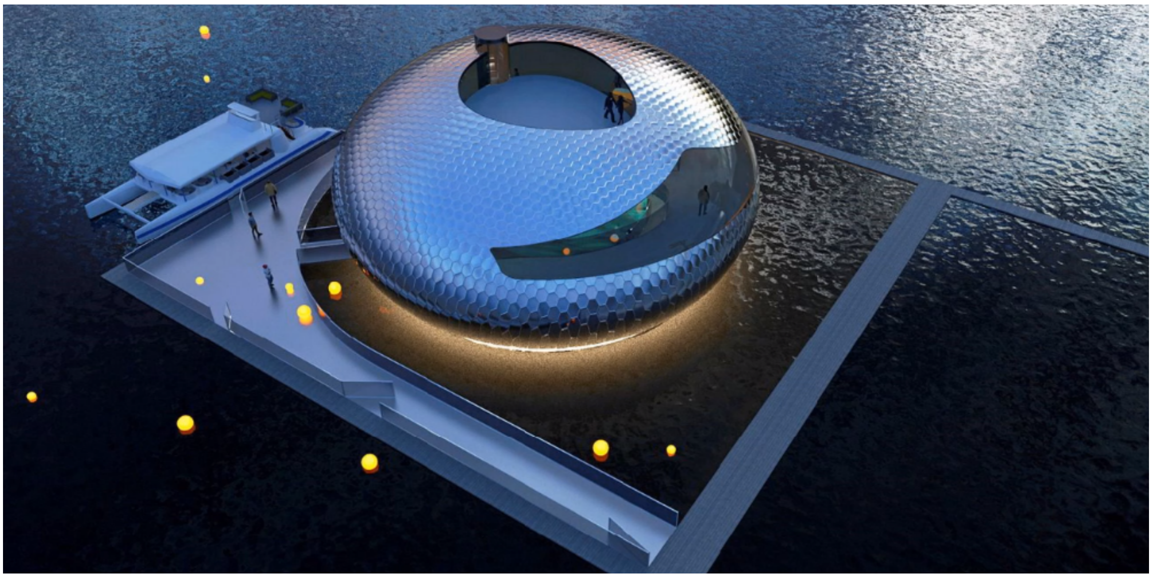


Figure 1. *Salmon Eye*

2.2 Vessel

The vessel carrying passengers to Salmon Eye is designed as a catamaran with the length of 16 meters and weighs 49 tons. The catamaran can carry up to 60 people, but the tour itself is planned for 30 people per group. The vessel will during on-season operate with three tours daily to Salmon Eye and back to Rosendal, via the production site Hågardsneset. During off-season it will only operate on request.

***Figure 2**. Catamaran with a perpendicular length of 16 meters.*

2.3 Engine & Battery

To execute a comparative analysis of an electric and diesel engine system, the two engines must be comparable in power. It is difficult to compare an electric and diesel engine as they have two different engine systems. The electric engine system consists of two engines and a battery system.

A Scania diesel engine were already chosen by MENG as one of the alternatives for the engines at the start of this project. The engine power for the diesel engine is 368 kW per engine. An electric engine must be able to produce approximately the same engine power to be comparable.

2.3.1 Engine System

The lifespan of engines and batteries is comprehensive and depends on all sorts of different factors. In figure 3 the important factors between production and disposal of an engine and a battery are presented. To narrow the thesis, only the yellow steps inside the square will be included in the calculator. The purple steps inside the dotted square will be discussed in the report but not included in the CO_2 calculations.

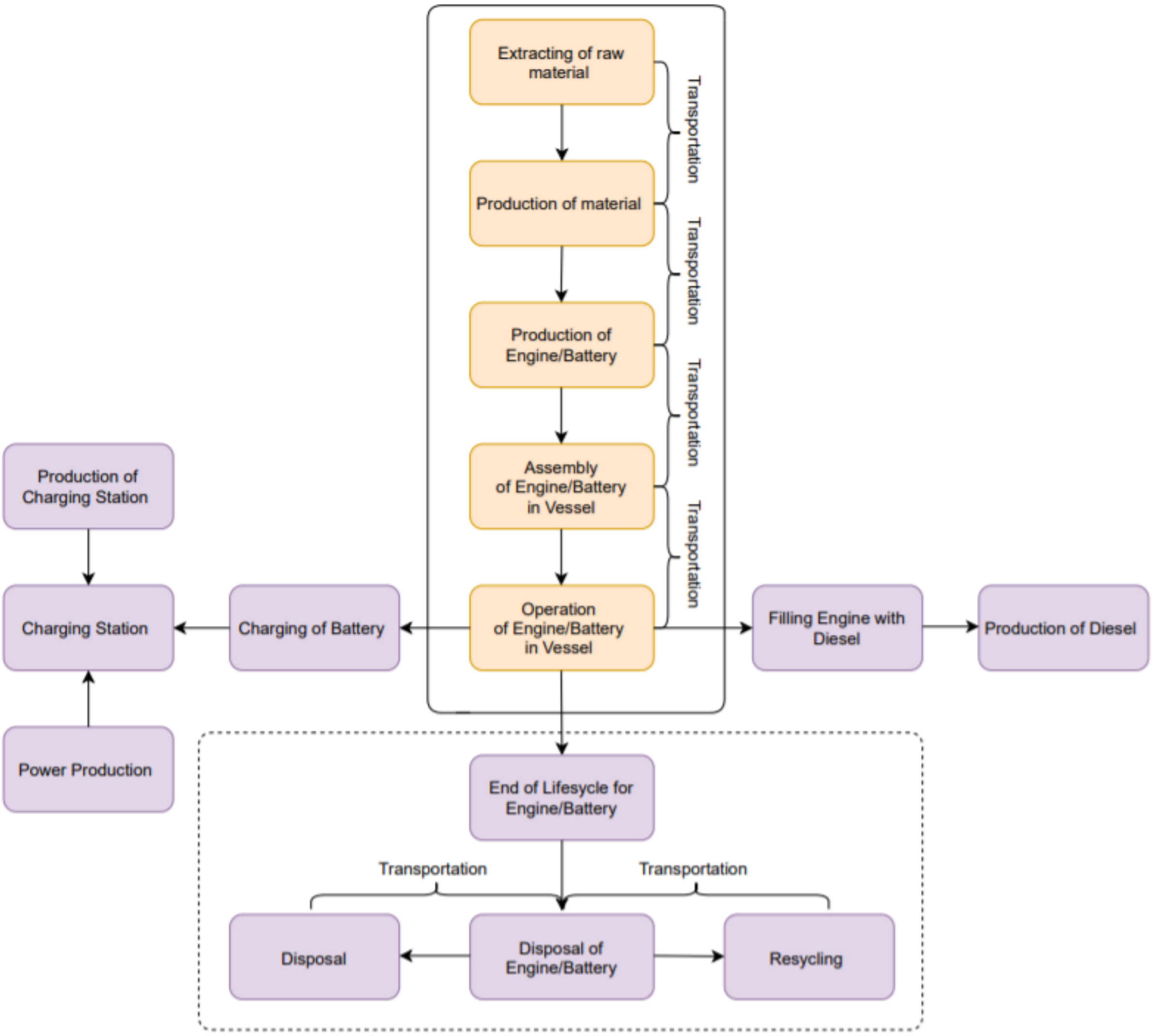


Figure 3. Flowchart of a lifespan for an engine and a batterie.

2.3.2 Electric System

2.3.2a) Engine

The thesis was presented to Tore Nymark, Sales Manager for Large AC Motors and generators at ABB, which recommended to compare the electric engine, M3BP 355MLC 4, to the chosen diesel engine. M3BP 355MLC 4 is air-cooled engine with cast iron stator housing (personal communication, 25.02.21) and an engine power of 350 kW per engine.

2.3.2b) Battery

The Dolphin Energy battery from Corvus Energy has been selected as the battery system in this thesis. This is the same battery system that is used in the hybrid-electric ship Brim Explorer [2]. Kristian Holmefjord, executive vice president and project director for fuel cells at Corvus

Energy, recommended this battery system after he was presented with the thesis and relevant information (personal communication, 08.04.21).

Dolphin Energy is a NMC battery system created for tourist vessels, canal boats, cruise ships, sightseeing vessels, and ferries [3].

2.3.3 Diesel System

Scania DI13 070M was chosen as the diesel alternative for this thesis. This engine is a supercharged diesel engine with a water-cooled charge air cooler for marine use.

3. Methods & Approach

3.1 Methods

Quantitative and qualitative are the two main methods for gathering information. The quantitative method is based on the process of collecting and analyzing numerical data. Quantitative is the opposite of qualitative method, which is based in investigating observations in depth by using literature or surveys. Literature covering the emission produced in the different steps will have to be studied and accounted for. A combination of both quantitative and qualitative will be relevant to use in this bachelor thesis.

3.2 Adopted Approach

Relevant and up to date information must be gathered to be able to understand the lifespan of a diesel and electric engine. All phases in the lifespan must be fully understood in order to continue with the calculations of the CO_2 emissions. Information regarding diesel engine, electric engine and batteries are gathered by contacting MENG, Eide Fjordbruk, ABB, Scania and Corvus Energy. Literature describing the emission of the different steps will be researched.

3.3 Calculator

The CO_2 calculator has been created with the intention to compare two engine systems in a vessel, electric and diesel. When discussing the pollution from operation, only the local emissions is considered. By including the other phases in the lifespan, the global emissions will give a more accurate picture of the total emitted CO_2 from the specific engine system.

The two engines used in this CO_2 calculator are comparable in power and can be used in the vessel. The calculator focuses on the following steps:

1. Manufacturing of engines and battery
2. Transportation of materials and parts
3. Operation of the vessel

Step number 3 is based on data specifically for the engines in this thesis and might not be suitable for all engines. The factors involved in the calculations from operation will also differ between diesel and electric engine. The other steps are more general and not restricted to the specific engines and battery.

3.3.1 Manufacturing

3.3.1a) Manufacturing of engine

Neither Scania or ABB could provide any data or information related to their manufacturing process. The materials in the engines are known and it was therefore decided to find data of emissions per ton material produced at different locations.

It is assumed that the materials used in the engines have not been recycled. The CO_2 emissions from manufacturing can be expressed as:

$$E_{mfg} = E_{material} * w \tag{1}$$

Where:

E_{mfg}	= CO_2 emissions from manufacturing [kg]
$E_{material}$	= CO_2 emissions per ton material produced [kg CO_2 / kg material]
w	= weight of material [kg]

3.3.1b) Manufacturing of battery

Battery technology is often seen as the green alternative for power sources running on fossil fuel. The battery used in this thesis is a NMC battery, which is one of the most commonly used lithium-ion batteries [4]. A literature survey on emissions from manufacturing of NMC batteries at different locations is executed and used in this thesis. It was recommended to focus on batteries produced in East Asia, specifically China and South Korea (K. Holmefjord, personal communication, 26.03.21).

NMC batteries can have different cathode combinations of Nickel, Manganese and Cobalt. A typical NMC battery consist of one-third Nickel, one-third Manganese and one-third Cobalt, also known as NMC111 [5]. Other common combinations are NMC622 and NMC822 [5]. Relevant studies of emissions from NMC battery production are listed in table 1.

Reference	Battery	Production location
[6]	NMC	East Asia / Norway
[7]	NMC333 (NMC111)	China
	NMC622	China
	NMC811	China
[5]	NMC111	China
	NMC111	EU
[8]	NMC111	United States
[9]	NMC + LMO	South Korea

Table 1. *Battery references.*

GWP shows no significant difference between the NMC chemistries [5]. This thesis will therefore not distinguish between NMC111, NMC622 and NMC811. A general NMC combination will be assumed when calculating emissions. The following formula was created based on the literature survey:

$$E_{Battery} = E_{Battery\,mfg} * kWh_{battery} \tag{2}$$

Where:

$E_{Battery}$ = CO_2 emissions from battery system manufacturing [kg]

$E_{Battery\ mfg}$ = CO_2 emissions from battery manufacturing [kg CO_2e / kWh]

$kWh_{battery}$ = Energy in battery system [kWh]

3.3.2 Transport Calculations

The different materials and parts of the engines and battery are transported over great distances, either by road or by sea. The calculator includes road and maritime transport with different transportation options.

3.3.2a) Road Transport

Assumptions related to vehicle type, fuel and weight of the cargo the vehicle carries must be made to calculate the emissions. Emissions will vary depending on fuel consumption, which again depends on traffic, roads, payload and driving behavior [10]. The calculation in this thesis is based on data from Volvo trucks [10]. This document presents an overview of guided values for fuel consumption as shown in table 2 below.

Typical fuel consumption in liters per 100 km				
	Payload in tons	Total weight in tons	Liters / 100 km empty	Liters / 100 km full load
Truck, distribution traffic	8,5	14	20-25	25-30
Truck, regional traffic	14	24	25-30	30-40
Tractor and semi-trailer, long-haul traffic	26	40	21-26	29-35
Truck with trailer, long-haul traffic	40	60	27-32	43-53

Table 2. *Typical fuel consumption, Volvo trucks [10].*

Average fuel consumption for an empty and fully loaded truck per kilometer has been used in the calculation as presented in table 3.

Typical fuel consumption in liters per 100 km				
	Payload in tons	Total weight in tons	Liters / km empty	Liters / km full load
Truck, distribution traffic	8,5	14	0,225	0,275
Truck, regional traffic	14	24	0,275	0,350
Tractor and semi-trailer, long-haul traffic	26	40	0,235	0,320
Truck with trailer, long-haul traffic	40	60	0,295	0,480

Table 3. *Average fuel consumption per kilometer.*

Fuel consumption for the vehicle type relies on weight of payload, referred to as cargo, and distance traveled. From table 3, the following equation is derived:

$$F_{consump} = \frac{F_{\max cargo} - F_{empty\ cargo}}{w_{max}} \tag{3}$$

Where:

$F_{consump}$ = Fuel consumption based on cargo [liter / (km*ton)]

$F_{max\ cargo}$ = Fuel consumption with maximum cargo [liter / kilometer]

$F_{empty\ cargo}$ = Fuel consumption empty vehicle [liter / kilometer]

w_{max} = Weight of maximum cargo [ton]

Table 4 present the fuel consumption calculated from the values in table 3 using equation 3.

	Fuel consumption based on cargo [liter / (km*ton)]
Truck, distribution traffic	0,005882
Truck, regional traffic	0,005357
Tractor and semi-trailer, long-haul traffic	0,003269
Truck with trailer, long-haul traffic	0,004625

Table 4. *Fuel consumption based on cargo.*

Equation 3 does not include the constant fuel consumption for an empty truck, or a variable for the weight of the cargo it carries. The equation for fuel consumption based on the cargo is used as the following function:

$$F_{cargo} = (F_{empty\ cargo} + F_{consump} * w_{cargo}) * d \quad (4)$$

Where:

F_{cargo} = Fuel consumption as a function of cargo and distance [liter]

$F_{empty\ cargo}$ = Fuel consumption empty vehicle [liter / kilometer]

$F_{consump}$ = Fuel consumption [liter / (km*ton)]

w_{cargo} = Weight of cargo on vehicle [ton]

d = distance [km]

When the total fuel consumption is established for a given truck, the emissions can be calculated by adding the CO_2 variable for the fuel type. The Volvo trucks use standard diesel fuel, EN590, which create approximately 2,6 kg CO_2 per liter fuel [10]. The CO_2 emissions from road transport can then be expressed as:

$$E_{trans} = F_{cargo} * k \quad (5)$$

Where:

E_{trans} = CO_2 emissions from road transport [kg]

F_{cargo} = Fuel consumption as a function of cargo [liter]

k = CO_2 variable for fuel [kg CO_2 / liter]

It is assumed that the transport vehicle will carry cargo other than the items considered in this thesis. This will contribute to a higher weight of cargo and larger fuel consumption. All cargo will contribute to the CO_2 emission from the fuel consumption. To calculate how much CO_2 the relevant cargo in this thesis contributes to, the specific emissions for the items in this thesis must be calculated. The specific CO_2 emissions can be expressed as:

$$E_{specific.road} = \frac{E_{trans}}{w_{cargo}} * \frac{w_{product}}{1000} \qquad (6)$$

Where:

$E_{specific.road}$ = Specific CO_2 emission from road transport of product [kg]

E_{trans} = CO_2 emissions from transport [kg]

w_{cargo} = Weight of cargo on vehicle [ton]

$w_{product}$ = Weight of product [kg]

3.3.2b) Maritime Transport

Transportation in Norway often include ferry connections. The Norwegian Public Roads Administration has published a report about CO_2 emissions from different types of ferries [11]. Table 5 below assumes that the traditional ferry concept with single-hull ferries is built in steel. For simplification, it is assumed that the ferries used for transportation in this thesis is single-hull ferries.

Concept	1 x 50 PBE + 1 x 70 PBE 10/10,4 knots & 6,8 km				1 x 120 PBE 10 knots & 6,8 km				1 x 120 PBE 12,9 knots & 6,8 km			
	Relative cost [%]	Energy consum-ption [MJ/(PBE *km)]	CO_2e [g/(PBE *km)]	CO_2e [g/ kWh]	Relative cost [%]	Energy consum-ption [MJ/(PBE *km)]	CO_2e [g/(PBE *km)]	CO_2e [g/ kWh]	Relative cost [%]	Energy consum-ption [MJ/(PBE *km)]	CO_2e [g/(PBE *km)]	CO_2e [g/ kWh]
Diesel mechanically on regular fossil diesel	100	5,0	374	694	104	4,4	327	703	117	6,4	480	717
Diesel mechanically with 100% biodiesel	108	5,0	87	161	112	4,4	76	162	128	6,4	109	162
Diesel / battery hybrid without charging form	110	4,9	366	641	110	4,3	319	648	123	6,3	466	649
Plug-in hybrid with diesel	141	4,1	255	413	125	3,3	193	370	141	5,3	344	457
Plug-in hybrid with 100% biodiesel and general measures	134	2,8	55	116	119	2,2	44	108	138	3,9	74	125
Pure battery ferry with general measures	135	1,8	37	75	116	1,5	31	75	131	2,2	46	75
Hydrogen ferry	-	3,4	105	188	-	2,9	92	-	158	4,3	136	194

Table 5. *Energy consumptions and CO_2 emissions in ferry connections [11].*

It is assumed that the values in table 5 can be used for ferry connections with other distances. The following equation is expressed to calculate CO_2 emissions from ferry transport:

$$E_{ferry} = \frac{CO_2e * PBE * d}{1000} \tag{7}$$

Where:

E_{ferry} = CO_2e emissions per trip with ferry [kg]

CO_2e = CO_2 equivalent [g / (PBE * km)]

PBE = Passenger car unit [PBE]

d = Distance [km]

Maritime transportation is often used when cargo is shipped over greater distances. These vessels have a much larger fuel consumption but can transport a significantly higher amount of cargo. The great variety of ships categorized as general cargo or ro-ro/passenger ship makes

(Entec, 2002)it difficult to calculate emissions. Especially without knowing the specific ship that will transport the cargo. A general equation for general cargo and ro-ro/passenger ship is expressed based on fuel consumption and engine power [12]:

$$E_{ship} = \frac{GP * E_{factor} * h}{1000} \quad (8)$$

Where:

E_{ship} = CO_2 emission per trip with ship [kg]

GP = Gross power [kW]

E_{factor} = Emission factor for ship type [g CO_2 / kWh]

h_{trans} = Transportation hours [hour]

As a larger ship will produce more CO_2 it is important to look at CO_2 emissions per ton cargo transported, which can be expressed as:

$$E_{specific.m} = \frac{E_{vessel}}{w_{cargo}} * \frac{w_{product}}{1000} \quad (9)$$

Where:

$E_{specific.m}$ = Specific CO_2 emission from ship transport of product [kg]

E_{vessel} = CO_2 emission per trip from ferry or ship [kg]

w_{cargo} = Weight of cargo on ferry [ton]

$w_{product}$ = Weight of product [kg]f

3.3.3 Operation

Calculations of CO_2 emissions from using the vessel will depend on the engine. The formulas derived under 'Operation' is based on data given in the engine description of fuel consumptions and kWh through the lifetime.

3.3.3a) Electric engine

To calculate the CO_2 emissions from the electric engine, the following equation were derived from appendix A:

$$E_{el.engine} = \frac{P_{tot.}}{lifespan} * E_{power\ source} * h_{op} \quad (10)$$

Where:

$E_{el.engine}$	= CO_2 emissions from electric engine per trip [kg]
$P_{tot.}$	= Total kWh during usage phase [kWh]
Lifespan	= Estimated lifetime of engine [hour]
$E_{power\ source}$	= CO_2 emissions from power source [kg CO_2 / kWh]
h_{op}	= Operating hours [hour]

The CO_2 emissions from the power source will depend on the country's main energy source.

3.3.3b) Diesel engine

The following table present the different fuel consumptions depending on engine load and speed for the chosen engine.

		Engine speed (rpm)		
	Rating	**1 200**	**1 500**	**1 800**
Gross power, full load (kW)	ICFN	292	350	368
Gross power, full load (hp, metric)	ICFN	396	476	500
Gross power, propeller curve (kW)	ICFN	134	233	368
Gross power, propeller curve (hp, metric)	ICFN	182	317	500
Gross torque (Nm)	ICFN	2 320	2 227	1 952
Spec fuel consumption. Full load (g/kWh)		192	191	200
Spec fuel consumption. ¾ load (g/kWh)		193	196	207
Spec fuel consumption. ½ load (g/kWh)		197	202	216
Spec fuel consumption. Propeller curve (l/h)		32	56	88
Optimum fuel consumption (g/kWh)		190		
Heat rejection to coolant (kW)		194	228	267

Table 6*. Fuel consumption, Scania diesel engine [13].*

The operating speed of the vessel and the distance is used to calculate the usage time. The vessel speed is connected to the engine speed (rpm) which is presented in appendix B. It is important to note that the connection between rpm and vessel speed will depend on the operating conditions such as passenger load, weather and currents. In this thesis these conditions are neglected. The connection between engine speed and vessel speed is assumed to be constant.

The following formulas were derived based on table 6 where the specific fuel consumption will depend on the engine speed and load.

$$E_{operation} = \frac{\left(\frac{F_{specific} * GP * h_{op}}{1000}\right)}{\rho_{fuel}} * E_{fuel} \tag{11}$$

Where:

$E_{operation}$	= CO_2 emission from operation of vessel per trip [kg]
$F_{specific}$	= Specific fuel consumption [g / kWh]
GP	= Gross power [kW]
H_{op}	= Operating hours [hour]
ρ_{fuel}	= Density of fuel [kg / liter]
E_{fuel}	= CO_2 emission per liter fuel [kg / liter]

When the engine load is unknown, the propeller curve is used to calculate CO_2 emissions as shown the following equation:

$$E_{operation} = F_{specific,\ propeller} * h * E_{fuel} \tag{12}$$

Where:

$E_{operation}$	= CO_2 emission from operation of vessel per trip [kg]
$F_{specific,\ propeller}$	= Specific fuel consumption, propeller curve [liter / hour]
h	= Time [hour]
E_{fuel}	= CO_2 emission per liter fuel [kg / liter]

3.3.4 Recycle

Recycling are essential to reduce the CO_2 emission. Information about the process and CO_2 emission for recycling will be gathered through literature surveys. If some of this information is not available, it will not be included in this thesis.

4. Calculations for CO2 Emission

4.1 Technical data

The analysis in this thesis is based on a 20-year lifespan. It is assumed that this is sufficient time to see the difference in CO_2 emissions for the two power source alternatives.

The electric engine has an estimated lifetime of 15 years. This estimation is based on 5 000 operating hours per year. By multiplying total trips per season with hours per trip, the result show that the engine, in this case, will be used far less. It will approximately be used 140 hours during on-season, when trips on request are excluded. Based on this calculation it is assumed that the engine can be used through a 20-year cycle without being replaced. A maintenance schedule is not considered for the lifespan of the engine.

The Dolphin Energy batteries used in this thesis have an estimated lifetime of 10 year (K. Holmefjord, personal communication, 08.04.21). This means that it will be necessary to order two battery systems during the 20-year period. The manufacturing process and transportation of batteries must therefore be done twice.

It is difficult to set the lifetime for the diesel engine. This is because of several factors that affects the lifespan such as maintenance, usage, environment, etc. However, through discussion it is assumed that the engine would last the 20-year span.

Technical data for the engines and battery used in upcoming calculations are presented below in table 7, 8 and 9.

ABB engine		**M3BP 355MLC 4**
Engine type:		IEC 34 motor
Engine power:	[kW]	375
Weight per engine:	[kg]	2 140
Maximal rpm:	[r/m]	1 500

Table 7. *Description of the Electric Engine (appendix A)*

Battery		**Corvus Dolphin Energy**		
System specifications				
Single module size / increments	[kWh]	11		
	[VDC]	128		
Single pack range	[kWh]	11-88		
Max gravimetric density - pack	[Wh / kg]	117		
	[kg / kWh]	5,6		
Max volumetricdensity - pack	[Wh / liter]	100		
Battery pack				
Modules		7		
Energy	[kWh]	77		
Voltage	[VDC]	Max	Nom	Min
		896	805	672
Dimensions (vertical)	[mm]	Height	Width	Depth
		2 380	655	500
Weight	[kg]	431		
Battery system				
Packs		3		
Energy	[kWh]	231		
Voltage	[VDC]	Max	Nom	Min
		896	805	672
Dimensions	[mm]	Height	Width	Depth
		2 380	1 965	500
Weight	[kg]	1 293,60		

***Table 8**. Description of battery [3].*

Scania Engine		**Scania DI13 070M**
Engine class:		IMO Tier II
Engine power:	[kW]	368
Weight per engine:	[kg]	1 190
Maximal rpm:	[r/m]	1 800

Table 9. *Description of Diesel Engine*

4.2 Manufacturing

4.2.1 Manufacturing Process

4.2.1a) Manufacturing process - Engines

Steel is the main material in both electric and diesel engine (see table 13 and 15). The steel industry is one of the three largest producers of CO_2 [14]. The calculations of CO_2 emissions from steel production are based on values presented in the Climate Transparency Report 2020 of the country profiles to all G20 countries [15]. It is assumed that the carbon intensity of steel production, presented in the countries' profile, include extraction of raw materials and the process within a steel plant (see figure 4).

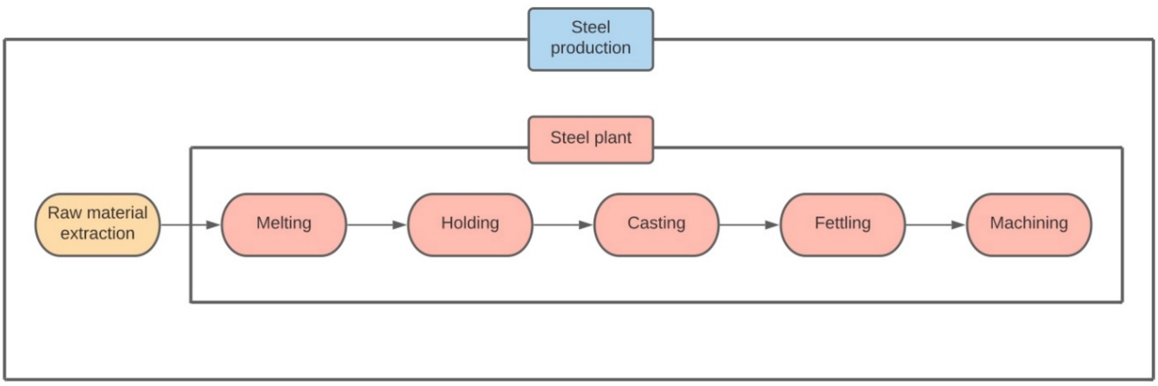


Figure 4. *Steel production.*

China is the world's largest steel producer with 53,3 % of the worlds share, with the European Union as the second largest with 8,5 % of the share [16]. For each ton steel produced in China, 1840 kg CO_2 is emitted [17]. For EU it is 1209 kg CO_2 [18]. This is below world average of 1900 kg CO_2 per ton steel [15].

Other materials included in the manufacturing process is aluminum and copper. The EU average CO_2 emission from aluminum production is 4,07 kg CO_2/kg aluminum [19]. World average (ICA members) CO_2 emissions from copper production is 4,10 kg CO_2/kg copper [20]. It is assumed that the finished product from steel production is the engine case.

4.2.1b) Manufacturing process - Battery

The battery system contains battery cells that are clustered into modules, which again is grouped into packs [5]. The manufacturing process from raw material acquisition to transport to costumer is shown in figure 5.

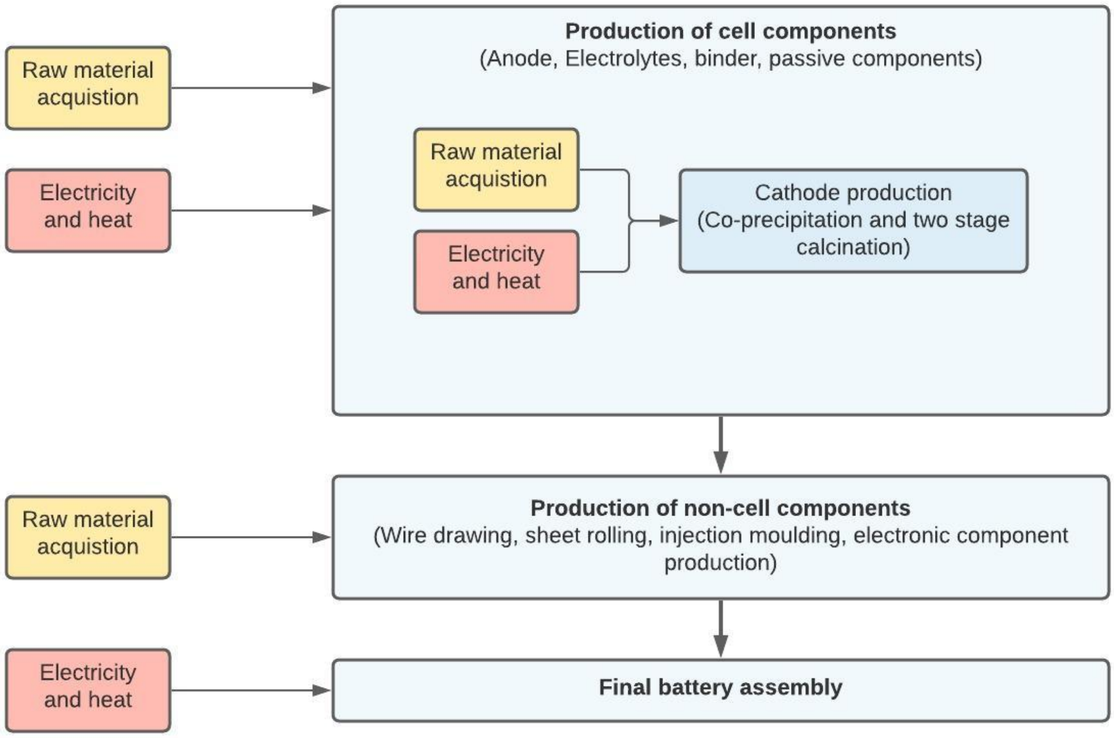


Figure 5. *Battery manufacturing process [5].*

The data presented in table 10 below is an overview of different published papers on LCA of NMC batteries with different production locations.

NMC battery						
Reference	**Battery**	**Production location**	**Battery mass [kg]**	**Battery capacity [kWh]**	**Manufacturing [kg CO_2e / kWh]**	**Recycling [kg CO_2e / kWh]**
[6]	NMC	East Asia / Norway	253	26,6	172,0	
[7]	NMC111	China	253	40,9	179,7	
	NMC622	China	253	46,2	160,2	
	NMC811	China	253	52,9	140,3	
[5]	NMC111	China	226	35	135,0	
	NMC111	EU	226	35	100,0	11,3
[8]	NMC111	US	165	23,5	72,9	
[9]	NMC + LMO	South Korea	303	24	140	

Table 10. *Battery manufacturing.*

There is no significant difference in GWP between the different NMC chemistries [5]. Therefore, it is assumed a general NMC battery combination through the rest of the paper. It will not be distinguished between NMC111, NMC622 and NMC811. Where the literature presents more than one manufacturing emission factor for a location, an average value is used for calculations (table 11).

Production location	Manufacturing [kg CO2e / kWh]	Recycling [kg CO2e / kWh]
China	153,8	
East Asia / Norway	172	
EU	100	11,3
South Korea	140	
United States	72,9	

Table 11. *Manufacturing location for NMC battery.*

4.2.2 Electric System

4.2.2a) Electric Engine

An environmental product declaration has not been retrieved for the selected ABB engine, but a declaration for a similar engine were presented. The two ABB engines are exceedingly similar. The values from M3BP 315 MLA in the declaration (appendix A) can be scaled up by weight to calculate the values needed for engine M3BP 355MLC, as shown in table 12 (T. Nymark, personal communication, 25.02.21).

Type of material	M3BP 315 MLA		M3BP 355MLC 4 – scaled up	
	Kg / product	% of product	Kg / product	% of product
Electrical steel	795	51,72 %	1 106,90	51,72 %
Other steel	136	8,85 %	189,36	8,85 %
Cast iron	455	29,60 %	633,51	29,60 %
Aluminum	24	1,56 %	33,42	1,56 %
Copper	91	5,92 %	126,70	5,92 %
Insulation material	6	0,39 %	8,35	0,39 %
Wooden packing material	15	0,98 %	20,88	0,98 %
Impregnation resin	7	0,46 %	9,75	0,46 %
Paint	8	0,52 %	11,14	0,52 %
Total	**1 537**	**100 %**	**2 140**	**100 %**

Table 12. *Engine scale*

The materials in the electric engine, M3BP 355MLC 4, are presented in table 13. The electrical steel, other steel and cast iron are categorized as ‘steel’ for simplification in this thesis. Materials such as insulation material, wooden packing material, impregnation resin and paint are categorized as ‘Others’. The weight share of the material categorized as ‘others’, is less than 3 % and the CO_2 impact is considered to be minimal. These materials are therefore neglected in the manufacturing process.

ABB Electric Engine				
Material	**Material category**	**Weight share [%]**	**Weight of material [kg]**	**Production location**
Electric steel	Steel	51,72 %	1 106,90	EU
Other steel	Steel	8,85 %	189,36	EU
Cast iron	Steel	29,60 %	633,51	EU
Aluminum	Aluminum	1,56 %	33,42	EU
Copper	Copper	5,92 %	126,70	World Average (ICA Members)
Insulation material	Other	0,39 %	8,35	N/A
Wooden packing material	Other	0,98 %	20,88	N/A
Impregnation resin	Other	0,46 %	9,75	N/A
Paint	Other	0,52 %	11,14	N/A
Total		**100,00 %**	**2 140,00**	

Table 13. *Bill of material, electric engine (appendix A)*

It is assumed that steel, aluminum and copper is produced in EU. Emission related to copper manufacturing is based on a world average.

4.2.2b) Battery

The NMC battery consist of cell materials and non-cell materials, further information is presented in table 14.

Bills of materials per kg of NMC battery pack			
	NMC111	**NMC622**	**NMC811**
Cell materials	**[kg]**	**[kg]**	**[kg]**
Active Cathode Material	0,287	0,263	0,253
Graphite	0,160	0,171	0,168
Carbon black	0,020	0,018	0,014
Binder (PVDF)	0,025	0,024	0,029
Copper	0,134	0,134	0,131
Aluminum	0,069	0,069	0,068
Electrolyte: LiPF6	0,018	0,018	0,021
Electrolyte: Ethylene Carbonate	0,050	0,050	0,057
Electrolyte: Dimethyl Carbonate	0,050	0,050	0,057
Plastic: Polypropylene	0,012	0,012	0,011
Plastic: Polyethylene	0,003	0,003	0,003
Non-cell materials			
Copper	0,003	0,002	0,003
Aluminum	0,184	0,186	0,187
Steel	0,007	0,004	0,006
PET	0,005	0,004	0,005
Electronics	0,037	0,037	0,038

Table 14. *Bill of material, NMC batteries [5].*

It is assumed that the battery is produced in Ningde, China, where battery manufacturing contributes to 153,8 kg CO_2 per kWh as shown in table 11.

4.2.3 Diesel System

Odd Ivar Opsahl, Sales Manager at Scania Norway, presented an environmental product declaration for the diesel engine (appendix C) with information about material content (personal communication, 27.01.21). This declaration was used to calculate emissions from manufacturing of the different materials.

The material with the largest weight share in the diesel engine is metals. In this thesis, metals are assumed to be steel. Other materials are neglected in the manufacturing process for simplifications. With steel making up 94 % of the engine, it is not considered to be necessary to include materials categorized as 'Other'. The CO_2 contribution from this category is assumed to be of little or no significance. The material contents and weight share are presented in table 15 below.

Scania Electric Engine				
Material (excl. fuel weight)	**Material class**	**Weight share [%]**	**Weight of material [kg]**	**Production location**
Metal	Steel	94,00 %	1 118,60	EU
Polymers	Other	1,00 %	11,90	N/A
Elastomers	Other	0,40 %	4,76	N/A
Fluids	Other	4,40 %	52,36	N/A
MONM* *modified organic natural materials, such as leather, wood, cardboard and cotton fleece.	Other	0,30 %	3,57	N/A
Others	Other	0,01 %	0,12	N/A
Total		**100,00 %**	**1 190,00**	

Table 15. *Material content (appendix C).*

From discussions with Erik Nellström-Montemartillo, Product Property Owner at Scania CV AB, the steel used in this engine is assumed to be from SSAB in Luleå, Sweden (personal communication, 18.03.21).

The Scania diesel engine is manufactured at Scandia's production site in Södertalje, Sweden, and transported to NOGVA in Søvik. At NOGVA a gear will be attached to the engine (see appendix D). The gear and its assembly process onto the engine have not been included in this analysis.

4.2.4 Calculations

The CO_2 emissions from manufacturing the engines is calculated using the following formula from chapter 3.3.1a:

$$E_{mfg} = E_{material} * w \quad (1)$$

4.2.4a) Electric Engine

Steel per engine:

$E_{material}$ = 1,209 [kg CO_2 / kg material]

$w_{material}$ = 1929,76 [kg]

$$E_{mfg} = 2\,333{,}08\ kg\ CO_2$$

Aluminum per engine:

$E_{material}$ = 4,070 [kg CO_2 / kg material]

$w_{material}$ = 33,42 [kg]

$$E_{mfg} = 136{,}00\ kg\ CO_2$$

Copper per engine:

$E_{material}$ = 4,100 [kg CO_2 / kg material]

$w_{material}$ = 126,70 [kg]

$$E_{mfg} = 519{,}48\ kg\ CO_2$$

CO_2 emission from engine production:

$$E_{mfg} = 2\,988{,}56\ kg\ CO_2$$

Number of engines: 2

Total CO_2 emissions from the manufacturing of the electric engines are:

$$\boldsymbol{E_{mfg} = 5\,977{,}11\ kg\ CO_2}$$

4.2.4b) Battery

CO_2 emission from battery manufacturing is calculated using the formula from chapter 3.3.1b:

$$E_{Battery} = E_{Battery\,mfg} * kWh_{battery} \tag{2}$$

$E_{Battery\ mfg}$ = 153,8 [kg CO_2e / kWh]

$kWh_{battery}$ = 231 [kWh]

$$\boldsymbol{E_{Battery} = 35\,527,8\ kg\ CO_2}$$

This process must be done again in ten years. The total emissions from manufacturing during the whole 20-year cycle will be:

$$\boldsymbol{E_{Battery} = 71\,055,6\ kg\ CO_2}$$

4.2.4c) Diesel Engine

Per engine:

$E_{material}$ = 1,209 [kg CO_2 / kg material]

$W_{material}$ = 1118,60 [kg]

$$E_{mfg} = 1\,352{,}39\ kg\ CO_2$$

Number of engines: 2

Total CO_2 emissions from the manufacturing of the diesel engines is:

$$\boldsymbol{E_{mfg} = 2\,704,77\ kg\ CO_2}$$

4.3 Transport

The following assumptions are considered for transport calculations:

- Assume all road transport by tractor and semi-trailer, long haul traffic.
- Transportation of two electric and two diesel engines.
- Transportation of battery systems is repeated after 10 years.
- Assumed cargo weight is constant at 70 % of max cargo for all transport options.
- Any stops or detours that are not related to transport of the material, engine and battery is neglected in the calculations.
- The incline of the roads is neglected in the calculations for simplifications.

It is important to note that the distance given in road transport does not include the distance of any maritime connections such as ferry connections. These distances will be added in maritime transport.

The transportations routes have been calculated using Google Maps, Google My Maps and Ports.

4.3.1 Transport of Electric Engine

The companies supplying ABB with materials for their engines are confidential, but information about where in the world they get their materials have been provided. Marko Laatu, Quality Manager at ABB Oy, have informed that the production of the three materials come from Finland, Sweden, and Norway (personal communication, 03.05.21).

SSAB is a highly specialized global steel company [21]. One of their factories are placed in Oy, Finland, which is close to the production location of the engine. It is therefore assumed that the steel for the electric engine is produced at SSAB in Oy, Finland.

Norsk Hydro is a leading industrial company that provides aluminum globally [22]. The aluminum used to produce the electrical engine, is assumed to be produced in Sunndal, Norway. The reason for this assumption is that Hydro Sunndal is Europe's largest and most modern plant for the production of primary aluminum [23].

Boliden Rönnskär in Skelleftehamn, Sweden is one of the world's most efficient copper smelters [24]. It is therefore assumed that the copper in the electric engine is produced at Boliden Rönnskär.

The production location for the electric engine is at ABB's factory in Vaasa, Finland (appendix A).

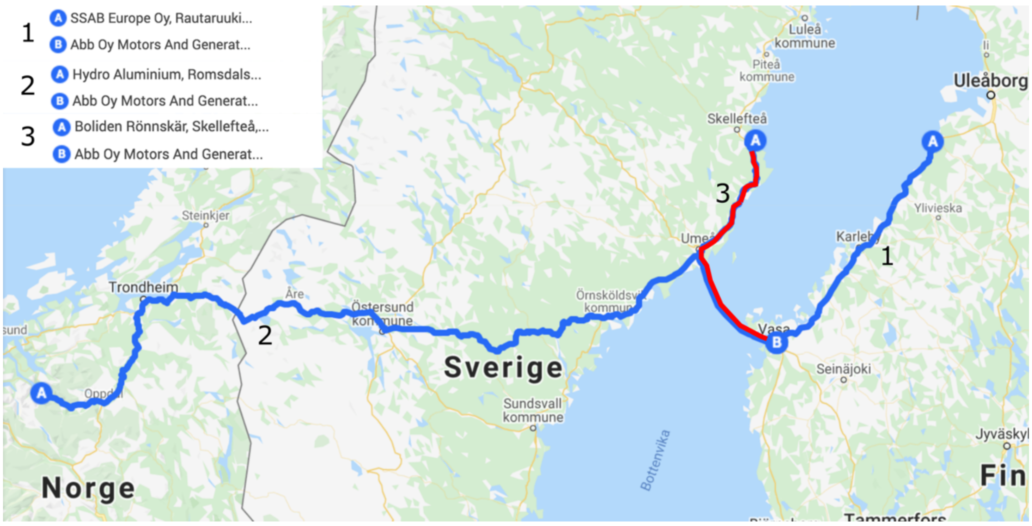


Figure 6. Transport of steel, aluminum & copper (Google My Maps)

The engine will be transported from Vaasa to Mundal Groups assembly location in Radøy, Norway. The route includes crossing the Bothnian Bay with the ship Wasa Express.

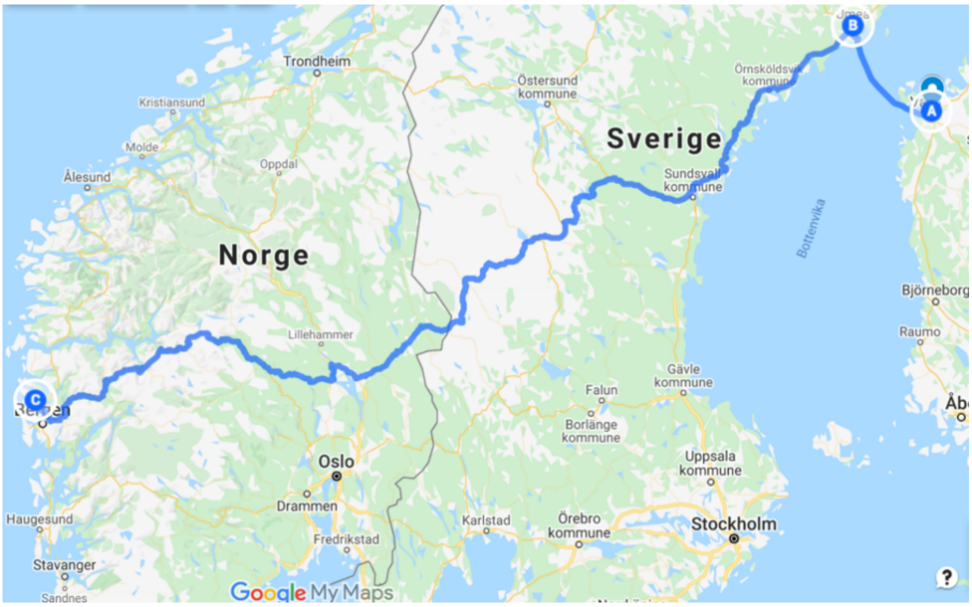


Figure 7. Electric Engine from ABB Vaasa Factory – Mundal, Radøy (Google My Maps)

All stages of transportation related to the electric engine is presented below, in table 16.

Stage	Item	Route	Transport option	Distance [km]
1	Steel	SSAB in Oy, Finland – ABB Vaasa Factory, Finland.	Tractor and semi-trailer, long haul traffic	245
			Total distance for steel	**245**
2	Aluminum	Hydro Aluminum, Sunndalsøram, – ABB Vaasa Factory, Finland	Tractor and semi-trailer, long haul traffic	822,2
3	Aluminum	Umeå Ferry Pier, Sweden - Vaasa Ferry Pier, Finland	Wasa Express	95,8
			Total distance for aluminum	**918**
4	Copper	Boliden Rönnskär, Sweden – ABB Vaasa Factory, Finland	Tractor and semi-trailer, long haul traffic	154,2
5	Copper	Umeå Ferry Pier, Sweden - Vaasa Ferry Pier, Finland	Wasa Express	95,8
			Total distance for copper	**250**
6	Engine	ABB Vaasa Factory, Finland – Vaasa Ferry Pier, Finland	Tractor and semi-trailer, long haul traffic	6,2
7	Engine	Vaasa Ferry Pier, Finland – Umeå Ferry Pier, Sweden	Wasa Express	95,8
8	Engine	Umeå Ferry Pier, Sweden – Mundal Group in Radøy, Norway	Tractor and semi-trailer, long haul traffic	1 245,5
			Total distance for engine	**1 347,5**

Table 16. *Transport route for electric engine.*

Wasa Express use 4,5 hours to transport the products (Google Maps, Vaasa Ferry Pier, Finland – Umeå Ferry Pier, Sweden). More information about the vessel is presented in table 17.

Name of vessel	Type of vessel	Gross power [kW]	E_{factor} [g CO_2 / kWh]
Wasa Express	Ro-Ro/Passenger Ship *[25]*	14 866 *[26]*	686 *[12]*

Table 17: *Data on Wasa Express*

4.3.1a) CO_2 Calculations for road transport of electric engine

Steel transport

$$F_{cargo} = (F_{empty\ cargo} + F_{consump} * w_{cargo}) * d \tag{4}$$

Where:

F_{cargo} = Fuel consumption as a function of cargo and distance [liter]

$F_{empty\ cargo}$ = 0,235 [liter / kilometer]

$F_{consump}$ = 0,003269 [liter / (km*ton)]

w_{cargo} = 18,2 [ton]

d = 245 [km]

$$F_{cargo} = 72{,}15\ liter\ fuel$$

The CO_2 emissions from road transport is calculated from equation:

$$E_{trans} = F_{cargo} * k \tag{5}$$

Where:

E_{trans} = CO_2 emissions from road transport [kg]

F_{cargo} = 72,15 [liter]

k = 2,6 [kg CO_2 / liter]

$$E_{trans} = 187{,}60\ kg\ CO_2$$

The specific CO2 emission from transport of the steel used in engine is calculated from equation:

$$E_{specific} = \frac{E_{trans}}{w_{cargo}} * \frac{w_{product}}{1000} \tag{6}$$

Where:

$E_{specific.road}$ = Specific CO_2 emission from road transport of product [kg]

E_{trans} = 187,60 [kg CO_2]

w_{cargo} = 18,2 [ton]

$w_{product}$ = 3 860 [kg]

$$\boldsymbol{E_{specific} = 39{,}78\ kg\ CO_2}$$

Aluminum transport

$$F_{cargo} = (F_{empty\ cargo} + F_{consump} * w_{cargo}) * d \tag{4}$$

Where:

F_{cargo}	= Fuel consumption as a function of cargo and distance [liter]
$F_{empty\ cargo}$	= 0,235 [liter / kilometer]
$F_{consump}$	= 0,003269 [liter / (km*ton)]
w_{cargo}	= 18,2 [ton]
d	= 822,2 [km]

$$F_{cargo} = 242{,}14\ liter\ fuel$$

The CO_2 emissions from road transport is calculated from equation:

$$E_{trans} = F_{cargo} * k \tag{5}$$

Where:

E_{trans}	= CO_2 emissions from road transport [kg]
F_{cargo}	= 242,14 [liter]
k	= 2,6 [kg CO_2 / liter]

$$E_{trans} = 629{,}56\ kg\ CO_2$$

The specific CO2 emission from transport of the aluminum used in engine is calculated from equation:

$$E_{specific} = \frac{E_{trans}}{w_{cargo}} * \frac{w_{product}}{1000} \tag{6}$$

Where:

$E_{specific.road}$	= Specific CO_2 emission from road transport of product [kg]
E_{trans}	= 629,56 [kg CO_2]
w_{cargo}	= 18,2 [ton]
$w_{product}$	= 67 [kg]

$$\boldsymbol{E_{specific} = 2,31\ kg\ CO_2}$$

Copper transport

$$F_{cargo} = (F_{empty\ cargo} + F_{consump} * w_{cargo}) * d \tag{4}$$

Where:

F_{cargo} = Fuel consumption as a function of cargo and distance [liter]

$F_{empty\ cargo}$ = 0,235 [liter / kilometer]

$F_{consump}$ = 0,003269 [liter / (km*ton)]

w_{cargo} = 18,2 [ton]

d = 154,2 [km]

$$F_{cargo} = 45{,}42\ liter\ fuel$$

The CO_2 emissions from road transport is calculated from equation:

$$E_{trans} = F_{cargo} * k \tag{5}$$

Where:

E_{trans} = CO_2 emissions from road transport [kg]

F_{cargo} = 45,42 [liter]

k = 2,6 [kg CO_2 / liter]

$$E_{trans} = 118{,}07\ kg\ CO_2$$

The specific CO2 emission from transport of the steel used in engine is calculated from equation:

$$E_{specific} = \frac{E_{trans}}{w_{cargo}} * \frac{w_{product}}{1000} \tag{6}$$

Where:

$E_{specific.road}$ = Specific CO_2 emission from road transport of product [kg]

E_{trans} = 118,07 [kg CO_2]

w_{cargo} = 18,2 [ton]

$w_{product}$ = 253 [kg]

$$\boldsymbol{E_{specific} = 1,65\ kg\ CO_2}$$

Engine transport

$$F_{cargo} = (F_{empty\ cargo} + F_{consump} * w_{cargo}) * d \qquad (4)$$

Where:

F_{cargo}	= Fuel consumption as a function of cargo and distance [liter]
$F_{empty\ cargo}$	= 0,235 [liter / kilometer]
$F_{consump}$	= 0,003269 [liter / (km*ton)]
w_{cargo}	= 18,2 [ton]
d	= 1251,7 [km]

$$F_{cargo} = 368{,}63\ liter\ fuel$$

The CO_2 emissions from road transport of engine is calculated from equation:

$$E_{trans} = F_{cargo} * k \qquad (5)$$

Where:

E_{trans}	= CO_2 emissions from road transport [kg]
F_{cargo}	= 368,63 [liter]
k	= 2,6 [kg CO_2 / liter]

$$E_{trans} = 958{,}43\ kg\ CO_2$$

The specific CO2 emission from transport of engine is calculated from equation:

$$E_{specific} = \frac{E_{trans}}{w_{cargo}} * \frac{w_{product}}{1000} \qquad (6)$$

Where:

$E_{specific.road}$	= Specific CO_2 emission from road transport of product [kg]
E_{trans}	= 958,43 [kg CO_2]
w_{cargo}	= 18,2 [ton]
$w_{product}$	= 4 280 [kg]

$$\boldsymbol{E_{specific} = 225{,}39\ kg\ CO_2}$$

4.3.1b) CO_2 Calculations for maritime transport of electric engine

Aluminum transport

$$E_{ship} = \frac{GP * E_{factor} * h}{1000} \quad (8)$$

Where:

E_{ship} = CO_2 emission per trip with ship [kg]

GP = 14 866 [kW]

E_{factor} = 686 [g CO_2 / kWh]

h = 4,5 [hour]

$$E_{ship} = 45\,891{,}34\ kg\ CO_2$$

The specific CO2 emission from maritime transport of the engine is calculated from equation:

$$E_{specific} = \frac{E_{vessel}}{w_{cargo}} * \frac{w_{product}}{1000} \quad (9)$$

Where:

$E_{specific.m}$ = Specific CO_2 emission from ship transport of product [kg]

E_{vessel} = 45 891,34 [kg CO_2]

w_{cargo} = 2905 [ton]

$w_{product}$ = 67 [kg]

$$\boldsymbol{E_{specific} = 1{,}06\ kg\ CO_2}$$

Copper transport

$$E_{ship} = \frac{GP * E_{factor} * h}{1000} \quad (8)$$

Where:

E_{ship} = CO_2 emission per trip with ship [kg]

GP = 14 866 [kW]

E_{factor} = 686 [gCO_2 / kWh]

h = 4,5 [hour]

$$E_{ship} = 45\ 891{,}34\ kg\ CO_2$$

The specific CO2 emission from maritime transport of the engine is calculated from equation:

$$E_{specific} = \frac{E_{vessel}}{w_{cargo}} * \frac{w_{product}}{1000} \tag{9}$$

Where:

$E_{specific.m}$ = Specific CO_2 emission from ship transport of product [kg]

E_{vessel} = 45 891,34 [kg CO_2]

w_{cargo} = 2905 [ton]

$w_{product}$ = 253 [kg]

$$\boldsymbol{E_{specific} = 4\ kg\ CO_2}$$

Engine transport

$$E_{ship} = \frac{GP * E_{factor} * h}{1000} \tag{8}$$

Where:

E_{ship} = CO_2 emission per trip with ship [kg]

GP = 14 866 [kW]

E_{factor} = 686 [gCO_2 / kWh]

h = 4,5 [hour]

$$E_{ship} = 45\ 891{,}34\ kg\ CO_2$$

The specific CO2 emission from maritime transport of the engine is calculated from equation:

$$E_{specific} = \frac{E_{vessel}}{w_{cargo}} * \frac{w_{product}}{1000} \tag{9}$$

Where:

$E_{specific.m}$ = Specific CO_2 emission from ship transport of product [kg]

E_{vessel} = 45 891,34 [kg CO_2]

W_{cargo} = 2905 [ton]

$W_{product}$ = 4280 [kg]

$$E_{specific} = 67,61\ kg\ CO_2$$

4.3.1c) Summary of CO_2 from transport of electric engine

Table 18 shows a summary of CO_2 emissions from transport of electric engine.

Transport	Specific CO_2 emissions
Road	269,13 kg CO_2
Maritime	72,67 kg CO_2
Total	***331,8 kg CO_2***

Table 18. *Summary of CO_2 emissions - transport of electric engine*

4.3.2 Transport of Battery

It is assumed that CATL (Contemporary Amperex Technology Co., Limited) is the manufacturer of the NMC batteries in this thesis. CATL is located in Ningde, China, and is the second largest battery manufacturer in the world [27]. From CATL it is assumed that the batteries are transported by sea from the port of Shanghai, the largest port in China [28].

The transportation route from port of Shanghai to Bergen, via Hamburg, is chosen by using Ports.com [29]. From Port of Shanghai to port of Hamburg the batteries are transported by the container ship, CMA CGM CHAMPS ELYSEES [30]. There will be a change of ships in Hamburg, to a smaller container ship, NCL Alesund, that will transport the batteries to Norway.

Transport of materials for production of batteries is assumed to be included in the calculations done in *chapter 4.2.4b) Battery.*

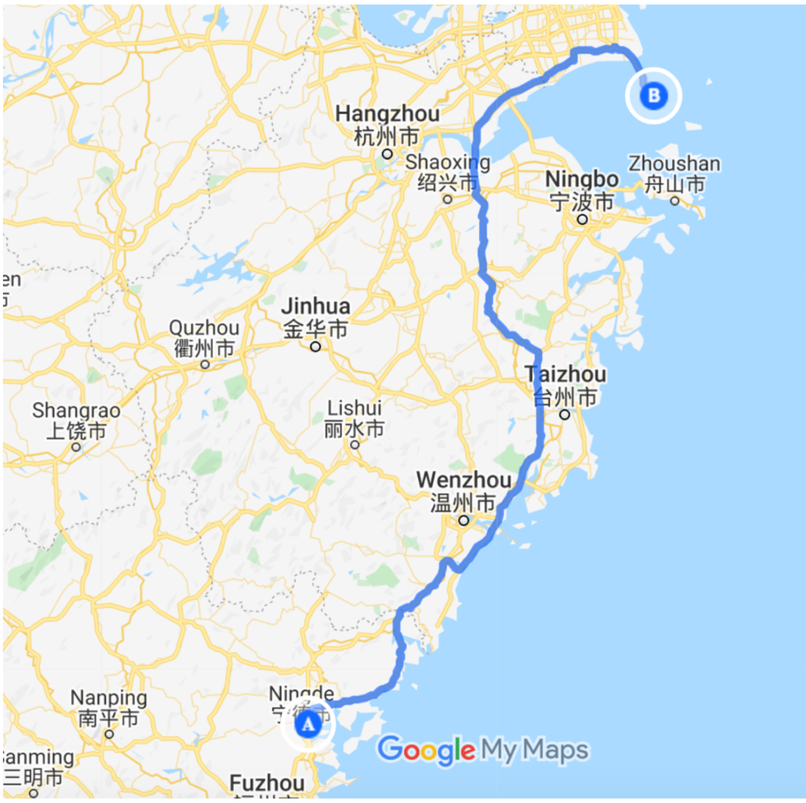


Figure 8. CATL in Ningde - Port of Shanghai (Google My Maps)

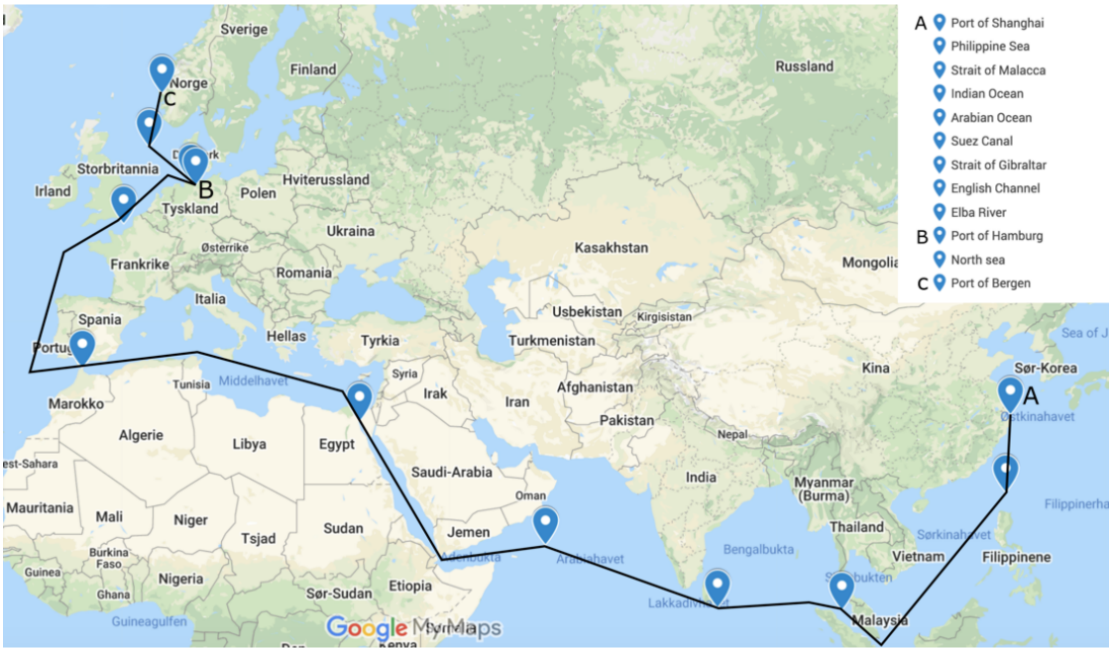


Figure 9. Port of Shanghai - Port of Hamburg – Port of Bergen (Google My Maps)

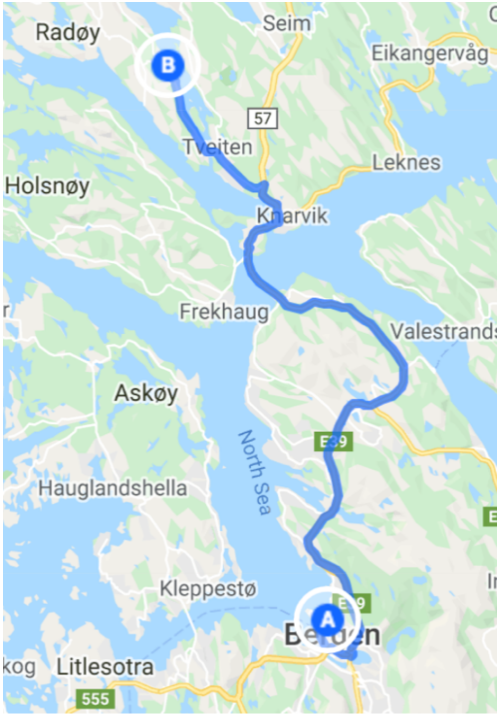


Figure 10. Port of Bergen - Mundal, Radøy (Google My Maps)

All stages of transportation related to the batteries are presented in table 19.

Stage	Item	Route	Transport option	Distance [km]
1	Battery	CATL in Ningde, China - Port of Shanghai, China	Tractor and semi-trailer, long haul traffic	723
2	Battery	Port of Shanghai, China - Port of Hamburg, Germany	CMA CGM CHAMPS ELYSEES, COSCO	22 737
3	Battery	Port of Hamburg, Germany - Port of Bergen, Norway	NCL Alesund	1 013
4	Battery	Port of Bergen, Norway - Mundal, Radøy, Norway	Tractor and semi-trailer, long haul traffic	36,8
			Total distance for battery	**24 509,8**

Table 19. Transportation stages from manufacturing to assembly

CMA CGM CHAMPS ELYSEES operate at a distance of 22 737 km (table 19) at a average speed of 40,7 km/hour [31]. Dividing distance by average speed, the vessel uses 558,65 hours on the route.

NCL Alesund transport the products at a distance of 1 013 km (table 19) at 25,9 km/hour. The speed of the vessel is provided by Nina A. Våge, Manager Vessel Operation in NCL (Personal communication, 21.04.21). Dividing distance by average speed, the vessel use 39,11 hours from port of Hamburg to port of Bergen.

More information about the vessels transporting the battery packs are presented in table 20. It is assumed that a container ship is categorized as a general cargo. Gross power for NCL Alesund is set to be 7 950 kW (N. A. Våge, personal communication, 21.04.21)

Name of vessel	Type of vessel	Gross power [kW]	E_{factor} [g CO_2 / kWh]
CMA CGM CHAMPS ELYSEES, COSCO	Container ship [32]	3 840 *[31]*	644 *[12]*
NCL Alesund	Container ship [33]	7 950	644 *[12]*

Table 20. Data on type of vessels

4.3.2a) CO2 Calculations for road transport of battery

Battery transport

$$F_{cargo} = (F_{empty\ cargo} + F_{consump} * w_{cargo}) * d \quad (4)$$

Where:

F_{cargo} = Fuel consumption as a function of cargo and distance [liter]

$F_{empty\ cargo}$ = 0,235 [liter / kilometer]

$F_{consump}$ = 0,003269 [liter / (km*ton)]

w_{cargo} = 18,2 [ton]

d = 759,8 [km]

$$F_{cargo} = 223{,}76\ liter$$

The CO_2 emissions from road transport is calculated from equation:

$$E_{trans} = F_{cargo} * k \quad (5)$$

Where:

E_{trans} = CO_2 emissions from road transport [kg]

F_{cargo} = 223,76 [liter]

k = 2,6 [kg CO_2 / liter]

$$E_{trans} = 581{,}78\ kg$$

The specific CO2 emission is calculated from equation:

$$E_{specific} = \frac{E_{trans}}{w_{cargo}} * \frac{w_{product}}{1000} \tag{6}$$

Where:

$E_{specific.road}$ = Specific CO_2 emission from road transport of product [kg]

E_{trans} = 581,78 [kg]

W_{cargo} = 18,2 [ton]

$W_{product}$ = 1 294 Weight of product [kg]

$$\boldsymbol{E_{specific}\ by\ tractor\ and\ semitrailer = 41.35\ kg}$$

4.3.2b) CO_2 Calculations for maritime transport of battery

Battery transport - CMA CGM CHAMPS ELYSEES, COSCO

$$E_{ship} = \frac{GP * E_{factor} * h}{1000} \tag{8}$$

Where:

E_{ship} = CO_2 emission per trip with ship [kg]

GP = 63 840 [kW]

E_{factor} = 644 [gCO_2 / kWh]

h = 558,65 [hour]

$$E_{ship} = 22\ 967\ 699{,}55\ kg$$

As a larger ship will produce more CO_2 it is important to look at CO_2 emissions per ton cargo transported, this is calculated from equation:

$$E_{specific} = \frac{E_{vessel}}{w_{cargo}} * \frac{w_{product}}{1000} \tag{9}$$

Where:

$E_{specific.m}$ = Specific CO_2 emission from ship transport of product [kg]

E_{vessel} = 22 967 699,55 [kg]

w_{cargo} = 151 830 [ton]

$w_{product}$ = 1 294 [kg]

$$\boldsymbol{E_{specific}\ Maritime\ transport = 195{,}69\ kg}$$

Battery transport - NCL Alesund

$$E_{ship} = \frac{GP * E_{factor} * h}{1000} \tag{8}$$

Where:

E_{ship} = CO_2 emission per trip with ship [kg]

GP = 7 950 [kW]

E_{factor} = 644 [gCO_2 / kWh]

h = 39,11 [hour]

$$E_{ship} = 200\ 245{,}46\ kg$$

As a larger ship will produce more CO_2 it is important to look at CO_2 emissions per ton cargo transported, this is calculated from equation:

$$E_{specific} = \frac{E_{vessel}}{w_{cargo}} * \frac{w_{product}}{1000} \tag{9}$$

Where:

$E_{specific.m}$ = Specific CO_2 emission from ship transport of product [kg]

E_{vessel} = 200 245,56 [kg]

w_{cargo} = 7 845,6 [ton]

$w_{product}$ = 1 294 [kg]

$$\boldsymbol{E_{specific}\ Maritime\ transport = \ 33.02\ kg}$$

4.3.2c) Summary of CO_2 from transport of battery

Transport	Specific CO_2 emissions
Road	41,35 CO_2
Maritime	228,71
Total	***270,06 kg CO_2***

Table 21. *Summary of CO_2 emissions - Transport of Battery*

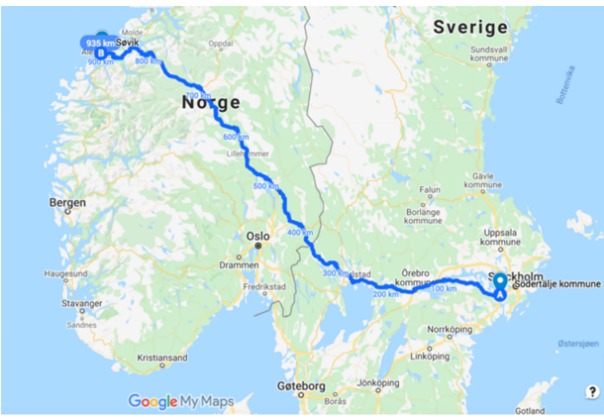
Because the battery must be replaced after ten years, this transportation route must be completed a second time for the new set of batteries. The total emissions for transportation of the two batteries are presented in table 22.

Transport	Specific CO_2 emissions
Road	82,70 kg CO_2
Maritime	457, 42 kg CO_2
Total	***540,12 kg CO_2***

Table 22. *Summary of CO_2 emissions during a 20-year span.*

4.3.3 Transport of Diesel System

The steel is transported from SSAB in Luleå to Scania Production Facility in Södertalje, Sweden. The engine is then transported to Mundal Groups Assembly location in Radøy, via Søvik (see figure 11-12 and table 24).



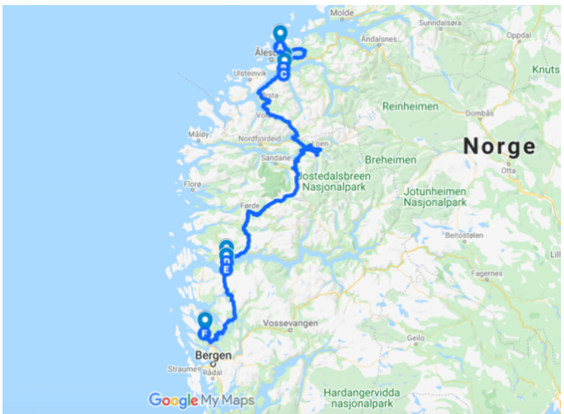


Figure 11. (left). Scania, Södertalje - Nogva, Søvik (Google My Maps)

Figure 12. (right). Nogva, Søvik - Mundal Group, Radøy (Google My Maps)

This route includes two ferry connections, Festøya – Solavågen and Oppedal – Lavik. The ferries operating the connections are presented in the table 23 below.

Ferry connection	Ferry	Capacity [PBE]	Distance [km]
Festøya - Solavågen	M/F Festøya	120	4,3
	M/F Solavågen	120	4,3
	M/F Tidefjord	120	4,3
Oppedal - Lavik	M/F Oppedal	120	5,8
	M/F Ampere	120	5,8
	M/F Stavanger	120	5,8

Table 23. *Ferry connections.*

It is assumed that the ferries used are M/F Festøya and M/F Oppedal. The total transportation route is described in table 24.

Stage	Item	Route	Transport option	Distance [km]
1	Steel	SSAB in Luleå, Sweden – Scania Production Facility in Södertalje, Sweden	Tractor and semi-trailer, long haul traffic	940
			Total distance for steel	**940**
2	Engine	Scania Production Facility, Sweden – Nogva in Søvik, Norway	Tractor and semi-trailer, long haul traffic	935
3	Engine	Nogva, Søvik – Solavågen Ferry Pier	Tractor and semi-trailer, long haul traffic	50,8
4	Engine	Solavågen – Festøya Ferry Connection	M/F Festøya	4,3
5	Engine	Festøya Ferry Pier – Lavik Ferry Pier	Tractor and semi-trailer, long haul traffic	252
6	Engine	Lavik – Oppedal Ferry Connection	M/F Oppedal	5,8
7	Engine	Oppedal Ferry Pier – Mundal Group, Radøy	Tractor and semi-trailer, long haul traffic	90,2
			Total distance for engine	**1 338,1**

Table 24. *Transport route for diesel engine.*

4.3.3a) CO_2 Calculations for road transport of diesel engine

Steel transport

$$F_{cargo} = (F_{empty\ cargo} + F_{consump} * w_{cargo}) * d \qquad (4)$$

Where:

F_{cargo}	= Fuel consumption as a function of cargo and distance [liter]
$F_{empty\ cargo}$	= 0,235 [liter / kilometer]
$F_{consump}$	= 0,003269 [liter / (km*ton)]
w_{cargo}	= 18,2 [ton]
d	= 940 [km]

$$F_{cargo} = 276{,}83\ liter\ fuel$$

The CO_2 emissions from road transport is calculated from equation:

$$E_{trans} = F_{cargo} * k \qquad (5)$$

Where:

E_{trans}	= CO_2 emissions from road transport [kg]
F_{cargo}	= 276,83 [liter]
k	= 2,6 [kg CO_2 / liter]

$$E_{trans} = 719{,}76\ kg\ CO_2$$

The specific CO2 emission from transport of the steel used in engine is calculated from equation:

$$E_{specific} = \frac{E_{trans}}{w_{cargo}} * \frac{w_{product}}{1000} \qquad (6)$$

Where:

$E_{specific.road}$	= Specific CO_2 emission from road transport of product [kg]
E_{trans}	= 719,76 [kg CO_2]

w_{cargo} = 18,2 [ton]

$w_{product}$ = 2 237,2 [kg]

$$\boldsymbol{E_{specific} = 88,47\ kg\ CO_2}$$

Engine transport

$$F_{cargo} = (F_{empty\ cargo} + F_{consump} * w_{cargo}) * d \tag{4}$$

Where:

F_{cargo} = Fuel consumption as a function of cargo and distance [liter]

$F_{empty\ cargo}$ = 0,235 [liter / kilometer]

$F_{consump}$ = 0,003269 [liter / (km*ton)]

w_{cargo} = 18,2 [ton]

d = 1 358 [km]

$$F_{cargo} = 399{,}93\ liter\ fuel$$

The CO_2 emissions from road transport of engine is calculated from equation:

$$E_{trans} = F_{cargo} * k \tag{5}$$

Where:

E_{trans} = CO_2 emissions from road transport [kg]

F_{cargo} = 399,93 [liter]

k = 2,6 [kg CO_2 / liter]

$$E_{trans} = 1\ 039{,}82\ kg\ CO_2$$

The specific CO2 emission from transport of engine is calculated from equation:

$$E_{specific} = \frac{E_{trans}}{w_{cargo}} * \frac{w_{product}}{1000} \tag{6}$$

Where:

$E_{specific.road}$ = Specific CO_2 emission from road transport of product [kg]

E_{trans} = 1 039,82 [kg]

w_{cargo} = 18,2 [ton]

$w_{product}$ = 2 380 [kg]

$$\boldsymbol{E_{specific} = 135,97\ kg\ CO_2}$$

4.3.3b) CO_2 Calculations for maritime transport of diesel engine

Engine transport

M/F Festøya and M/F Oppedal are similar ferries running on the same fuel. It is therefore possible to use the same formula for calculating the emissions. The total distance will then be 10,1 km when including both ferries.

$$E_{ferry} = \frac{CO_2e * PBE * d}{1000} \tag{7}$$

Where:

E_{ferry} = CO_2e emissions per trip with ferry [kg]

CO_2e = 327 [g / (PBE * km)]

PBE = 120 [PBE]

d = 10,1 [km]

$$E_{ferry} = 396{,}32\ [kg]$$

The specific CO2 emission from marine transport is calculated from equation:

$$E_{specific} = \frac{E_{vessel}}{w_{cargo}} * \frac{w_{product}}{1000} \tag{9}$$

Where:

$E_{specific.m}$ = Specific CO_2 emission from ship transport of product [kg]

E_{vessel} = 396,32 [kg]

w_{cargo} = 350 [ton]

$w_{product}$ = 2 380 [kg]

$$E_{specific} = 2,70\ kg\ CO_2$$

4.3.3c) Summary of CO_2 from transport of diesel engine

Table 25 show a summary of total CO_2 emission from transport of diesel engine.

Transport	Specific CO_2 emissions
Road	224,45 kg CO_2
Maritime	2,70 kg CO_2
Total	***227,14 kg CO_2***

Table 25. *Summary of CO2 emissions - transport of diesel engine*

4.4 Operation

4.4.1 Operating routes

The vessel will operate between Rosendal and Salmon Eye, via the production plant Hågardsneset. In a situation where Hågardsneset is not in use, the vessel will travel via Hondskår. This will typically be 6 months during a cycle of two years. The operating routes were not completely decided when the thesis was given, but it was decided to use these routes for the calculations. During on-season the vessel will operate with three tours daily during weekdays and on request. During off-season it will only operate on request. On and off season is 6 months each.

The battery solution from Corvus Energy can operate fully electric via Hondskår, but not as often as requested (K. Holmefjord, personal communication, 09.04.21). In the calculation, three different routes can be chosen (table 26). It was decided to use route number 2, Rosendal – Salmon Eye – Hågardsneset – Rosendal, as the main route for the CO_2 calculations. This route can be operated with diesel and electric engine at the same rate. Route 1 was also included as an option since it most likely will be requested trips to Salmon Eye without any stop at any production plant.

Route	Destinations	Distance (km)
1	Rosendal - Salmon Eye - Rosendal	8,8
2	Rosendal - Salmon Eye – Hågardsneset - Rosendal	11,84
3	Rosendal - Salmon Eye - Hondskår – Rosendal	34,04

Table 26. *Operating routes.*

Figure 13. *Route 2: Rosendal - Salmon Eye – Hågardsneset - Rosendal (Google My Maps)*

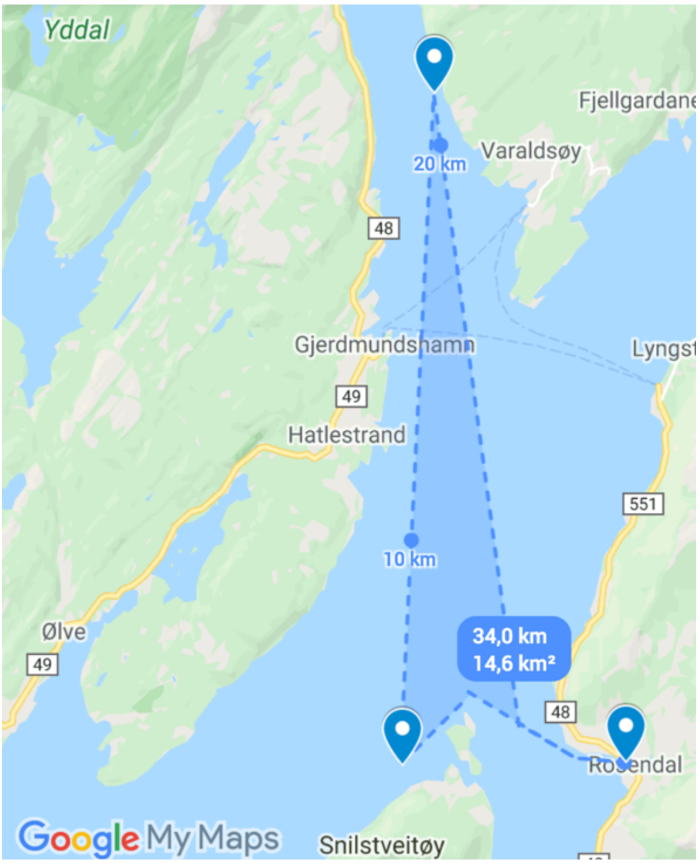


Figure 14. *Route 3: Rosendal - Salmon Eye - Hondskår – Rosendal (Google My Maps)*

Fuel consumption or energy demand will vary with countercurrent, passenger load, hull of the vessel and weather. These variables will also affect the speed of the vessel. For simplification, the calculation will be based on the engine speed or power.

4.4.2 Use of Electric system

4.4.2a) CO_2 Calculation

It is assumed that the electric engine operates at 1 500 rpm at full engine load. CO_2 emissions from an electric engine and battery during operation is calculated from the following equation:

$$E_{el.engine} = \frac{P_{tot.}}{lifespan} * E_{power\ source} * h_{op} \tag{10}$$

The calculation is based on a CO_2 emission from the Norwegian energy mix with only 0,017 kg CO_2 per kWh [34]. The operating hours are calculated from speed and distance.

Where:

Speed	= 18 knots
Distance	= 11,84 km
$P_{tot.}$	= 1 110 986 kWh
Lifespan	= 75 000 hours
$E_{power\ source}$	= 0,017 kg CO_2 / kWh
h	= 0,36 hours

$$E_{el.engine} = 34{,}92\ kg\ CO_2\ per\ trip$$

Trips per day	= 3
Days per week	= 5
Weeks during on-season	= 26
Total trips during season	= 390

Total CO_2 emissions per year:

$$\boldsymbol{E_{el.engine} = 34,92\ kg\ CO_2}$$

Table 27 present a summary of CO_2 emission during a 20-year lifetime. Note that this does not include any trips done on request on any of the routes during on or off-season.

Summary of CO_2 emission through operation phase	
CO_2 emissions after 1 year [kg]	34,92
CO_2emissions after 5 years [kg]	174,59
CO_2emissions after 10 years [kg]	349,19
CO_2emissions after 15 years [kg]	523,78
CO_2emissions after 20 years [kg]	698,38

Table 27. *Summary of CO_2 emission using electric system.*

4.4.3 Use of Diesel system

4.4.3a) CO_2 Calculation

It is assumed that the engine operates at 1500 rpm and 75 % engine load. CO_2 emissions from using a diesel engine to operate the vessel is calculated from the following equation:

$$E_{operation} = \frac{\left(\frac{F_{specific} * GP * h}{1000}\right)}{\rho_{fuel}} * E_{fuel} \tag{11}$$

The calculations use diesel with a density of 0,84 kg / liter [13]. The emissions from one liter diesel fuel is 2,6 kg CO_2 [10]. The time is calculated from speed and distance.

Where:

Speed = 18 knots

Distance = 11,84 km

$E_{operation}$ = CO_2 emission from operation of vessel per trip [kg]

$F_{specific}$ = 196 g / kWh

GP = 350 [kW]

h = 0,36 hours

ρ_{fuel} = 0,84 kg / liter

E_{fuel} = 2,6 kg CO_2 / liter

$$E_{operation} = 29\,443,56\ kg\ CO_2$$

Table 28 present a summary of CO_2 emission during a 20-year lifetime. Note that this does not include any trips done on request on any of the routes during on or off-season.

Summary of CO_2 emission through operation phase	
CO_2 emissions after 1 year [kg]	58 887,11
CO_2 emissions after 5 years [kg]	294 435,56
CO_2 emissions after 10 years [kg]	588 871,11
CO_2 emissions after 15 years [kg]	883 306,67
CO_2 emissions after 20 years [kg]	1 177 742,22

Table 28. *Summary of CO_2 emission using diesel engine.*

4.5 End of Lifespan

Mining and production of materials for the engines and battery takes a lot of effort and generate a great amount of CO_2 emission. Additionally, the excess of the material will at some point come to an end. Recycling is therefore important at the end of the lifecycle. However, recycling is a difficult and expensive process, especially for NMC-batteries. The development of innovative recycling methods is an ongoing process and therefore it is few studies about CO_2 emissions for recycling [35].

The recycling process in this thesis is not included in the CO_2 calculator and will not affect the result, but information about the process and the numbers found will be presented.

4.5.1 Recycling of Engines

The method used to recycle an engine is to sperate every part and then recycle them separately. The recycling depends on the various engines and what type of material it consists. Both the electric and diesel engine mostly consist of steel, as shown in table 13 and 15. Additionally, the electric engine contains copper and aluminum.

Steel is 100 % recyclable and are easily recovered by magnets. Steel has the quality that it can be recycled infinitely without loss of quality. The material is therefore the most recyclable in the world [36].

Aluminum has some of the same qualities as steel and can also be infinitely recyclable without the loss of its essential properties. The power needed to drive the recycling process is only a fraction of the primary production, just 5 %. The disadvantage with recycling of aluminum is that it depends on there being enough aluminum scrap for remelting and refining [37].

Copper can also be recycled repeatedly without any loss of functioning. The recycling requires minimum 15 % of the primary production. Annually this saves 40 million tons of CO_2 globally. Nearly 50 % of the copper demand in Europe is recycled material [38].

4.5.2 Recycling of Batteries

Accardo et al. (2021) presents information about the CO_2 emission for recycling of NMC-batteries in Europe. As presented in table 10 the emission for recycling is 11,3 kg CO_2e / kWh. There have not been found any other information about CO_2 emission for recycling of batteries and therefore it is difficult to manifest reliable data.

4.5.3. Electric System

4.5.3a) Engine

The recycling of the electric engine, M3BP 355MLC 4, is proposed in table 29.

Proposed recycling method for engine	
Cast iron	Material recycling
Steel	Material recycling
Aluminum	Material recycling
Copper	Material recycling
Plastic and rubber	Material recycling
Lubricating grease from the bearings	Hazardous waste
Insulation material	Landfill waste

Table 29. *Proposed recycling method for engine (appendix A)*

4.5.3b) Battery

The Dolphin Energy provided by Corvus Energy is 99 % recyclable (appendix E). The recycling process today is limited because many of the batteries produced by Corvus are still in their first life. As the volume of batteries for recycling increases, the recycling cost per unit is expected to drop substantially which will increase the recycling of batteries [39].

Corvus have developed a procedure for recycling of NMC batteries, shown in figure 15.

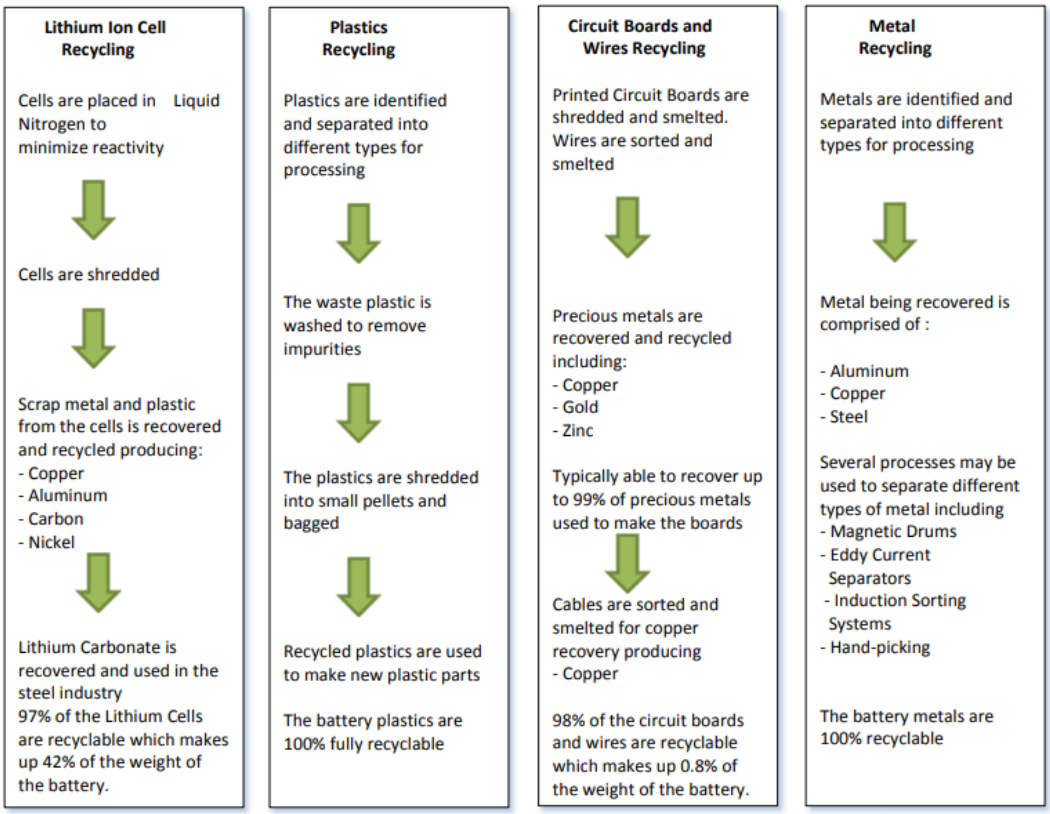


Figure 15. *Recycling method for batteries (appendix E)*

4.5.4 Diesel System

The diesel engine, Scania DI13 070M, consists mainly of metal and is therefore 99,99 % recyclable (see appendix C). Table 30 show a proposed recycling method for the engine.

Proposed recycling method for engine	
Scrap metal	Material recycling
Plastics	Material recycling, energy recovery
Batteries	Material recycling
Chemicals/oils	Reuse if possible. Material recycling, otherwise, destruction by an approved company.
Fuel- and oil filter	Material recycling, otherwise, destruction by an approved company.
Paint	No known methods. Energy recovery.
Electronics	Material recycling

Table 30. *Recycling method for diesel engine (appendix C)*

5. Results & Discussion

The total CO_2 emissions for the electric and diesel system through a 20-year period is presented in figure 16. The values include emissions from manufacturing, transport, and operation.

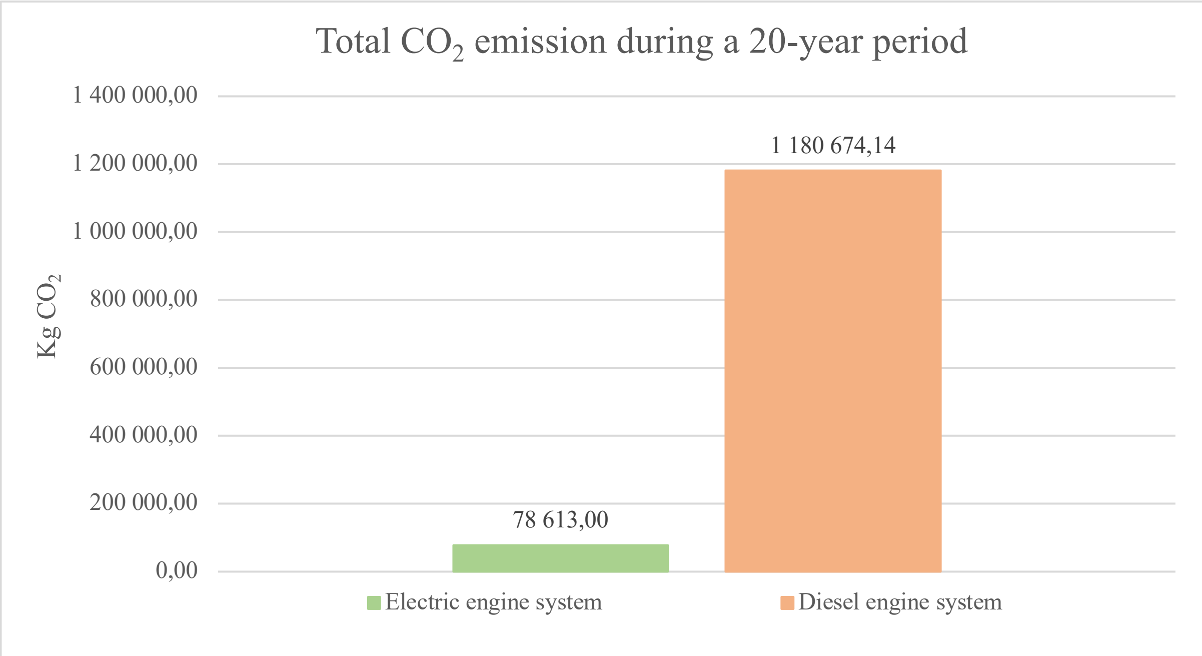


Figure 16. *Total CO_2 emissions.*

The results show a clear and significant difference in CO_2 emissions between the two systems. The diesel engine system produces about 15 times as much CO_2 as the electric system. To get a clearer picture of the outcome, the share of emissions from the electric and diesel engine system are presented in figure 17 and 18.

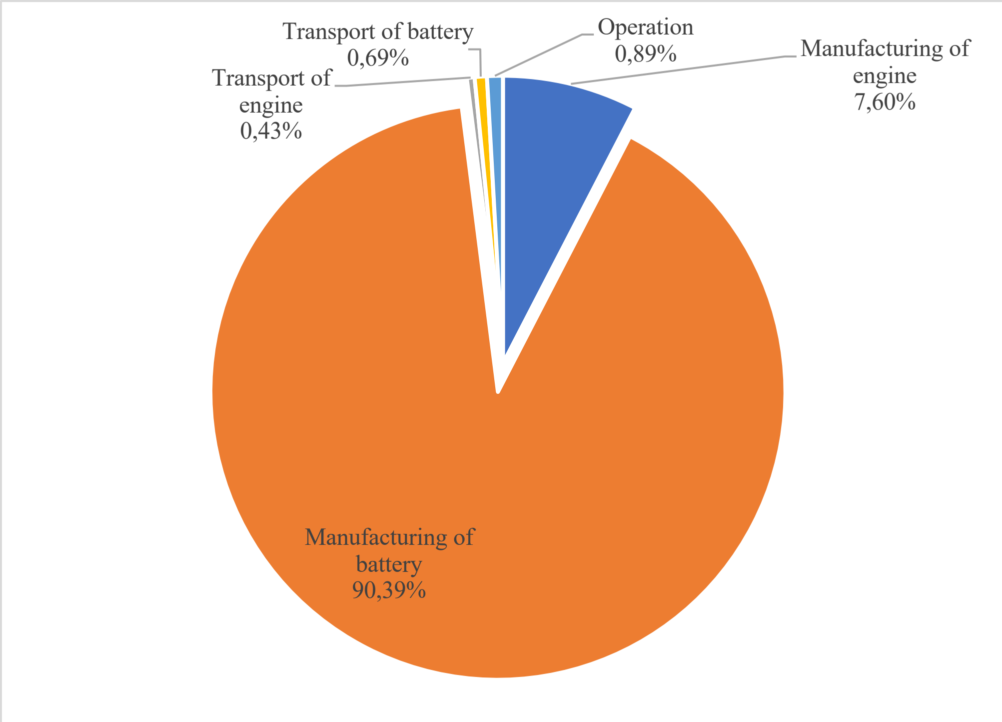


Figure 17. *Share of emissions from electric engine system.*

For the electric system it is the manufacturing of batteries that contributes to the largest share of CO_2 emissions (figure 17). The manufacturing of three battery packs for one battery system produces 35 527,80 kg CO_2. This process must be repeated after ten years, giving a total of 71 055,60 kg CO_2 for the battery packs.

An important factor in emission from manufacturing of the batteries is the main energy source in China, coal and lignite. The energy sector in China produces over twice as much CO_2 per kWh compared to EU [15]. By moving the production to EU, the emissions could be lowered dramatically.

The total emission from manufacturing of the electric engine system will be 77 032,71 kg CO_2, which is about 28 times higher than the total emission from manufacturing the diesel engine.

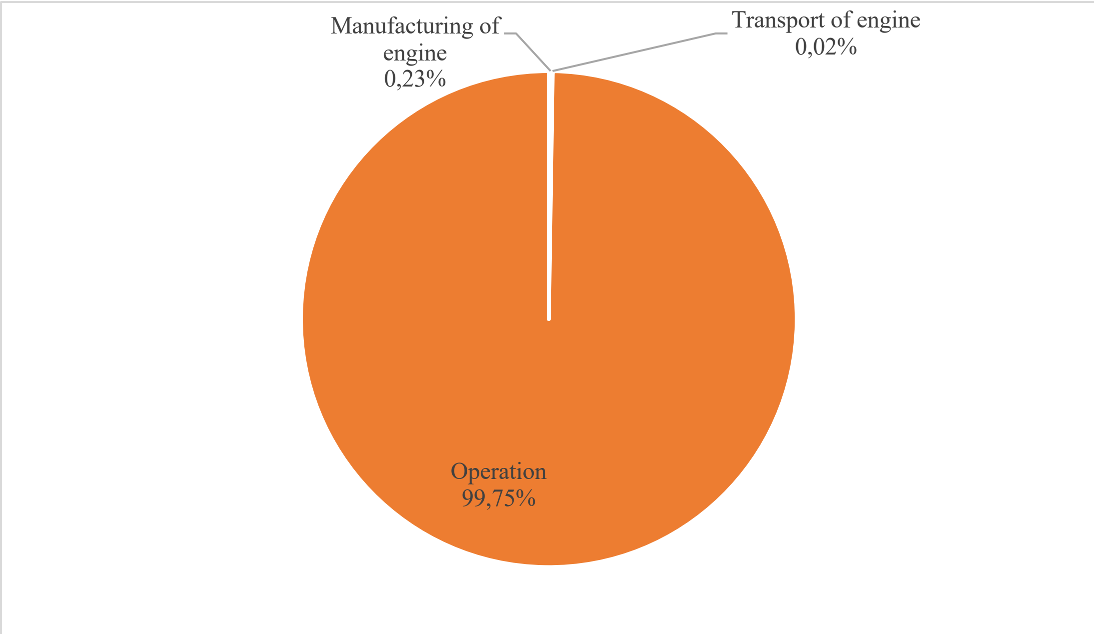


Figure 18. *Share of emissions from diesel engine system.*

For the diesel system, it is the operation phase that contributes with the most emissions (figure 18). Operation of the diesel engine system will emit 58 887,11 kg CO_2 every year. For the electric engines, this value is only 34,92 kg CO_2.

A graph of the emissions from the electric and diesel engine system during a 20-year period is presented in figure 19. The purpose of this graph is to get a better perspective of how the emission evolves over the years.

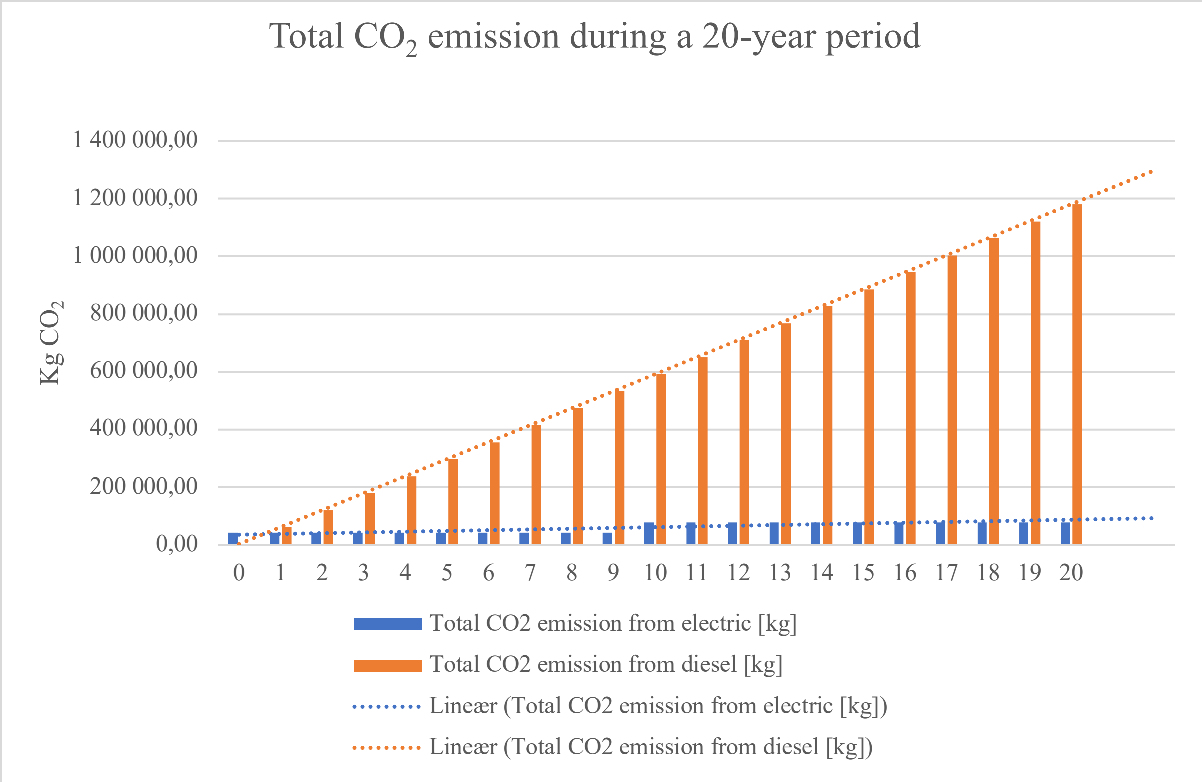


Figure 19. *Emissions increase during the 20-year period.*

The emissions from the diesel engine system have a steep increase in the total emission each year (see figure 19). The electric engine system on the other hand have almost no increase in emissions after production. The only significant increase in CO_2 emissions for the electric engine system is in year 10, when a new battery system must be manufactured to replace the first system.

The results show that the electric system emit less CO_2 than the diesel engine system. However, the results depend on the chosen engines and batteries. Other engines with more similarities could be more suitable. The size of the battery system was chosen in a scenario where route 2 is the only operated route. Even though the battery system can fuel the engine with power for route 3, it still cannot operate at the same rate as with a diesel engine. If the vessel mainly will operate on route 2, it could be more beneficial to choose a smaller engine.

The weight of engines and batteries have not been considered in this thesis for calculating the energy and fuel consumption. A higher weight of batteries or engines would cause a larger resistance when operating the vessel and have an impact on the energy and fuel consumption. Fuel and power consumption during operation are however in this thesis assumed to be constant. In this case the electric system weights twice as much as the diesel engine system, which can affect important qualities.

This analysis does not consider that the manufacturing of batteries in ten years can have changed drastically in terms of location and emissions. The battery production will probably have advanced with new technology making it more environmentally friendly. Other production location might also contribute to lower emissions due to energy sources.

Transportation contributes to a very small part of the total CO_2 emissions in both cases. This is because the specific emissions related to the transported item is calculated.

All calculations in this analysis are based mainly on available information and documentation provided by MENG, Eide Fjordbruk, Scania, ABB and Corvus Energy. This can in some cases restrict the calculations. Not all data and information relevant for the calculation could be shared. Where information or data were lacking, assumptions had to be made. This could have affected the results, especially for the transportation and manufacturing.

6. Conclusion

The thesis presents a comparative analysis between an electric and diesel system in the scope of CO_2 emissions. The analysis includes calculations of emissions through three phases: manufacturing, transportation and operation. The end-of-life phase has been described and discussed, but not included in the calculations.

For the electric engine system, it is the manufacturing of batteries that contributes to most of the CO_2 emissions. The battery production accounts for over 90 % of the total emissions during the 20-year period. However, battery technology is evolving and will probably release less CO_2 to the environment in the future.

The diesel engine system emits most of its CO_2 during the operation phase, which was not unexpected. With the total emissions from the diesel system being 15 times higher than from the electric engine system, there is without a doubt a clear and significant difference between the two alternatives presented in this thesis.

In conclusion, the CO_2 emissions from the ABB electric engine and Corvus Dolphin Energy battery system emits far less CO_2 than the Scania diesel engine through a 20-year phase.

7. Recommendation for Further Work

This thesis presents an analysis and calculations of CO_2 through a 20-year lifespan for an electric and diesel engine system. Since this is a bachelor thesis, the time has been limited and limitations had to be set to narrow the project.

The results show that battery manufacturing contributes the most to CO_2 emissions in the electric engine system. It is not taken into account that the batteries produced ten years into the future might cause less emissions. The production site can change, and the power sectors will probably produce less CO_2 per kWh. The battery industry is evolving at high speed, and it will be important to update the information from battery production frequently to get more accurate results. Manufacturing calculations for batteries do not include charging stations that would be required for the vessel to operate with an electric engine. The CO_2 impact from manufacturing and using these charging stations could reduce the CO_2 difference between electric and diesel engine system.

More accurate CO_2 calculations from transport can be done by including other vehicle types than Volvo trucks, and a larger selection of ships.

It is during the operation phase where the diesel engine emits most of the CO_2. The calculations are based on an average speed and does not take any environmental factors into account. The speed is assumed constant at 18 knots. In reality the speed will be vary during arrival, departure and crossing, which in will affect the fuel consumption. By including this information into the thesis and calculator, the results would be more accurate. This also applies to the electric engine.

This thesis is not a full life cycle analysis, but more accurate data and information from companies and literature have to be collected and used to complete a full LCA. This way different assumptions and limitations can be reduced to get a more accurate result. Data such as production location, material location, material content, engine/battery lifetime and recycling are some of the data needed. It is also important to keep up with the market and stay up to date on development and new technology.

Recycling is another part of the thesis that would be interesting to look more into, especially for batteries. As of today, there are no regulations that would drive companies to recycle batteries and the financial gains still outweighs the benefits. It will be interesting to see if there will be any governmental regulations in the future for battery recycling, and if it will have any effect on the recycling method. It would also be interesting to look into what happens with the batteries and engines if they are not recycled.

Furthermore, it would be exciting to include cost, maintenance and infrastructure for the two engines system in the comparative study.

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List of Figures

List of Tables

Appendix

Appendix A

Environmental Product Declaration

AC Low voltage cast iron motor,
type M3BP 315

ABB

Organizational framework

Manufacturer:

ABB Oy, BA Electrical Machines, LV Motors
P.O.Box 633, FIN-65101 Vaasa, Finland
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Contact person EPD: Marko Laatu

ABB is a global leader in power and automation technologies that enable utility and industry customers to improve performance while lowering environmental impact.
ABB has 152,000 employees in more than 100 countries.
As a key element of its business strategy, ABB has committed to a broad program of product development and positioning under the Industrial IT umbrella.
This initiative is geared towards increasing integration of ABB products as the 'building blocks' of larger solutions, while incorporating functionality that will allow multiple products to interact seamlessly as components of real-time automation and information systems.
Motors and generators represent one of the fundamental building blocks in the Industrial IT architecture.

ABB Oy, Electrical Machines, LV Motors forms a part of ABB's Automation Technology Products segment. LV Motors is designing, manufacturing and marketing low voltage induction motors and generators for the industry and power production.

Environmental management

The ISO 14001 international environmental management standard has been implemented and the Vaasa factory has been certified since 1996. Life cycle assessment (LCA) is applied continually to all product development.

Product description

ABB Oy, Electrical Machines, LV Motors manufacturers cast iron motors in shaft heights from 160 to 400. The range of rated outputs is 11-710 kW. Typical applications include pumps, fans, blowers, compressors, conveyors.
This document applies to the M3BP 315MLA 4 B3 model which is a 200 kW, 400 V product.

Material according to the table below is used for the product:

Type of material	kg / product	kg / kW
Electrical steel	795	3.98
Other steel	136	0.68
Cast iron	455	0.12
Aluminium	24	0.12
Copper	91	0.45
Insulation material	6	0.03
Wooden packing material	15	0.08
Impregnation resin	7	0.04
Paint	8	0.04

Environmental performance

The data and calculations are in accordance with Product Specific Requirements (PSR) for Rotating Electrical Machines, which specifies the following baselines for the LCA calculation.

Functional unit

The functional unit for the LCA is 1 kW of rated output power.

System boundaries

The life cycle assessment covers all environmental aspects for extraction and production of raw materials, manufacturing of main parts, assembly, transportation and use of the product, dismantling, fragmentation and disposal and recycling of scrap after end of life. It includes consumption of material and energy resources as well as emissions and waste generation.

Calculations are based on an estimated lifetime of 15 years when operating 5,000 hours per year. A Finnish mix of energy has been used for calculating energy consumption during manufacturing and an European mix of energy for calculating energy consumption during use and disposal.

The operational point chosen for the usage phase 200 kW, 1500 rpm and efficiency 96.2%. The operational point in reality will vary considerably depending on the specific application.

Allocation unit

The factor for allocation of common environmental aspects during manufacturing (such as manufacturing waste) is calculated as the rated output power of the product in relation to the total annual production volume in factory.

Resource utilisation	Manufacturing phase unit / kW	Usage phase unit / kW	Disposal phase unit / kW
Use of non-renewable resources			
Coal kg	5.06	408.20	-3.30
Aluminium (Al) kg	0.11	0.00	-0.10
Copper (Cu) kg	0.35	0.00	-0.29
Iron (Fe) kg	4.97	0.00	-4.42
Manganese (Mn) kg	0.01	0.01	-0.01
Natural Gas kg	0.51	71.89	-0.15
Uranium (U) kg	0.00	0.03	0.00
Oil kg	0.85	62.99	0.15
Use of renewable resources			
Wood kg	0.62	30.90	0.00
Hydro Power MJ	1.02	2,802.67	0.00

2

Energy consumption and losses	kWh / product			kWh / kW		
Energy form	Manufacturing phase	Usage phase	Disposal phase	Manufacturing phase	Usage phase	Disposal phase
Electrical energy	756.7	592,515.6	56.9	3.78	2,962.58	0.28
Heat energy	637.7	-	-	3.19	-	-

The Finnish electricity mix is defined as being 13 percent gas, 21 percent hydro, 31 percent nuclear, 2 percent oil, 12 percent stone coal, 7 percent lignite coal and 14 percent biomass & waste. The average European electrical energy mix is defined as being 13 percent gas, 17 percent hydro, 30 percent nuclear, 7 percent oil, 20 percent stone coal, 11 percent lignite coal, 1.5 percent biomass & waste and 0.5 percent wind. The resultant resource utilisation is shown in the table above.

Waste	kg / kW
Hazardous waste	
During manufacturing	0.02
At disposal phase	0.11
Regular waste (to landfill)	
During manufacturing phase	0.05
At disposal phase	0.01

The classification data for emissions are as follows:

Environmental effect	Equivalent unit	Manufacturing phase	Usage phase
Global warming potential GWP	kg CO2 / kW	17.617	1,615.789
Acidification potential AP	kmol H+ / kW	0.004	0.329
Eutrophication	kg O2 / kW	0.269	18.058
Ozone depletion potential ODP	kg CFC-11 / kW	0.000	0.000
Photochemical oxidants POCP	kg ethylene / kW	0.006	0.279

Additional qualifying factors

Recycling and disposal

The main parts of the product can be recycled - some parts need to be fragmented to separate different types of material. A list of parts and components that can be fragmented and recycled can be obtained from the manufacturer. See references.

Usage phase in relation to the total

It should be observed that the environmental impact during the usage phase is the most important. As an example, GWP for the usage phase is approximately 92 times larger than GWP for the manufacturing phase.

Category of impact	Usage in % of total
Global warming GWP	99.4 %
Acidification AP	99.0 %
Eutrophication	98.5 %
Ozone depletion ODP	100 %
Photochemical oxidants POCP	98.3 %

References

- LCA report, 3GZF500930-7
- PSR 2000:2 for Rotating Electrical Machines, The Swedish Environmental Management Council
- Machine instructions for Induction Motors, LV Motors/Machine Instructions 00-10
- Recycling instructions, cast iron, steel motors 280-400, Ex-motors 80-400, 3GZF 500930-5.
- MSR 1999:2 Requirements for Environmental Product Declarations, EPD, The Swedish Environmental Management Council

The above mentioned documents are available upon request.

3

GLOSSARY

Acidification, AP
Acidification originates from the emissions of sulphur dioxide and oxides of nitrogen. In the atmosphere, these oxides react with water vapour and form acids which subsequently fall down to the earth in the form of rain or snow, or as dry depositions. Acidification potential translates the quantity of emission of substances into a common measure to compare their contributions to the capacity to release hydrogen ions.

Eutrophication
Nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilised farmland accelerate the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen resulting in oxygen deficiency and fish kill. Eutrophication translates the quantity of emission of substances into a common measure expressed as the oxygen required for the degradation of dead biomass.

Global warming potential, GWP
Some of the gases in the earth's atmosphere (in particular water vapour and carbon dioxide) have an ability to absorb infrared radiation. They do not prevent sunlight reaching the earth's surface, but they do trap some of the infrared radiation emitted back into space causing an increase in the surface temperature. Global Warming Potential, GWP100, translates the quantity of emission of gases into a common measure to compare their contributions - relative to carbon dioxide - to the absorption of infrared radiation in 100 years perspective.

Life cycle assessment, LCA
A management tool for appraising and quantifying the total environmental impact of products or activities over their entire life cycle of particular materials, processes, products, technologies, services or activities. Life cycle assessment comprises three complementary components-inventory analysis, impact analysis and improvement analysis.

Ozone depletion potential, ODP
Ozone forms a layer in the stratosphere protecting plants and animals from much of the sun's harmful UV-radiation. The ozone levels have declined as a consequence of CFCs and halons released into the atmosphere. A depletion of the ozone layer will increase the UV-radiation at ground level. Ozone depletion potential translates the quantity of emission of gases into a common measure to compare their contributions - relative to CFC-11 (a freon) - to the breakdown of the ozone layer.

Photochemical ozone creation, POCP
Photochemical ozone or ground level ozone is formed by the reaction of volatile organic compounds and nitrogen oxides in the presence of heat and sunlight. Ground-level ozone forms readily in the atmosphere, usually during hot summer weather. Photochemical ozone creation potential translates the quantity of emission of gases into a common measure to compare their contributions - relative to ethylene - to the formation of photochemical oxidants.

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LV Motors/EPD M3BP315 GB 05-2002
3GZF500931-22

Motor Technical Data Sheet

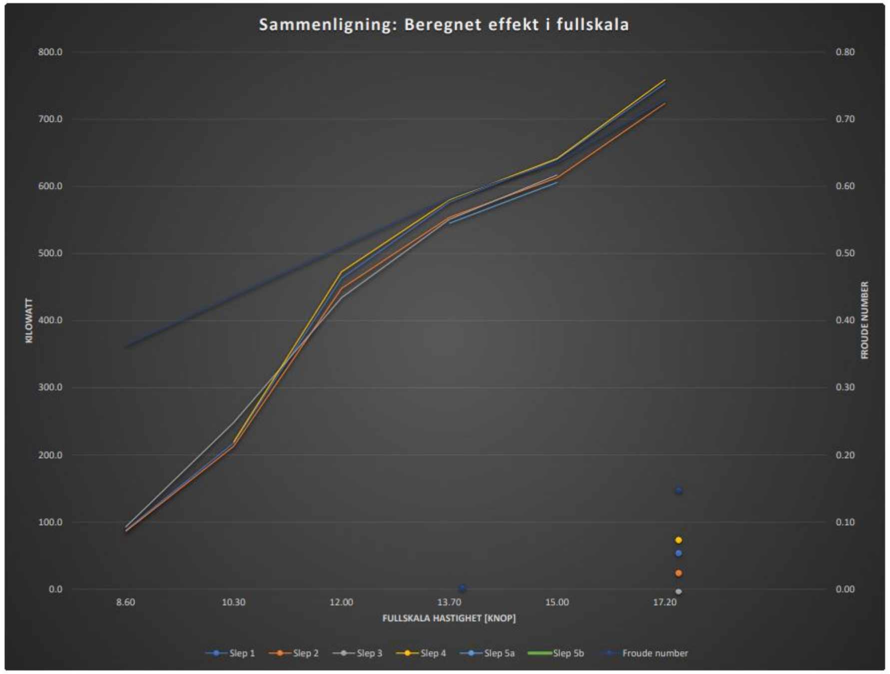
Item No.	1.1.1	**M3BP 355MLC 4**

Specifications		**Catalogue data**	
Name	[undefined]	Product code	3GBP352430-ADM
No.of motors	1	Voltage [V]	690
Motor type	IEC 34 motor	Frequency [Hz]	50
ProductionUnit	Not specified	Power [kW]	450
FrameMaterial	Not specified	Poles	4
Family	Not specified	Speed [rpm]	1489
Polenumber	Automatic	Max mech.speed [rpm]	2000
Term. box location	Top	Current [A]	452
Efficiency	Not specified	Torque [Nm]	2886
Winding	Standard and restamp	Tmax/Tn	2,8
Design	Not specified	Power factor	0,86
Connection	Not specified	Efficiency [%]	96,6
IP class	IP55	Efficiency class	IE4
IC class	IC411 self ventilated	Winding	standard
IM class	IM1001, B3(foot)	Temperature rise class	B
Max. speed rule	Standard	Insulation class	F
Insulation	Special	Temperature rise [K]	80
Temp. rise	B (<80 K)	Inertia [kgm2]	8,4
Temp reserve	Utilize		
Tmax margin	43 %		

Load type	**Pump/fan load**		**Calculations**	**Requirec**	**Result**	**Margin**
Overload Type	Simple		Torque [Nm]			
n min [rpm]	1500		n base	2387	2496	5 %
n base [rpm]	1500		Power [kW]			
n max [rpm]	1500		n base	375	392	5 %
Pbase [kW]	375		Overload [Nm]			
Olbase [%]	100		n base	2387	4925	106 %
Olmax [%]	100					
Temperature [°C]	40					
Altitude [m]	1000					
Ol definition:	RMS 10min					
1500-1500 rpm / 100 %		590s				
1500-1500 rpm / 100 %		10s				

Result is computed with Utilizing temperature reserve

Appendix B



			Beregnet effekt fullskala [kW]					
Fullskala [knop]	Modellskala [m/s]	Fn	Slep 1: Uten turb. stim. 49 tonn	Slep 2: Med turb. stim. 49 tonn	Slep 3: Foil 0 grader	Slep 4: Med turb. stim. 50,37 tonn	Slep 5a: Foil -2 grader	Slep 5b: Foil + 2 grader
8.60	1.25	0.36	88.1	86.4	92.9			
10.30	1.50	0.44	217.7	212.9	248.3	219.3		
12.00	1.75	0.51	463.3	448.1	434.2	472.8		
13.70	2.00	0.58	576.2	553.7	550.7	579.8	545.0	
15.00	2.18	0.64	640.1	612.9	616.9	641.3	605.8	636.1
17.20	2.50	0.73	753.4	723.8		758.9		

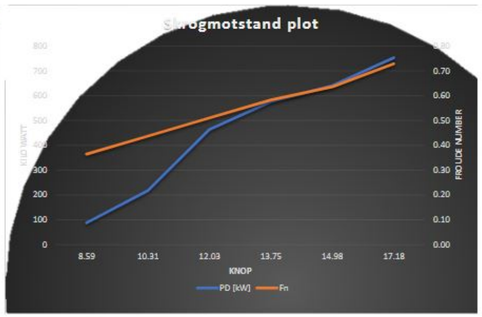
Fullskala testing		
kt	Pe	
13.2	1000	
13.2	543	
	84.2	% error

Differanse Slep 5a - Slep 4 (reduksjon i beregnet fullskala effekt, ekskludert frisksjonsmotstand fullskala foiler)				
Fullskala [knop]	Slep 4	Slep 5a	[kW]	[%]
13.7	579.8	545.0	-34.8	-6.00
15	641.3	605.8	-35.6	-5.54

Slepeforsøk		Skala	12.5
Kjøring 1, depl. 49 tonn. Uten turbulensstimulator			
Parameter		Fullskala (sjø)	Modell (ferskvann)
Lwl	m	14.99	1.199
B	m	2.556	0.204
T	m	1.53	0.122
Δ	t	50	0.026
Cb		0.407	0.407
S (våt overflate)	m2	108.3	0.693
ρ	kg/m3	1025	998.7
FORMFAKTOR (MARINTEK)			
(k+1)		1.123	
phi		0.107	
VANN SPESIFIKASJON			
Vanntemperatur v. forsøk	C	15.00	15.00
Kin. viskositet	m2/s	1.1892E-06	1.1386E-06
LUFTMOTSTAND			
Cd			0.8
AT (Projisert tverr. areal)	m2	51	0.12
ρ luft	kg/m3		1.23
Caa (luftmotstandskoeff.)			8.20E-05
RUHETSTILLEGG(ΔCF)			
Ruhet	µm	200	
Ca (korreksjonsfaktor)		0.0004	
VIRKNINGSGRADER			
η propell		0.65	
η aksling		0.98	
η gir		0.95	
η total		0.60515	

Resultat slepeforsøk

Nr.	Vm [m/s]	Vm [kn]	RTm [N]	Ctm	Rnm	Cfm	Fn	Cr
1	0.10	0.19		0.00E+00	1.05E+05	8.21E-03		-9.30E-03
2	0.13	0.24		0.00E+00	1.32E+05	7.71E-03		-8.74E-03
3	0.15	0.29		0.00E+00	1.58E+05	7.33E-03		-8.32E-03
4	0.20	0.39		0.00E+00	2.11E+05	6.79E-03		-7.71E-03
5	0.25	0.49		0.00E+00	2.63E+05	6.41E-03		-7.28E-03
6	0.30	0.58		0.00E+00	3.16E+05	6.12E-03		-6.96E-03
7	0.40	0.78		0.00E+00	4.21E+05	5.71E-03		-6.49E-03
8	0.50	0.97		0.00E+00	5.27E+05	5.42E-03		-6.16E-03
9	0.75	1.46		0.00E+00	7.90E+05	4.94E-03		-5.63E-03
10	1.00	1.94		0.00E+00	1.05E+06	4.64E-03		-5.29E-03
11	1.25	2.43	6.73	1.24E-02	1.32E+06	4.42E-03	0.36	7.40E-03
12	1.50	2.92	13.27	1.70E-02	1.58E+06	4.25E-03	0.44	1.22E-02
13	1.65	3.21		0.00E+00	1.74E+06	4.17E-03		-4.77E-03
14	1.70	3.30		0.00E+00	1.79E+06	4.15E-03		-4.74E-03
15	1.75	3.40	23.63	2.23E-02	1.84E+06	4.12E-03	0.51	1.76E-02
16	1.85	3.60		0.00E+00	1.95E+06	4.08E-03		-4.66E-03
17	2.00	3.89	25.76	1.86E-02	2.11E+06	4.01E-03	0.58	1.40E-02
18	2.18	4.24	26.32	1.60E-02	2.30E+06	3.94E-03	0.64	1.15E-02
19	2.50	4.86	27.11	1.25E-02	2.63E+06	3.84E-03	0.73	8.14E-03



ITTC: Beregnet fullskala motstand

Nr.	Vm [m/s]	Vs [kn]	Rns	Cfs	ΔCF	ΔCF (+)	Cts	Rluft (kN)	Rts [kN]	Rtotal [kN]	Pe [kW]	PD [kW]	PD [HK]
1	0.35	0.69	4.46E+06	3.47E-03	-1.61E-03	0.00E+00	-5.01E-03	3.14E-03	-3.47E-02	-3.16E-02	0.0	0.0	0.0
2	0.44	0.86	5.57E+06	3.33E-03	-1.34E-03	0.00E+00	-4.60E-03	4.90E-03	-4.99E-02	-4.50E-02	0.0	0.0	0.0
3	0.53	1.03	6.68E+06	3.22E-03	-1.14E-03	0.00E+00	-4.30E-03	7.06E-03	-6.71E-02	-6.00E-02	0.0	-0.1	-0.1
4	0.71	1.37	8.91E+06	3.06E-03	-8.55E-04	0.00E+00	-3.87E-03	1.25E-02	-1.07E-01	-9.49E-02	-0.1	-0.1	-0.2
5	0.88	1.72	1.11E+07	2.94E-03	-6.62E-04	0.00E+00	-3.58E-03	1.96E-02	-1.55E-01	-1.35E-01	-0.1	-0.2	-0.3
6	1.06	2.06	1.34E+07	2.85E-03	-5.18E-04	0.00E+00	-3.35E-03	2.82E-02	-2.09E-01	-1.81E-01	-0.2	-0.3	-0.4
7	1.41	2.75	1.78E+07	2.72E-03	-3.14E-04	0.00E+00	-3.04E-03	5.02E-02	-3.37E-01	-2.87E-01	-0.4	-0.7	-0.9
8	1.77	3.44	2.23E+07	2.62E-03	-1.72E-04	0.00E+00	-2.82E-03	7.84E-02	-4.89E-01	-4.11E-01	-0.7	-1.2	-1.6
9	2.65	5.15	3.34E+07	2.46E-03	5.16E-05	5.16E-05	-2.41E-03	1.76E-01	-9.40E-01	-7.64E-01	-2.0	-3.3	-4.6
10	3.54	6.87	4.46E+07	2.35E-03	1.89E-04	1.89E-04	-2.04E-03	3.14E-01	-1.41E+00	-1.10E+00	-3.9	-6.4	-8.7
11	4.42	8.59	5.57E+07	2.27E-03	2.85E-04	2.85E-04	1.07E-02	4.90E-01	1.16E+01	1.21E+01	53.3	88.1	119.7
12	5.30	10.31	6.68E+07	2.21E-03	3.57E-04	3.57E-04	1.55E-02	7.06E-01	2.41E+01	2.48E+01	131.8	217.7	296.1
13	5.83	11.34	7.35E+07	2.18E-03	3.93E-04	3.93E-04	-1.48E-03	8.54E-01	-2.79E+00	-1.94E+00	-11.3	-18.7	-25.4
14	6.01	11.68	7.58E+07	2.17E-03	4.04E-04	4.04E-04	-1.45E-03	9.06E-01	-2.91E+00	-2.00E+00	-12.0	-19.9	-27.0
15	6.19	12.03	7.80E+07	2.16E-03	4.14E-04	4.14E-04	2.09E-02	9.61E-01	4.44E+01	4.53E+01	280.3	463.3	630.0
16	6.54	12.72	8.24E+07	2.14E-03	4.34E-04	4.34E-04	-1.37E-03	1.07E+00	-3.24E+00	-2.17E+00	-14.2	-23.4	-31.9
17	7.07	13.75	8.91E+07	2.12E-03	4.61E-04	4.61E-04	1.73E-02	1.25E+00	4.81E+01	4.93E+01	348.7	576.2	783.6
18	7.71	14.98	9.72E+07	2.09E-03	4.90E-04	4.90E-04	1.48E-02	1.49E+00	4.88E+01	5.03E+01	387.4	640.1	870.5
19	8.84	17.18	1.11E+08	2.05E-03	5.34E-04	5.34E-04	1.14E-02	1.96E+00	4.96E+01	5.16E+01	455.9	753.4	1024.6

Appendix C

SCANIA

Date :

Environmental Product Declaration and Material Declaration

Regarding vehicle / engine:

Type of engine:	Power:	Emission: According to table below
SDoC ID No.:		

Manufacturer	Environmental information: www.scania.com
Scania CV AB	Scania Corporate Communications
SE-151 87 Södertälje, Sweden	Telephone: +46 8 553 81000

SCANIA IN GENERAL

Scania constantly works with the environmental characteristics of its vehicles and lower resource consumption and raise efficiency in its production system as much as possible.
Scania is implementing an Environmental Management System and is certified according to the standard ISO 14001 (environment) and ISO 9001 (quality). Scania's environmental work is described in the Scania Annual Report.

SCANIA ENVIRONMENTAL POLICY

Scania continuously improves the environmental performance of its products, processes and services.
Business demands and other requirements form the basis for improvement, where fulfilment of legislation is fundamental.

Scania's environmental work is proactive, based on a life-cycle perspective and the principle of precaution.

ENGINE EMISSIONS

Exhaust emissions requirements, for engine group (g/kWh)

Valid emission	Regulation	NOx	HC	NOx+HC	PM	CO	Segment	Region
☐	**Stage I**	-	-	7,2	0,2	5,0	Marine	China
☐	**Stage II**	-	-	5,8	0,12	5,0		
☐	**Stage IIIA** (Inland Waterway Vessels)	-	-	7,2	0,2	-	Marine propulsion	Europe
☐	**CCNR II**	6,0	1,0	-	0,2	-	Marine River Rhine	
☐	**Tier 2**	-	-	7,2	0,2	-	Marine Commercial	USA
☐	**Tier 2**	-	-	7,2	0,2	-	Marine Recreational	
☐	**Tier 3**	-	-	5,6	0,11	-	Marine Commercial (<35 kW/l)	
☐	**Tier 3**	-	-	5,8	0,12	-	Marine Commercial (>35 kW/l)	
☐	**Tier 3**	-	-	5,8	0,12	-	Marine Commercial (>600 kW)	
☐	**Tier 3**	-	-	5,8	0,12	-	Marine Recreational	
☐	**Tier 4**	1,8	0,19	-	0,04	-	Marine Commercial (>600 kW)	
☐	**IMO Tier II**	NOx: 8.2-7.7 (1500-2000 rpm)					Marine	International
☐	**IMO Tier III***	NOx: 2.0 (in US and Barbados NECA zone)						

☒Please tick appropriate

*Will be valid in NOx ECA (Emission Control Areas). For other areas IMO Tier II will continue.

VOLUME OF OILS AND LIQUIDS IN PRODUCT

Other oils	Litres DI9	Litres DI13	Litres DI16	Remark
Engine oil	37	37	49	Valid for engine with standard oil sump

Other oils	Litres	Litres	Litres	Remark
Coolant liquid	30	40	63	Valid for engine with heat exchanger
Coolant liquid	18	24	53	Valid for engine with keel cooling

ENGINE EXHAUST NOISE EMISSIONS

Exhaust noise emissions*	Sound level dB(A)	1/3 octave band (Hz)
1500 rpm		63 + 125
1800 and 2100 rpm		80 + 160

*Applies for non silenced exhaust noise measured 1m after turbocharger at maximum power

MATERIAL CONTENTS AND RECYCLING

Material class [excl. fuel weight]	Weight share DI9	Weight share DI13	Weight share DI16
Metals	94,0 %	94,0 %	94,0 %
Polymers	1,0 %	1,0 %	1,0 %
Elastomers	0,4 %	0,4 %	0,4 %
Fluids	4,4 %	4,4 %	4,4 %
MONM*	0,3 %	0,3 %	0,3 %
Others	0,01%	0,01%	0,01%

* modified organic natural materials, such as leather, wood, cardboard and cotton fleece

Recyclability and recoverability (ISO 22628)	
Recyclability rate**	98,4 %
Recoverability rate	99,99 %

** No dismantling considered; only pre-treatment of fluids

Proposed recycling method for engine	
Scrap metal	Material recycling
Plastics	Material recycling, energy recovery
Batteries	Material recycling
Chemicals/oils	Reuse if possible. Material recycling, otherwise destruction by an approved company
Fuel- and oil filter	Material recycling, otherwise destruction by an approved company.
Paint	No known methods. Energy recovery.
Electronics	Material recycling

Dismantling information is published on Scania Technical Information Library (https://til.scania.com/).

CHEMICALS AND HAZARDOUS SUBSTANCES IN PRODUCTS

For information on safe handling and content of chemical products you can find the (Material) Safety Data Sheets on Scania Technical Information Library.

Information on substances of very high concern listed on the Candidate List in concentrations above 0,1% weight by weight in the article according to article 33 of REACH legislation can be found in the REACH information sheets for the affected part numbers on Scania Technical Information Library.

No asbestos in Scania's products.

For more information on Scania's responsible use on chemicals in products and processes see Scania homepage on http://www.scania.com/sustainability/how-scania-works/responsible-chemicals-use/.

OTHER ENVIRONMENTAL EQUIPMENT AND PRODUCTS

Environmental equipment/products		

Material Declaration (MD)

INTRODUCTION

This material declaration was issued under the provisions of IMO MEPC.197(62) Appendix 1, EU Regulation No 1257/2013 Annex I/II and Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, Inventory of Hazardous Materials (IHM). This document declares the amount of hazardous materials and substances contained in 1 piece of the supplied product.

HAZARDOUS MATERIALS AND SUBSTANCES IN THE SUPPLIED PRODUCT

Table A: Obligatory for supplied products in new and existing ships

Material/Substance name		Thres hold	Present above threshold level?	If Yes, specify substance mass		If Yes, give information on where it is used
			Yes / No	Mass	Unit	
Asbestos		-*	No	-	-	-
Polychlorinated biphenyls (PCBs)		-*	No	-	-	-
Ozone depleting substance	Chlorofluorocarbons (CFCs)	-*	No	-	-	-
	Halons	-*	No	-	-	-
	Other fully halogenated CFCs	-*	No	-	-	-
	Carbon tetrachloride	-*	No	-	-	-
	1,1,1-Trichloroethane	-*	No	-	-	-
	Hydrochlorofluoro-carbons	-*	No	-	-	-
	Hydrobromofluoro-carbons	-*	No	-	-	-
	Methyl bromide	-*	No	-	-	-
	Bromochloro-methane	-*	No	-	-	-
Anti-fouling systems containing organotin compounds as a biocide		-*	No	-	-	-
Perfluorooctane sulfonic acid (PFOS)		-*	No	-	-	-

Table B: Obligatory for supplied products in new ships and installations; Voluntary for supplied products in existing ships

Material/Substance name	Thres hold	Present above threshold level?	If Yes, specify substance mass		If Yes, give information on where it is used
		Yes / No	Mass	Unit	
Cadmium and cadmium compounds	0,01%	No	-	-	-
Hexavalent chromium and hexavalent chromium compounds	0,1%	Yes	400	mg	Screws, washers, nuts, bolts (surface treatment) [≈50 parts]
Lead and lead compounds	0,1%	Yes	500	g	Sensors, electronics (soldering), bearings, bushings, valves, banjos, bolts, pins, plugs [≈80 parts]
Mercury and Mercury Compounds	0,1%	No	-	-	-
Polybrominated Biphenyl (PBBs)	0,1%	No	-	-	-
Polybrominated Dephenyl Ethers (PBDEs)	0,1%	No	-	-	-
Polychlorinated Naphthalanes(Cl >3)	-*	No	-	-	-
Radioactive Substances	-*	No	-	-	-
Certain shortchain chlorinated paraffins (Alkanes, C10-C13, chloro)	1%	No	-	-	-
Brominated Flame Retardant (HBCDD)	-*	No	-	-	-

*Any intentionally added content

Appendix D

Engineering Manual

For

Scania DI13 70M (HE)

HC-258

Propulsion

Document number: T92-14443-01

B-96, Mundal Båt AS

Nogva Contract number: 14443

NOGVA MOTORFABRIKK AS
N-6280 SØVIK
T: +47 70 20 84 00
F: +47 70 20 84 01
E-POST: firmapost@nogva.no
> nogva.no

NOGVA

Drawing No.	Table of Contents	Revision
	1. Specifications	
T93-1211	Basic engine data, Scania DI13 070M/080M-series	
T93-1229	Scania DI13 070M (HE) 500 HP / 1800 rpm	
T93-1526	Nogva HC-258	
	2. Installation Drawing	
T91-07251	Fremdrift, Scania DI13 (HE), HC-258, Flex mount, Flex susp,	
T92-14443-70	Propeller, N4-260-85, Water lub, Stainless	Rev02
	3. Engine Connection	
T93-1103	Engine connections, Scania DI13 (HE)	
	4. Electrical System	
T92-14443-11	Interface EMS, DI13 + HC-258	
T92-14443-12	System block diagram, Scania DI13 70M	
T91-06806	Nogva, HCK-Main and HCK-Remote + Slave	
	5. System Drawings	
T91-05342	Fuel system Scania DI9 og DI13	
T91-05819	Cooling system, Scania DI9 & DI13 (HE), Gear cooler	
T91-05611	Exhaust system, Scania DI13, Wet system,	
T91-05343	Lub oil system, Scania DI13	
	6. Equipment Drawings	
T91-05441	Nogva Motor Computer terminal T3	
T91-05515	Fuel filter, Racor 75-900MAXM	
T91-06616	Nogva Gear control - main unit, HCK-MAIN	
T91-06615	Nogva Gear control - slave unit, HCK-SLAVE	
T91-06614	Nogva Gear control - remote unit, HCK-REMOTE	
	7. Installation Instructions	
T93-1038	Fuel System, Scania general (DI9 DI13 DI16)	
T93-1039	Cooling System, Scania general (DI9 DI13 DI16)	
T93-1040	Exhaust system, Scania general (DI9 DI13 DI16)	
T93-1114	Lubrication system, Scania DI13	
T93-1041	Air intake system, Scania general (DI9 DI13 DI16)	
T93-1336	Measuring instructions for, Scania general	
T93-1334	Engine, Scania general (DI9 DI13 DI16)	
	8. Technical Manuals	
T93-1105	Operators manual, Scania DI13 (Separate document)	
T93-1855	Manual, Nogva HC-258 (Separate document)	
T93-1541	Nogva Motor Computer V2-P/G (Separate document)	

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1.Specifications

NOGVA MOTORFABRIKK AS
N-6280 SØVIK

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Basic data

General

Configuration and number of cylinders	6 in-line	
Working principle	4-stroke	
Bore x stroke	130 x 160	mm
Displacement	12.7	dm^3
Compression ratio		
DI13 070//071/072/073/077/078M	16.3:1	
DI13 080/081/082M	17.3:1	
Firing order	1 - 5 - 3 - 6 - 2 - 4	
Piston speed		
at 1500 rpm	8.0	m/s
at 1800 rpm	9.6	m/s
Pistons	Steel pistons	
Camshaft	High position alloy steel	
Connection rods	I-section press forgins of alloy steel	
Crankshaft	Alloy steel with hardened and polished bearing surfaces	
Rotation, seen from flywheel end	Counter clockwise	
Total moment of inertia with flywheel		
SAE 14	3.11	kgm^2
Number of teeth on flywheel ring gear	158	
Weight approx. (excl. oil and coolant)		
with heat exchanger	1190	kg
with keel cooling	1140	kg

Lubrication system

Oil capacity (deep front oil sump with ladder frame)		
min	39	dm^3
max	45	dm^3
Oil consumption	<0.2	g/kWh
Oil change intervals	500	h
Oil grade		
engines run on low-sulphur fuel	ACEA E5 or E7	
engines not run on low-sulphur fuel	Total Base Number (TBN) at least 12 (ASTM 2896)	
Oil pressure		
normal	3-6	bar
minimum permitted at idle speed	0.7	bar
Oil temperature		
normal	90-110	°C
Oil cleaner	Centrifugal	
filtration	5-7	Micron
Oil filter	Paper/Full flow	
Oil cooler	Water cooled/Full flow	

Injection system

Type	Unit injectors
Governor	Scania Engine Management System, EMS
Fuel filter	Paper filter element

SCANIA DATA HANDBOOK
Marine all-speed engines

Engine data
13-series

Cooling system

Coolant volume		
with heat exchanger	40	dm^3
with keel cooling, single circuit	24	dm^3
with keel cooling, double circuit	20	dm^3
Coolant temperature		
with heat exchanger	90-95	°C
with keel cooling	83-88	°C
Number of thermostats	1	
Opening temperature		
with heat exchanger	80/87	°C
with keel cooling	75	°C

Intake system

Permissible pressure drop in intake system with cleaned or new filter	30	mbar
Permissible pressure drop in intake system with blocked (dirty) filter	65	mbar

Electrical system

Type	2-pole, 24V, DC
Starter, standard equipment	2-pole, 24V, 7.0 kW
Alternator, standard equipment	2-pole, 28V, 100A

5A

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SCANIA DATA HANDBOOK Marine all-speed engines — Engine data 13-series

Technical data

DI13 070M, 368 kW / 500 hp - With heat exchanger (engine ref. 03-03)

Emission compliance	Fuel injection system	Rating
EU Stage IIIA, US Tier 2, IMO Tier II	PDE	ICFN, Continous service

	Engine speed (rpm)				Unit
	1200	1500	1700	1800	
Gross power					
Full load curve	292	350	368	368	kW
	396	476	500	500	hp
Propeller curve (assumed exponent 2.5)	134	233	319	368	kW
	182	317	434	500	hp
Gross torque	2320	2227	2067	1952	Nm
Spec. fuel consumption					
full load	192	191	196	200	g/kWh
3/4 load	193	196	203	207	g/kWh
1/2 load	197	202	206	216	g/kWh
Propeller curve (assumed exponent 2.5)	32	56	77	88	l/h
Heat rejection					
to coolant	194	228	255	267	kW
to exhaust gas	174	209	225	235	kW
to surrounding air	13	16	17	18	kW
Air consumption	19	27	31	32	kg/min
Pressure in intake manifold	1.5	1.8	1.8	1.8	Bar
Exhaust flow	20	28	32	33	kg/min
Exhaust temperature	489	436	416	417	°C

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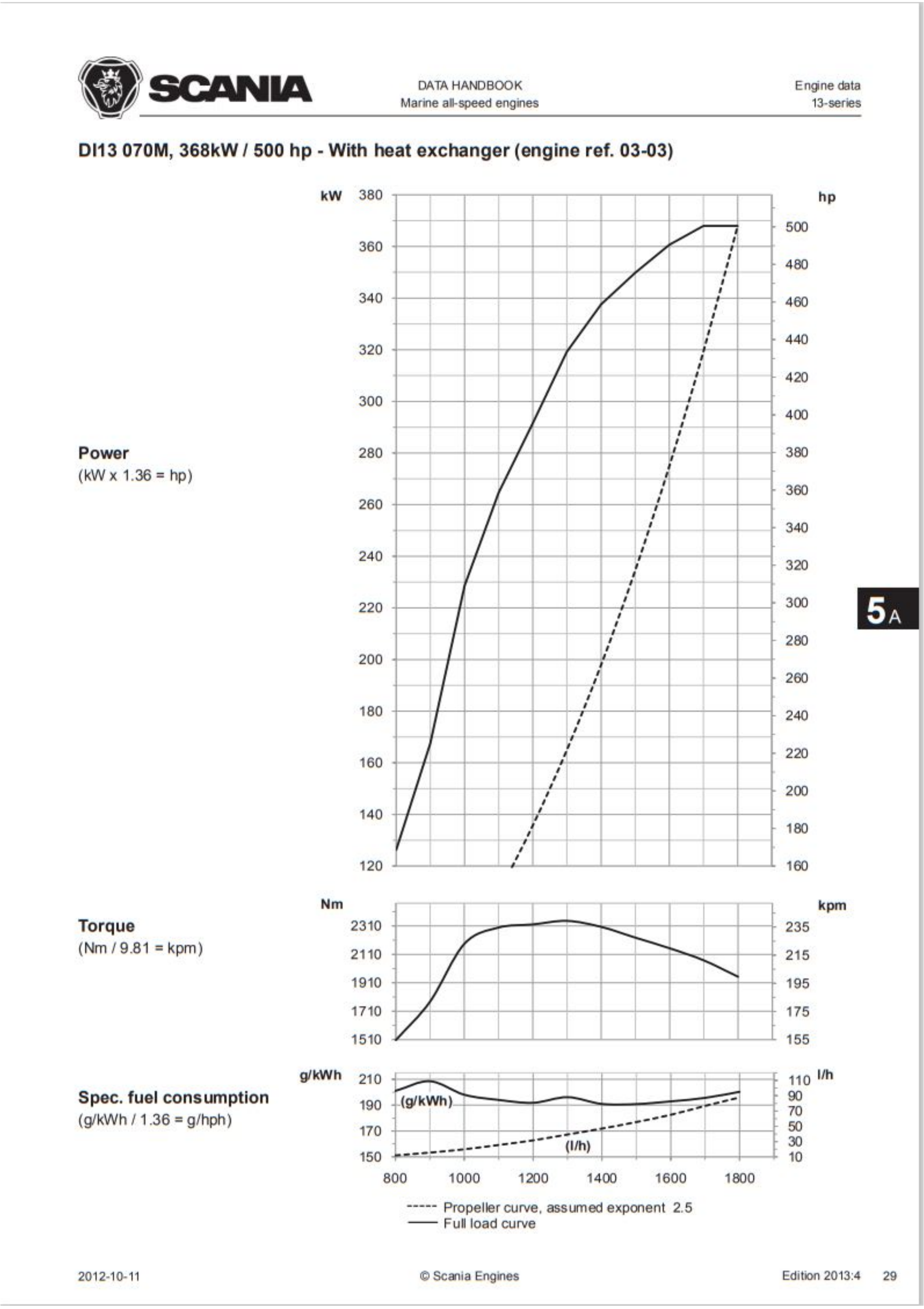
SCANIA
DATA HANDBOOK
Marine all-speed engines
Engine data
13-series
DI13 070M, 368kW / 500 hp - With heat exchanger (engine ref. 03-03)
Power
(kW x 1.36 = hp)
kW
hp
Torque
(Nm / 9.81 = kpm)
Nm
kpm
Spec. fuel consumption
(g/kWh / 1.36 = g/hph)
g/kWh
l/h
(g/kWh)
(l/h)
800
1000
1200
1400
1600
1800
Propeller curve, assumed exponent 2.5
Full load curve
5A
2012-10-11
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Edition 2013:4
29

NOGVA

NOGVA GEAR HC-258

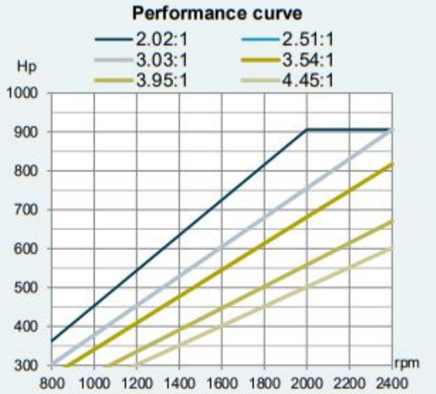
> 37,7 HP @ 100 RPM (3.03:1)

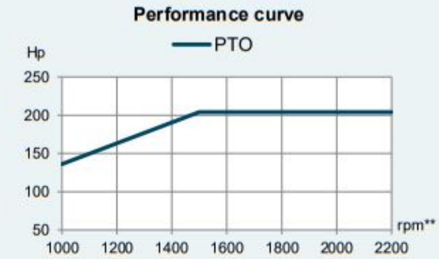
- Servo for CPP
- Optional with 1 or 2 PTO's
- Propeller shaft break built in
- Hydraulic multiplate clutch
- Controlled in test bench
- More than 3000 gearboxes on the market

Nogva Gearbox HC-258

Built-in servo for CPP. Construction in rigid cast iron house, helical gearwheels, conical roller bearings and hydraulic multiplate clutch. Individually controlled in test bench.

Technical specifications	
Connection flange	SAE 1
Flexible coupling	SAE 14"
Weight with 1 PTO	620 kg (SAE 1)
Weight with 2 PTO	660 kg (SAE 1)
Servo force	83 000 N
Servo stroke	85 mm
Rotation (outgoing shaft)	Clockwise
Maximum torque	
Reduction	Torque
2.02:1	3180 Nm
2.51:1	2650 Nm
3.03:1	2650 Nm
3.54:1	2390 Nm
3.95:1	1960 Nm
4.45:1	1760 Nm
Power take off (PTO)	
Ratio	1:1.16
Torque	955 Nm
Max power	150 kW
Flange	SAE C 12/24 DP (standard)
Pump rotation	Clockwise





**rpm on PTO

Doc. no: T93-1526

NOGVA GEAR HC-258

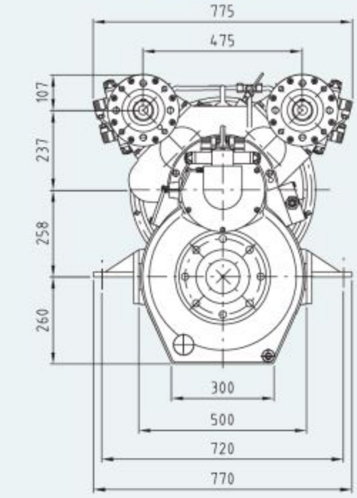
Standard equipment

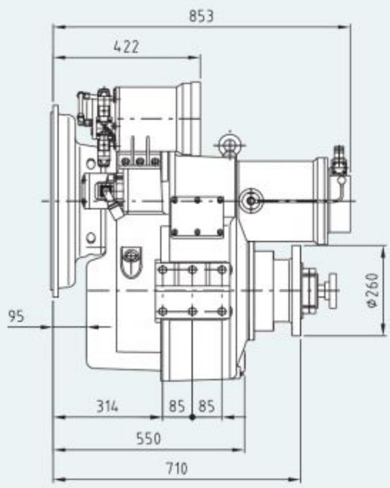
- Oil pump
- Oil cooler
- Oil filter
- Flexible coupling

Optional equipment

- Nogva CPP
- HC-gear control
- Monitoring (oil temperature/pressure)

Dimensions





* SAE 1 and SAE 2

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Appendix E

corvus energy

Orca ESS (Energy Storage System)

Orca Energy Battery Recycling

A	Release to Customers	JS	2018-11-13
0	Release for Comment	AZ	2018-10-02
REV	DESCRIPTION	BY	(YYYY-MM-DD)

Orca Energy Battery Recycling		Document Number
Page 1 of 2		1013343 Rev A

corvus energy

Corvus Energy's Lithium Ion batteries are fully serviceable and are 99% recyclable by weight.

Our experienced team of professionals are able to repair our batteries - whether it is to replace Printed Circuit Boards, Damaged Connectors or even a single Lithium Ion cell.

Corvus can also dispose of the batteries at their end of life ensuring that all battery components are recycled using the top recycling processes to minimize waste.

Lithium Ion Cell Recycling

Cells are placed in Liquid Nitrogen to minimize reactivity

↓

Cells are shredded

↓

Scrap metal and plastic from the cells is recovered and recycled producing:
- Copper
- Aluminum
- Carbon
- Nickel

↓

Lithium Carbonate is recovered and used in the steel industry
97% of the Lithium Cells are recyclable which makes up 42% of the weight of the battery.

Plastics Recycling

Plastics are identified and separated into different types for processing

↓

The waste plastic is washed to remove impurities

↓

The plastics are shredded into small pellets and bagged

↓

Recycled plastics are used to make new plastic parts

The battery plastics are 100% fully recyclable

Circuit Boards and Wires Recycling

Printed Circuit Boards are shredded and smelted.
Wires are sorted and smelted

↓

Precious metals are recovered and recycled including:
- Copper
- Gold
- Zinc

Typically able to recover up to 99% of precious metals used to make the boards

↓

Cables are sorted and smelted for copper recovery producing
- Copper

98% of the circuit boards and wires are recyclable which makes up 0.8% of the weight of the battery.

Metal Recycling

Metals are identified and separated into different types for processing

↓

Metal being recovered is comprised of :

- Aluminum
- Copper
- Steel

Several processes may be used to separate different types of metal including
- Magnetic Drums
- Eddy Current Separators
- Induction Sorting Systems
- Hand-picking

The battery metals are 100% recyclable

Orca Energy Battery Recycling		Document Number
Page 2 of 2		1013343 Rev A

Attachments

The main task of this project is collecting data and using it to make a CO_2 calculator. The following attachments are screenshots of the CO_2 calculator.

CO2 Emissions Summary

Electric engine system

Year	Process	Part	Yearly CO2 emission [kg]	Total CO2 emission [kg]
0	Manufacturing	Electric engines	5 977,11	42 116,76
		Batteries	35 527,80	
	Transport	Electric engines + materials	341,80	
		Batteries	270,05	
1	Operation	Power system	34,92	42 151,68
2	Operation	Power system	34,92	42 186,60
3	Operation	Power system	34,92	42 221,52
4	Operation	Power system	34,92	42 256,44
5	Operation	Power system	34,92	42 291,36
6	Operation	Power system	34,92	42 326,28
7	Operation	Power system	34,92	42 361,20
8	Operation	Power system	34,92	42 396,12
9	Operation	Power system	34,92	42 431,04
10	Manufacturing	Batteries	35 527,80	78 263,81
	Transport	Batteries	270,05	
	Operation	Power system	34,92	
11	Operation	Power system	34,92	78 298,73
12	Operation	Power system	34,92	78 333,65
13	Operation	Power system	34,92	78 368,57
14	Operation	Power system	34,92	78 403,48
15	Operation	Power system	34,92	78 438,40
16	Operation	Power system	34,92	78 473,32
17	Operation	Power system	34,92	78 508,24
18	Operation	Power system	34,92	78 543,16
19	Operation	Power system	34,92	78 578,08
20	Operation	Power system	34,92	78 613,00
Total CO2 Emission Electric Engine [kg]			**78 613,00**	

Diesel engine system

Year	Process	Part	Yearly CO2 emission [kg]	Total CO2 emission [kg]
0	Manufacturing	Diesel engines	2 704,77	2 931,92
	Transport	Diesel engines + materials	227,15	
1	Operation	Power system	58 887,11	61 819,03
2	Operation	Power system	58 887,11	120 706,14
3	Operation	Power system	58 887,11	179 593,25
4	Operation	Power system	58 887,11	238 480,37
5	Operation	Power system	58 887,11	297 367,48
6	Operation	Power system	58 887,11	356 254,59
7	Operation	Power system	58 887,11	415 141,70
8	Operation	Power system	58 887,11	474 028,81
9	Operation	Power system	58 887,11	532 915,92
10	Operation	Power system	58 887,11	591 803,03
11	Operation	Power system	58 887,11	650 690,14
12	Operation	Power system	58 887,11	709 577,25
13	Operation	Power system	58 887,11	768 464,37
14	Operation	Power system	58 887,11	827 351,48
15	Operation	Power system	58 887,11	886 238,59
16	Operation	Power system	58 887,11	945 125,70
17	Operation	Power system	58 887,11	1004 012,81
18	Operation	Power system	58 887,11	1062 899,92
19	Operation	Power system	58 887,11	1121 787,03
20	Operation	Power system	58 887,11	1 180 674,14
Total CO2 Emission Diesel Engine [kg]			**1 180 674,14**	

Manufacturing of fully electric engine power system
Including engine and battery solution

			1. Choose category		2. Choose region / country / organization				3. Fill in number of engines		
Engine	**Weight of engine [kg]**	**Materials**	**Material category**	**Share of material in engine [%]**	**Production region / country / organization**	**kg CO2 / kg material produced**	**kg CO2 from material**	**CO2 emissions from engine**	**Total engines in vesssel**	**Total CO2 emissions from engine production [kg]**	**% of engine manufacturing**
ABB electric engine	2140	Electric steel	Steel	51,72%	EU	1,209	1338,24	2 988,56	2	**5 977,11**	97,66%
		Other steel	Steel	8,85%	EU	1,209	228,93				
		Cast iron	Steel	29,60%	EU	1,209	765,91				
		Aluminium	Aluminum	1,56%	EU	4,070	136,00				
		Copper	Copper	5,92%	World average (ICA members)	4,100	519,48				
		Insulation material	Other	0,39%	N/A	N/A	N/A				
		Wooden packing material	Other	0,98%	N/A	N/A	N/A				
		Impregnation resin	Other	0,46%	N/A	N/A	N/A				
		Paint	Other	0,52%	N/A	N/A	N/A				
							2 333,08				

			1. Fill in number of modules		2. Fill inn number of packs		3. Choose location		
Battery	**System specifications**		**Battery pack**		**Battery system**		**Production location**	**Manufacturing [kg CO2e / kWh]**	**Total CO2 emissions from battery system [kg]**
Corvus Dolphin Energy	Single module size [kWh]	11	Modules	7	Packs	3	China	153,8	**35 527,80**
	Single module size [VDC]	128	Energy [kWh]	77	Energy [kWh]	231			
	Max gravimetric density - pack [Wh / kg]	177	Voltage (max) [VDC]	896	Voltage (max) [VDC]	896			
	Max gravimetric density - pack [kg / kWh]	5,6	Weight [kg]	431	Weight [kg]	1294			

Manufacturing of diesel engine power system
Diesel engine

			1. Choose category		2. Choose region / country / organization				3. Fill in number of engines		
Engine	**Weight of engine [kg]**	**Materials**	**Material category**	**Share of material in engine [%]**	**Production region / country / organization**	**kg CO2 / kg material produced**	**kg CO2 from material**	**CO2 emissions from engine**	**Total engines in vesssel**	**Total CO2 emissions from engine production [kg]**	**% of engine manufacturing**
Scania diesel engine	1190	Metals	Steel	94,00%	EU	1,209	1352,39	1352,39	2	**2 704,77**	94,00%
		Polymers	Other	1,00%	N/A	N/A	N/A				
		Elastomers	Other	0,40%	N/A	N/A	N/A				
		Fluids	Other	4,40%	N/A	N/A	N/A				
		MONM*	Other	0,30%	N/A	N/A	N/A				
		Other	Other	0,01%	N/A	N/A	N/A				

Transportation of electric engine system

Including transport of engine and battery solution

Road Transport

1. Choose product	2. Fill inn note if necessary	3. Fill inn transport route if necessary	4. Choose transport option	5. Fill in distance			6. Fill in assumed cargo load										
Product	**Note**	**Transport route**	**Road transport option**	**Distance [km]**	**Weight unloaded [ton]**	**Max cargo [ton]**	**Assumed cargo [%]**	**Weight cargo [ton]**	**Weight of specific product [kg]**	**Fuel consumption empty [liter/km]**	**Fuel consumption max cargo [liter/km]**	**Fuel consumption [liter/(km*ton)]**	**Fuel consumptio as a function of cargo and distance [liter]**	**Fuel**	**kg CO2 / liter fuel**	**CO2 emission from transport [kg]**	**Specific CO2 emission from transport of product [kg]**
Steel	From SSAB Europe, Rautaruukintie, Finland to ABB Factory in Vaasa	Oy - Vaasa	Tractor and semi-trailer, long haul traffic	245	14	26	70 %	18,2	3860	0,235	0,320	0,003269	72,15	Diesel	2,6	187,60	39,78
Aluminum	From Hydro Sunndal to production assembly in Vaasa. 1 ferry conection.	Hydro Sunndal - Umeå Ferry Pier	Tractor and semi-trailer, long haul traffic	816	14	26	70 %	18,2	67	0,235	0,320	0,003269	240,31	Diesel	2,6	624,81	2,29
Aluminum		Vaasa Ferry Pier - ABB Factory, Vaasa	Tractor and semi-trailer, long haul traffic	6,2	14	26	70 %	18,2	67	0,235	0,320	0,003269	1,83	Diesel	2,6	4,75	0,02
Copper	From Boliden Rönnskär to production assembly in Vaasa. 1 ferry conection.	Boliden Rönnskär - Umeå Ferry Pier	Tractor and semi-trailer, long haul traffic	148	14	26	70 %	18,2	253	0,235	0,320	0,003269	43,59	Diesel	2,6	113,32	1,58
Copper		Vaasa Feryy Pier - ABB Factory, Vaasa	Tractor and semi-trailer, long haul traffic	6,2	14	26	70 %	18,2	253	0,235	0,32	0,003269	1,83	Diesel	2,6	4,75	0,07
ABB electric engine	From ABB factory to assembly location in Mundal. 1 ferry connection.	ABB Factory, Vaasa - Vaasa Ferry Pier	Tractor and semi-trailer, long haul traffic	6,2	14	26	70 %	18,2	4280	0,235	0,320	0,003269	1,83	Diesel	2,6	4,75	1,12
ABB electric engine		Umeå Feryy Pier - Mundal, Radøy	Tractor and semi-trailer, long haul traffic	1245,5	14	26	70 %	18,2	4280	0,235	0,320	0,003269	366,80	Diesel	2,6	953,68	224,27
Battery	From CATL Ningde to assembly location in Mundal. 2 ferry conection.	CATL in Ningde - Port of Shanghai	Tractor and semi-trailer, long haul traffic	723	14	26	70 %	18,2	1294	0,235	0,320	0,003269	212,92	Diesel	2,6	553,60	39,35
Battery		Port of Bergen - Mundal, Radøy	Tractor and semi-trailer, long haul traffic	36,8	14	26	70 %	18,2	1294	0,235	0,320	0,003269	10,84	Diesel	2,6	28,18	2,00

Maritim Transport

1. Choose product	2. Fill in note if necessary	3. Fill inn transport route if necessary	4. Choose transport option				5. Fill in assumed cargo load								
Product	**Note**	**Transport route**	**Maritim transport option**	**Distance [km]**	**PBE (Passenger Car Capacity)**	**Max weight of cargo [ton]**	**Assumed cargo load on vessel [%]**	**Weight of cargo on vessel [ton]**	**Weight of specific product [kg]**	**Fuel/power source**	**CO2e [g/(PBE*km)]**	**Engine power [kW]**	**gCO2 / kWh**	**CO2e per trip [kg]**	**Specific CO2 emission from transport of**
Aluminum		Umeå Ferry Pier - Vaasa Ferry Pier	Wasa Express	95,8	-	4150	70 %	2905	67	Diesel	-	14 866,00	686	45 891,34	1,06
Copper		Umeå Ferry Pier - Vaasa Ferry Pier	Wasa Express	95,8	-	4150	70 %	2905	253	Diesel	-	14 866,00	686	45 891,34	4,00
ABB electric engine		Vaasa - Umeå	Wasa Express	95,8	-	4150	70 %	2905	4280	Diesel	-	14 866,00	686	45 891,34	67,61
Battery		Shanghai - Hamburg	CMA CGM CHAMPS ELYSEES	22737	-	216900	70 %	151830	1294	Diesel	-	63 840,00	644	########	195,69
Battery		Hamburg - Bergen	NCL Alesund	1013	-	11208	70 %	7845,6	1294	Diesel	-	7 950,00	644	200 245,46	33,02

Total CO2 emissions from transport of electric engine [kg]
612

Transportation of diesel engine system

Scania diesel engine

Road Transport

1. Choose product	2. Fill inn note if necessary	3. Fill inn transport route if necessary	3. Choose transport option	4. Fill in distance			5. Fill in assumed cargo load										
Product	**Note**	**Transport route**	**Road transport option**	**Distance [km]**	**Weight unloaded [ton]**	**Max cargo [ton]**	**Assumed cargo [%]**	**Weight cargo [ton]**	**Weight of specific product [kg]**	**Fuel consumption empty [liter/km]**	**Fuel consumption max cargo [liter/km]**	**Fuel consumption [liter/(km*ton)]**	**Fuel consumptio as a function of cargo and distance [liter]**	**Fuel**	**kg CO2 / liter fuel**	**CO2 emission from transport [kg]**	**Specific CO2 emission from transport of product [kg]**
Steel	From steel plant SSAB to Scania Production Facility	Luleå - Södertalje	Tractor and semi-trailer, long haul traffic	940	14	26	70 %	18,2	2237,2	0,235	0,320	0,003269	276,83	Diesel	2,6	719,76	88,47
Scania diesel engine	From Scania Production Facility to Nogva Motor Factory (local supplier of engine).	Södertalje - Søvik	Tractor and semi-trailer, long haul traffic	935	14	26	70 %	18,2	2380	0,235	0,320	0,003269	275,36	Diesel	2,6	715,93	93,62
Scania diesel engine	From Nogva Motor Factory to Mundal Group. 2x ferry crossover	Søvik - Rødøy	Tractor and semi-trailer, long haul traffic	423	14	26	70 %	18,2	2380	0,235	0,320	0,003269	124,57	Diesel	2,6	323,89	42,35

Maritim Transport

1. Choose product	2. Fill inn note if necessary	3. Fill inn transport route if necessary	4. Choose transport option				5. Fill in assumed cargo load								
Product	**Note**	**Transport route**	**Maritim transport option**	**Distance [km]**	**PBE (Passenger Car Capacity)**	**Max weight of cargo [ton]**	**Assumed cargo load on vessel [%]**	**Weight of cargo on vessel [ton]**	**Weight of specific product [kg]**	**Fuel/power source**	**CO2e [g/(PBE*km)]**	**Engine power [kW]**	**gCO2 / kWh**	**CO2e per trip [kg]**	**Specific CO2 emission from transport of** [rest of label cut off]
Scania diesel engine		Søvik - Rødøy	M/F Festøya	4,3	120	500	70 %	350	2380	Diesel mechanically on regular fossil diesel	327,00	-	-	168,73	1,15
Scania diesel engine		Søvik - Rødøy	M/F Oppedal	5,8	120	500	70 %	350	2380	Diesel mechanically on regular fossil diesel	327,00	-	-	227,59	1,55

Total CO2 emissions from transport of diesel engine [kg]
227,15

During a 1 year cycle

Step		Electric engine	1	2	3	4
1	Choose engine	Engine	ABB electric engine	ABB electric engine		
		Engine speed [rpm]	1500	1500		
		Gross power [kW]	375	375		
2	Fill inn number of engines in vessel	Total engines	2	2		
		Total gross power [kW]	750	750		
		Speed [knots]	18	18		
		kWh during lifespan	1 110 968	1 110 968		
		Lifespan [hour]	75 000	75 000		
3	Choose power source	Power Source	Norway	Norway		
		kg CO2 / kWh	0,017	0,017		
		kg CO2 through lifespan	18 886	18 886		
		kg CO2 / operating hour	0,25	0,25		
4	Choose route	Route	Rosendal - Salmon Eye - Hågardsneset - Rosendal	Rosendal - Salmon Eye - Hågardsneset - Rosendal		
		Distance [km]	11,84	11,84		
		Time per trip [hour]	0,36	0,36		
		CO2 emission per trip [kg]	0,09	0,09		
5	Choose season	Season	On	Off		
		Trips per day	3	0		
		Operating days per week	5	5		
6	Fill in number of weeks. Note: total weeks can not exceed 52.	Number of weeks per season	26	26		
7	Fill in number of trips on request.	Trips on request				
		Total trips during season	390	0		
		Total CO2 emissions from route during season [	34,92	0,00		

Summary	
CO2 emissions after 1 year [kg]	34,92
CO2 emissions after 5 years [kg]	174,59
CO2 emissions after 10 years [kg]	349,19
CO2 emissions after 15 years [kg]	523,78
CO2 emissions after 20 years [kg]	698,38

During a 1 year cycle

Step		Diesel engine	1	2	3	4
1	Choose engine	**Engine**	Scania diesel engine	Scania diesel engine		
2	Choose engine speed	**Engine speed [rpm]**	1500	1500		
		Gross power [kW]	350	350		
3	Fill in number of engines in vessel	**Total engines**	2	2		
		Total gross power [kW]	700	700		
		Speed [knots]	18	18		
4	Choose load	**Engine load**	75 %	75 %		
		Specific fuel consumption [g / kWh]	196	196		
		Specific fuel consumption, propeller curve [liter / hour]	-	-		
		Fuel	Diesel	Diesel		
		Density of fuel [kg / liter]	0,84	0,84		
		kg CO2 / liter fuel	2,6	2,6		
5	Choose route	**Route**	Rosendal - Salmon Eye - Hågardsneset - Rosendal	Rosendal - Salmon Eye - Hågardsneset - Rosendal		
		Distance [km]	11,84	11,84		
		Time per trip [hour]	0,36	0,36		
		CO2 emission per trip [kg]	150,99	75,50		
6	Choose season	**Season**	On	Off		
		Trips per day	3	0		
		Operating days per week	5	5		
7	Fill in number of weeks. Note: total weeks can not exceed 52	**Number of weeks per season**	26	26		
8	Fill in number of trips on request.	**Trips on request**				
		Total trips during season	390	0		
		Total CO2 emissions from route during season [kg]	58 887,11	0,00		

Summary	
CO2 emissions after 1 year [kg]	58 887,11
CO2 emissions after 5 years [kg]	294 435,56
CO2 emissions after 10 years [kg]	588 871,11
CO2 emissions after 15 years [kg]	883 306,67
CO2 emissions after 20 years [kg]	1 177 742,22