August 2013

Sustainability of Carbon Ferries

DTU

Meta Christina Borgen Dam
and Niels Brehm Nielsen

Danish Technical University

Preface

This master thesis has been done in equal collaboration between Meta Christina Borgen Dam and Niels Brehm Nielsen in the spring and summer of 2013. The thesis was made at DTU Management Engineering under the study programme Engineering Management. The scope was 30 ETCS for each author.

The supervisors have been Associate Professor Lauge Baungaard Rasmussen from DTU Management Engineering ("Innovation Systems and Foresight"/ "Technology and Innovation Management"), Associate Professor Stig Irving Olsen from DTU Management Engineering ("Quantitative Sustainability Assessment"). PhD student Ingrid Marie Vincent Andersen from Department of Mechanical Engineering has been contact person.

The thesis presents an interdisciplinary approach combining sustainability with strategic methods for ferries built in carbon fibre reinforced polymer (CFRP).

Kongens Lyngby, 5 August 2013

Meta Christina Borgen Dam

Niels Brehm Nielsen

Acknowledgement

A special thanks to Tuco Marine Group and CEO Jonas Pedersen, production manager Kai Nielsen and all the other employees for who without this study would not have been possible. Tuco Marine Group delivered insight and production specifications to give the project an empirical foundation.

A special thanks to our two supervisors Associate Professor Lauge Baungaard Rasmussen and Associate Professor Stig Irving Olsen for valuable feedback and discussions throughout the project. With their support it was possible to combine two transdisciplinary academic fields and view reality from new angles. Furthermore a special thank to PhD student Ingrid Marie Vincent Andersen for her insight into the maritime sector, and her ability to answer technical maritime questions. A thank has to go to Associate Professor Morten Birkved from DTU Management Engineering for assisting with Gabi issues.

Thanks to Skibsteknisk Selskab for giving a grant enabling us to travel to Tromsø in Norway to collect information and perform interviews regarding the use and operation of CFRP ferries. In this regard special thanks have to go to daily operation manager Steiner Mathisen from Boreal transport Nord in Norway for letting two students onboard Kistefjell, Sollifjell and Fløyfjell in voyage as well as in the docks, and for answering a large amount of questions.

Lastly thanks to all the other people who was interviewed on telephone, Skype or in person.

Abstract

The main purpose of this study was to analyse the sustainability of carbon fibre reinforced polymer (CFRP) ferries in Denmark. Sustainability of the composite shipbuilding industry has been determined by an interdisciplinary approach combining life cycle thinking with strategic models and methods.

A comparative Life Cycle Assessment (LCA) analysis was made to assess the environmental impacts from a high speed catamaran ferry build in carbon fibre reinforced polymer versus a high speed catamaran ferry build in aluminium. Both catamaran ferries were capable of operating the same route between Harstad and Tromsø in Norway and were built in accordance to the high speed craft code. The hulls of the CFRP ferries were build in 2009-10 by a Danish shipyard Tuco Marine Group which has been the focus company in this case study.

The results showed that the operation stage had the biggest environmental impacts mainly caused by the extensive fuel consumption of both ferries. A comparison between the construction stages of each ferry was made to see which processes and materials accounted for the largest impacts during production. A number of limitations and assumption was made especially for the aluminium modelling.

It was found that a lightweight CFRP ferry could be beneficial for the environment, the economy and the society. However, it depended on the specific route and ferry and whether the extra investment needed for buying a CFRP ferry was offset by the lower fuel consumption and maintenance costs during the lifetime of the ferry. Furthermore it was found that environmental break-even occurred after 3 month while economic occurred after 4 years.

Porter's Five Forces and PEST analysis were used and supplemented with the results obtained in the LCA study. The strategic analysis showed that market potential and perspectives of a CFRP ferry in Denmark do exist, but under different conditions than the Norwegian high speed ferries. The main competitive parameters in the industry were identified to be cost, trust, time, and references, and their influence on a sustainable development were discussed.

The interdisciplinary approach made it possible to focus on patterns of sustainability, where the LCA gave a quantitative measure of alternatives. The LCA could not be used in the search for potential markets for a CFRP ferry, here the PEST analysis were of help. The interdisciplinary approach could be used for actors considering being more sustainable, and the approach could assist in finding and prioritizing areas of focus.

Description of Terms

Term	Meaning
Actor	Human or non-human participating in actions
CFRP	Carbon fibre reinforced polymer
Competitive parameters	Things that make a customer buy a specific product
Composites	In this study used as a general term for glass fibre and carbon fibre
Deadweight	The carrying capacity of a ship
Displacement	The amount of water a ship displace
Downstream	Processes that occur later on in a product system
DMA	Danish Maritime Authority
Eco-sphere	The environment containing life
Damage endpoint	Damage done by a product or service on areas of protection
EOL	End-of-life
GLO, RER, CH, NO, DK, SE	Regional codes used in LCI. GLO=global, RER=region Europe, CH= Schweiz, NO=Norway, SE=Sweden and DK=Denmark
Gross tonnage	A measure of volume for ships over a certain length (1 GT= 2.83 m^3)
Hull	In this study a term for both the hull and substructures of a ship, boat or ferry
IMO	International Maritime Organization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCT	Life Cycle Thinking
Midpoint	Environmental mechanisms of a product or service on the eco-sphere
NM	Nautical mile (1 NM = 1.85 km)
NOK	Norwegian Kroner (assumed exchange rate of 1 NOK = 0.95 DKK)
PEST	Political, Economical, Social and Technological
Plastic helper	All plastic materials used in the manufacturing of composite sandwich structures, but which is not part of the finished product
Stakeholder	Any actor or group of actors with a direct or indirect interest of the area in focus
Techno sphere	Manmade world of products and services
Tuco	Short name for the company Tuco Marine Group ApS
Upstream	Processes that occur earlier on in product system
Weighted	Decision of which damages at endpoint is most important.

List of Tables

List of Figures

Contents

Chapter 1 Introduction

Large shipyards in Denmark like B&W and Lindø have closed down within the recent decades. Today the production of large ships primarily takes place in Korea and China (1). Ships are traditionally made in steel (Appendix 14), but the introduction of new and lighter materials like composites in recent years has opened up for new ways of building ships. During the last ten years there has been a change of focus inside the maritime industry from weight reduction in relation to higher speed to a focus on weight reduction in relation to lower fuel consumption and less emission (Appendix 4).

In Denmark a couple of small and medium sized shipyards still persists and have focused their product range on retrofit of existing ships and maintenance. Other shipyards have entered a new market and begun to build commercial ships in composite materials like carbon fibre or glass fibre. These shipyards claim composites are stronger than steel or aluminium and the application to be more environmental friendly. At the conference "Billige Grønne Færger" in January 2013 the CEO of MARCOD (Appendix 16) expressed his hope that Denmark in the light of these new composite materials once again could become a shipbuilding nation.

From the Danish government's side there is an increased focus on creating employment opportunities within the Danish maritime sector underpinned by the Blue Growth Plan (Blå Vækstplan) launched in December 2012 (2). This plan explicit mentions carbon fibre as a technology with environmental and growth potential. To determine the environmental potential a quantitative sustainability assessment tool like LCA can be used, while growth potential can be determined using strategic analyses identifying the market potential and competitive parameters. A product might have environmental potential, but if the product cannot compete with existing products it will make no environmental difference or societal growth.

There are various reasons for looking at the shipbuilding industry and the market segment for composite materials used in shipbuilding. First because the prices of composite materials like carbon fibre is now competitive with a price of around 5 USD per pound (3) (see also section 4.4). Second since the maritime industry is cost driven and fuel prices is constantly increasing, there is a focus to develop lighter and less fuel consuming ships, and composite materials can aid in this development. A ship hull made in CFRP weights approximately 34% of a steel hull and approximately 55% of an aluminium hull with the same deadweight (4).

In Tromsø in Norway three CFRP high speed catamaran ferries are operating (a picture of one of the ferries can be seen on the front page). The CFRP hulls for all three ferries were manufactured at the Danish shipyard Tuco Marine Group ApS. The empirical data for this report will be based on these three ferries.

Figure 1: The CFRP ferry "Kistefjell" in Tromsø port

In a previous Danish-Swedish research project called the Eco-Island ferry project a LCA study (5) identifying the environmental impacts of a fictive CFRP ferry compared to an existing steel ferry was conducted. The steel ferry studied was a vehicle carrying ferry operating on the route Hov-Tunø in Denmark. The Eco-island ferry project looked at a fictive CFRP single hull ferry compared to an existing Danish steel single hull ferry. In this report an existing Norwegian CFRP catamaran ferry will be compared to an existing Norwegian aluminium catamaran ferry. The Eco-Island project also included a complete life cycle cost analysis for the two ferries, a full-scale fire risk analysis and a demonstration of reduced fuel consumption as a result of lower hull weight (6).

Field of study for this report is the environmental and growth potentials of composite ferries in Denmark. Ferries are a type of commercial ship, which is defined as a ship requiring professional crew for the service provided meaning that leisure crafts such as sailing vessels, rowboats, yachts and sport-boats are excluded in this study. Previous studies have mainly focused on the economic and environmental gains of a composite ferry, but little has been written about the composite shipbuilding industry's market potential and competitive parameters in relation to sustainable development. The report will use and test an interdisciplinary approach combing life cycle thinking with strategic methods to answer the main objective:

How can sustainability in the composite shipbuilding industry in Denmark be determined using an interdisciplinary approach?

It will be investigated whether such an approach is useful. Furthermore strength, weaknesses and limitations of the approach will be outlined. The case study consists of three catamaran ferries where the hulls were built in carbon fibre reinforced polymer (CFRP) by Tuco Marine Group between 2009 and 2010. To determine the sustainability of the composite shipbuilding industry, exemplified by the company Tuco Marine Group, strategic and life cycle thinking will be combined. This raises the first sub questions:

What does it mean for the depth and width of the analysis that an interdisciplinary approach combining theories and concepts from strategy and life cycle thinking has been used? (Sub-question 1)

The method used will be described in Chapter 2 and the application and usefulness of it will be discussed in the end of the report (see Chapter 8). The quantitative sustainability assessment tool used will be a LCA analysis because it was the selling point to the CEO at Tuco Marine Group to start cooperation. This is related to the second sub-question which assesses the environmental impacts occurring in the different life cycle stages of a ferry:

Which environmental effects occurs under production, operation and disposal of a ferry build in carbon fibre reinforced polymer and how are these effects compared to a relevant reference? (Sub-question 2)

The purpose of sub-question 2 is to compare the environmental impacts from two reference ferries fulfilling the same function. Sub-question 3 looks at strategic aspects. The purpose is to investigate the macro environmental factors and competitive forces affecting a sustainable development of the industry:

How do the competitive parameters in the industry influence a sustainable development? (Sub-question 3)

The fourth sub-question looks at future perspectives and potential market segments related to the use of composite materials for shipbuilding in Denmark:

What are the perspective and market potential for commercial ships build in composite materials in Denmark? (Sub-question 4)

Sub-question 2 will be answered by doing a comparative LCA analysis on the three CFRP catamaran ferries compared to an aluminium catamaran ferry (see Chapter 5). Sub-question 3 will be answered using two strategic analyses Porter’s Five Forces and PEST and supplemented with results from the LCA analysis. Finally sub-question 4 will be a discussion based on the findings in the previous sub-questions (see Chapter 7). The restriction to the Danish industry and market is done to limit the size and scope of the report.

Chapter 2 Theory

To prepare for a discussion of the relation between businesses and the environment a number of methods used to assess environmental impacts and strategy analysis will be presented. Afterwards the interdisciplinary approach used in this study will be introduced.

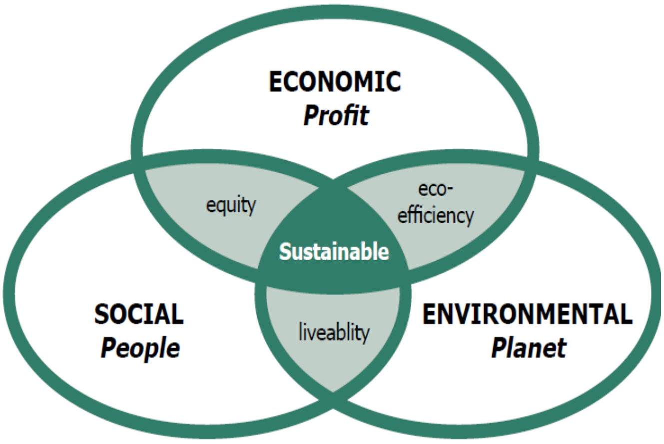
2.1.Sustainability

In 1987 the United Nations World Commission on Environment and Development (WCED) published the Brundtland Report (7). In this report sustainable development was defined as:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

The underlying assumption for this definition was that the world was not sustainable and the current strains on resources and ecosystems would compromise the ability of future generations' life on Earth.

A number of protagonists and authors like Herman E. Daly describe three pillars of sustainable development namely economic, social and environmental (8). Some authors (9) even refer to a fourth time pillar. To cover the first three pillars an approach that combines sustainability and strategy is needed, because according to Jones, Rose, and Tull (10) the combined effects of environment together with economic and social factors is crucial to make progress towards sustainability. To make progress new actions and values must be cultivated.



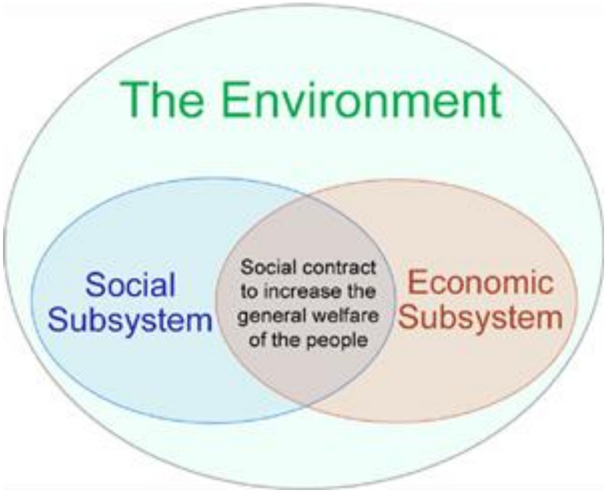


Figure 2: The left figure shows the three pillars of sustainability consisting of the economic, social, and environmental pillars (11). If any of the pillars are weak then the system as a whole is unsustainable. The right figure shows the social and economic systems as being part of the bigger environmental system or biosphere (12)

When attempting to attain sustainability the focus should be on all three pillars at the same time (see figure 1 left). If e.g. the economy goes badly and a population lives in poverty then the environmental pillar would get less attention, since eating and surviving is prioritized higher than saving the environment. Likewise the social pillar is critical, because if a conflict or civil war breaks out environmental focus has zero priority. Solutions must aim at making all three pillars sustainable.

When looking at the right side of figure 1 illustrating the overall system we live in, it is evident that environmental sustainability should have the highest priority, since the two others are subsystems. If the supporting capacity of the environment is lowered then the common good delivered by the social system and the output produced by the economic system would decrease. So even though all three pillars should be accounted for at the same time, the environment is the basis for the two others (8).

In the United Nations definition of sustainable development the aim of meeting the needs of the present and the needs of future generations are specified (7). When looking at social aspect, not only the basic needs have to be considered but also the subjective experience of well-being. Sustainability is therefore more than preserving our natural resources and ecosystems, but also about securing that the present population on Earth are having their basic needs fulfilled and achieve an acceptable level of well-being (13). To ensure that all people on Earth have a chance of attaining the same level of human well-being initiatives like peace, social justice, and poverty reduction are needed. An acceptable level of well-being can be difficult to define, but include issues like working conditions, labour rights, discrimination, health and safety, and education level. The social pillar of sustainability is therefore connected to the present generations' needs and definition of well-being and an ethical responsibility concerning the ability of people to develop and meet their needs.

2.1.1. Business and Sustainability

Companies in an industry are an active part of a society and for them to support a sustainable development they must gain something in return. The authors of this report believe it is unrealistic to assume that all relevant stakeholders in an industry will behave philanthropic and seek sustainability out of own conscience unless it create value or provide economic profit. As Jones, Rose, and Tull (10) describe the most environmentally optimal solution does not necessarily produce optimal economic results for all of the stakeholders. In Scherer, Palazzo, Seidl (14) the business perspective of sustainability is viewed as an external force on the company, not something the businesses actively seeks. According to Berns et al. (15) the relationship between business and sustainability has changed over the last years. Formerly, when people talked about business and sustainability together the usual question was "how management could affect sustainability". Today more and more leaders are however beginning to recognize that the question to be asked should be "how will sustainability change management". Sustainability thinking is changing the way of doing business and is gradually becoming a requirement instead of a choice to incorporate in strategy formulation in order to increase competitive advantage and economic profitability.

2.2. Strategy

In order to obtain sustainability new ways of conducting business must be developed to comply with the three pillars of sustainability (see Figure 2 left). Strategic management is one tool to ensure that a business is thriving.

There are a number of definitions within strategy of what strategy is, and which definitions is the best depends on the given situation in a given company. One of the most recognized strategy authors are Henry Mintzberg which in 1987 published an article with the title "Five Ps for strategy" (16). In this article Mintzberg states that strategy is what a kid uses to get over a fence. The five Ps stands for ploy, plan, position, pattern and perspective. A ploy is "a manoeuvre intended to outwit or trick an opponent or competitor", a plan is a "conscious intended course of action", a pattern is how many small actions can converge, position is the match between a firm and the external environment, and perspective is the way to see the world and the firm's "personality" or driving force. The perspective is often not changeable.

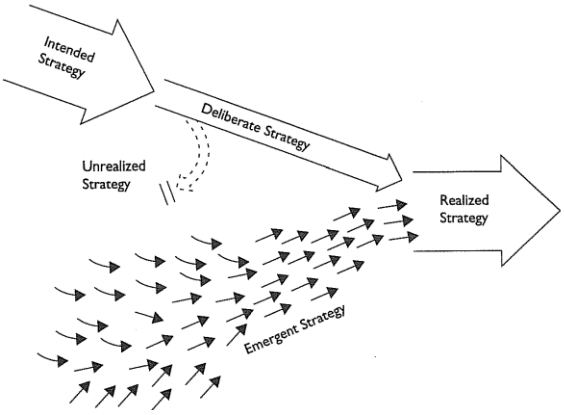


Figure 3: Showing how intended and emergent strategy can become reality (16).

According to Mintzberg a strategy can be intended, deliberate, emergent, or realized. An intended strategy can be a plan and be executed through the deliberated strategy of a ploy. An emergent strategy is not something one person conjures, but more a result of many actions pointing the same way which ends up becoming a strategy. According to another author Michael Porter strategy is "choosing a unique and valuable position rooted in systems of activities" (17) which is related to Mintzberg description of position as a strategy.

Companies use strategies to survive in a competitive market with other companies. If the objective of a company is to pursue sustainability, the creation of new plans and ploys to help in the transition phase can be needed. However, a company may support a sustainable development without actively having it as an objective but by repeatedly acting in a pattern that unintentionally support a sustainable development.

A strategy can also be described as the link between a firm and its environment (18), or in other terms how the company is going to position itself in relation to the industry environment:

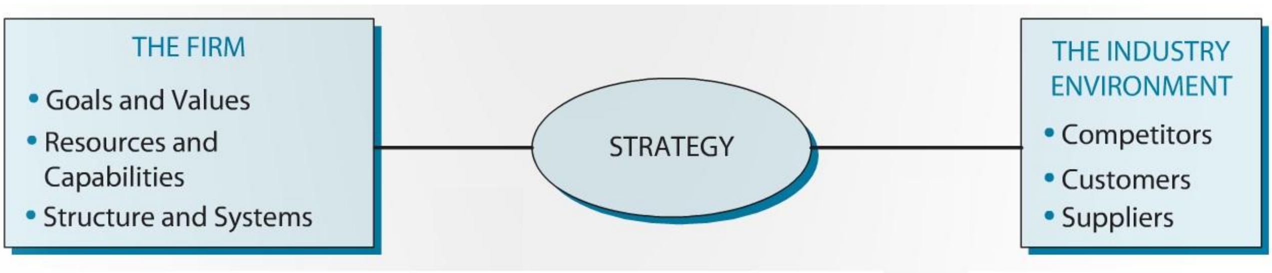


Figure 4: Strategy as a link between the firm and the industry environment (18).

A firm´s strategy defines where it is going to conduct business and which customer needs it is going to serve, on the basis of the firm´s core competencies (19). The industry environment is here defined as competitors, customers and suppliers (see Figure 4). The factors and level of competition affecting a firm in a given industry environment can be described by a model known as Porter's Five Forces (see Figure 5).

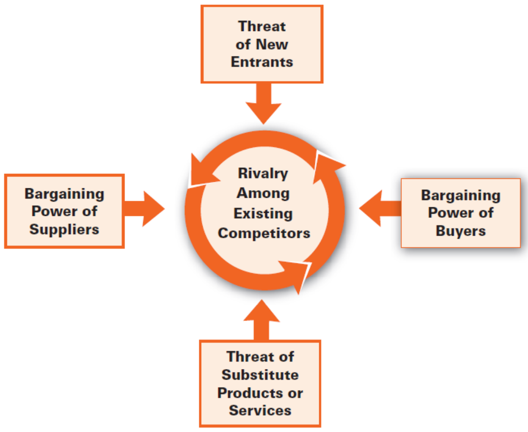


Figure 5: The five forces that shape industry competition (20).

According to Porter (20) it is the job of a strategist to understand and cope with competition. Porter's Five Forces consist of five competitive forces; threat of entry, threat of substitutes, supplier power, buyer power, and industry rivalry. Each of these competitive forces determines the intensity of competition and the level of profitability for a company, where the company is seen as part of an industry.

Threat of entry can be high if e.g. suppliers selling to a profitable retailer want to enter and gain market shares on the retailer's market. Profit and retaliation within the industry respectively increases and decreases the treat of entry. The threat of entry is much related to barriers of entry which can be unequal access to distribution channels, capital requirements, supply side economic of scale and demand side benefits of brand or network (20).

Threat of substitutes can decrease profitability of the industry if another product can perform the same function, if the switching cost for a buyer is low or if the price-performance relation of a substitute is attractive. One way of minimizing the threat of substitutes is by distancing or differentiating the product from the substitutes.

Supplier power is high if there is high switching cost for the companies, the supplier do not depend on the industry revenues, the supplier is more concentrated than the industry, the supplier have a differentiated product, there are few substitutes or if the supply industry can integrate downstream.

Likewise buyer power is high if the buyer have low switching cost, the buyer have negotiations leverage, the buyers are more concentrated than the industry, the supplier have an un-differentiated product, there are many substitutes, or if the buyers can threaten to integrate upstream. A buyer is price sensitive if the product from a supplier accounts for a significant fraction of the buyers overall costs. In addition intermediate customers, customers who purchase the product but are not the end user, have bargaining power if they can influence the decision of end users (20).

Industry rivalry defines the profitability of an industry. A high level of rivalry can drive down profitability, especially if companies in the industry compete on the same parameters e.g. price. Competition on other parameters than price like service or brand does not represent the same risk of rivalry and decreased profitability. Rivalry in an industry can be high if there is slow growth in the industry, high exit barriers, the goods are perishable, there is excess capacity, are high fixed costs, are low marginal costs, or if there are many companies of similar size and power. In addition a few companies aspiration for superiority or lack of familiarity with one another can increase industry rivalry.

Porter presents with the five competitive forces an analytical tool to understand the industry environment. The industry environment is what a company is part of and have to consider when developing a business strategy.

2.3.PEST

In the previous section the competitive forces influencing an industry were described. However, an industry is part of a macro environment (21) consisting of factors influencing profitability and competitiveness of an industry. Porter (20) recognizes that an industry is influenced by external factors like e.g. governments setting boundaries for the company´s conduct. Porter uses the term factor because government should not be seen as a sixth force, since government involvement is neither inherently good nor bad for industry profitability as the five forces are. Hence the term factors will be used to describe the macro-environment.

One way of scanning the macro environment is to use a PEST analysis which stands for political, economical, social, and technological (21). A PEST analysis is part of an external analysis when doing market research and it gives an overview of the different macro environmental factors a company has to take into consideration. Sometimes other factors like environmental or legal are included which give other combination of letters like PESTEL. In this study a PEST analysis will be made, because as Henry (21) argues environmental factors can be included in any of the four factors and in addition the legal factor can be attributed to the political factor.

The role of any factor outlined in the PEST can be related to each of the five competitive forces in Porter's model (20). An example could be if a government allows patents this would raise barriers to entry or if a new policy favouring unions was approved this could raise supplier power. According to Porter the consideration of factors like government, industry growth rate, and complement products or services should investigate the effect these factors have on the five competitive forces.

Even though strategic thinking mainly has been developed for companies in competitive environments with little or no interest in sustainability different frameworks exist which let companies think in more sustainable ways. These frameworks which have different focus areas and ways of implementation are e.g. Environmental and Social Accounting, Environmental Management Systems, Design for the Environment, co-efficiency, Eco-labelling, Corporate Social Responsibility, Environmental and Social Accounting, Factor X, Green Chemistry and The Natural Step, to name a few (9).

2.4.Life Cycle Assessment

In the following a description of the LCA methodology and associated life cycle thinking will be made. The main reason for doing a Life Cycle Assessment (LCA) is since it was the selling point to the CEO at Tuco Marine Group. LCA is a tool used in life cycle thinking (LCT), which embraces the importance of viewing the whole life cycle of a product or service and the impact it has on the surrounding environment. A life cycle includes the different stages a product or service goes through including extraction of raw materials from nature, the production phase, the use phase, and the disposal of waste after use. The purpose is to include all the environmental impacts a product or service makes throughout its lifetime (11).

A LCA analysis evaluates how much a product or service impacts the physical environment throughout its life cycle, for example how much CO_2 is emitted or how much agricultural land the production of a product occupy. In short LCA is a quantitative method that assesses the environmental impacts a product or service cause throughout its life cycle from cradle to grave (22).

One reason for considering the whole life cycle and not only a single life cycle stage like e.g. manufacturing is because one could effectively address the issues of sustainability on a manufacturing stage. However, broader elements of sustainability like human health or ecosystems could still be degraded because of other life cycle stages (23). LCA is used to quantify all relevant emissions and resources consumed by a product chain, from extraction of raw materials through production, use, and recycling and up to the disposal of remaining waste (22).

To conduct a LCA the function of the product or service must be known, in other words what kind of need do the product fulfil. A central element of a LCA is the systems functional unit which names and quantifies the qualitative and quantitative aspects of the function of a product or service. The functional unit allows making comparisons that are valid as the compared products or services are fulfilling the same function. Another central element is reference flow which is the amount of product or service needed to realise the functional unit for a given time period. If a comparative LCA study is done, two reference flows fulfilling the same functional unit will be compared.

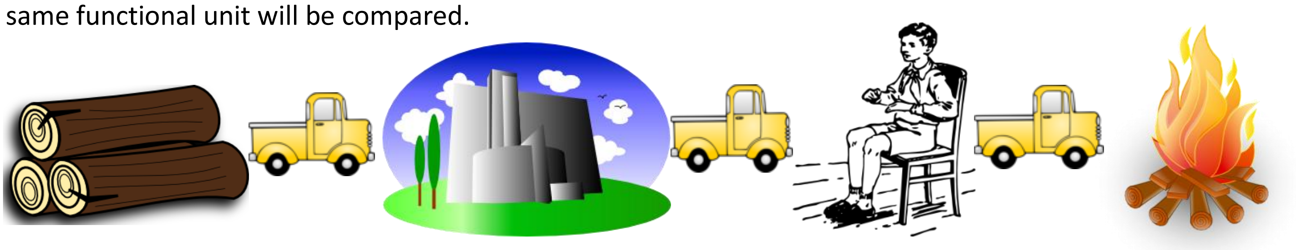


Figure 6: Illustration of an example of the product chain of a chair from cradle as being lumber to grave at being burnt. The pictures are taken from (120).

The LCA analysis starts by collecting data for the Life Cycle Inventory (LCI). Based on the LCI environmental impacts are calculated for different midpoints. Each midpoint is related to one of the three areas of protection human health, natural environment (ecosystems), or natural resources. These three areas are termed damage endpoints in LCA methodology (see Figure 7) (22).

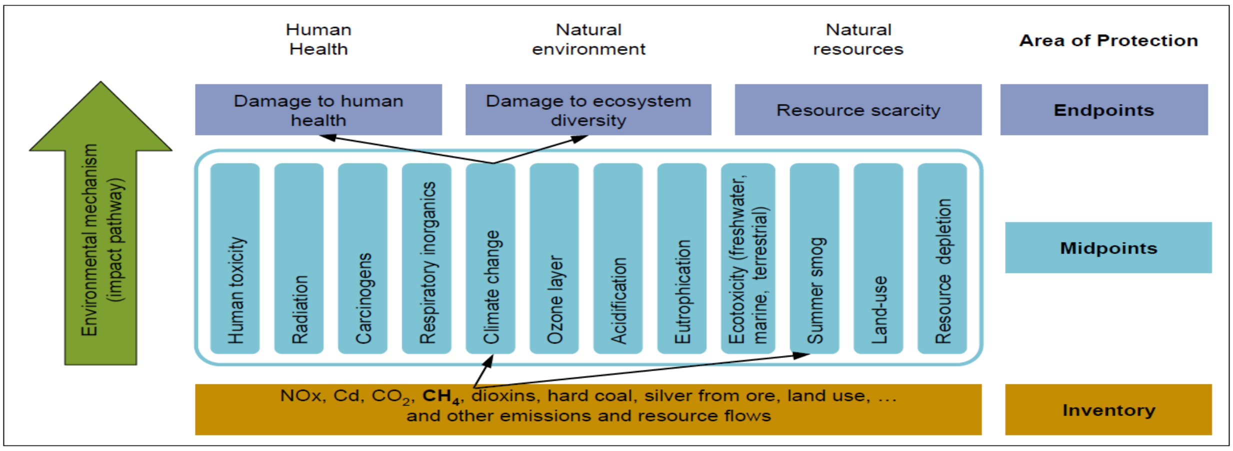


Figure 7: Life Cycle Impact Assessment. Schematic steps from inventory to midpoints to endpoints (22).

Ny et al. (24) suggest that environmental LCA alone has not had much of an impact on either business or policy decisions because the methods to date do not fully incorporate the multiple aspects of sustainability. Grimes-Casey et al. (25) further suggests that industrial ecologists which are mainly focused on material and energy balances, have had a hard time to incorporate the strategic behavioural interactions and management in life cycle thinking since the knowledge required is resident primarily in the social sciences, rather than the physical. So transdisciplinary modelling might be a way to incorporate aspects like social and economic factors in life cycle methods.

2.5.Life Cycle Cost

Life cycle cost (LCC) is a tool in life cycle thinking to incorporate economic aspects. LCC can be done to analyse the total cost of a given product or service during its lifetime. The idea is to incorporate costs from all phases in the life cycle; including cost of extraction, cost of production, cost of operation, cost of disposal and income from resale or recycling. LCC can be used to compare the costs of two reference flows fulfilling the same functional unit, assess which life cycle stage accumulates the highest costs and calculate the economic break-even point between two references (26).

2.6.Social LCA

Parallel to LCA, evaluating environmental impacts related to product life cycles, there is a tool for assessing the social impacts of a product over its life cycle called social life cycle assessment (SLCA).

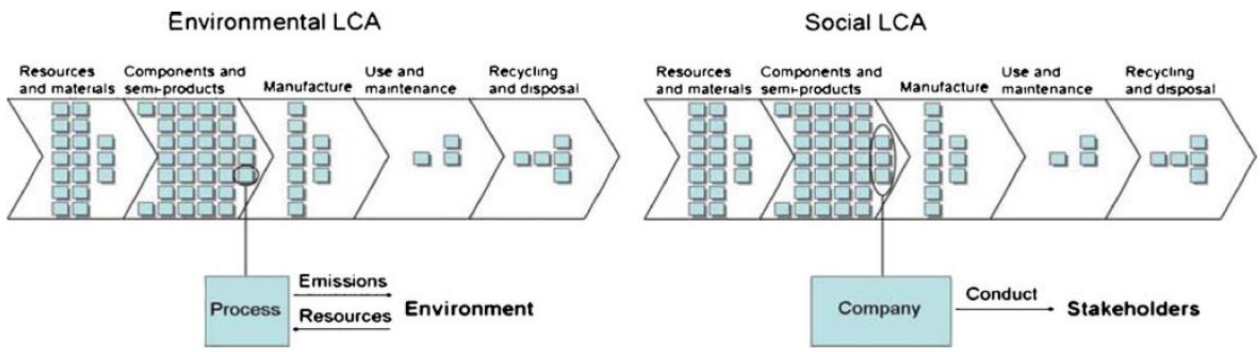


Figure 8: The difference between environmental LCA which focuses in individual processes and the physical flows they exchange with the environment (on the left), and social LCA (SLCA) which focuses on companies and the impact their conduct has on stakeholders (on the right) (27).

The methodology for social LCA has been under development for the last 10 years and is still not completed, but is based on the assumption that social action can lead to changes in human well-being (28). Human well-being is related to individual stakeholder's experiences of being well and can be both physical health and psychological well-being. Well-being can be measured using objective indicators related to living or working conditions like income, health, or number of friends.

According to Dreyer et al. (27) the social impacts on individuals or groups of stakeholders are related to the conduct of the companies engaged in the product chain. Groups of stakeholders can be the workers in the life cycle, the local or regional community around the product life cycle stages, product users, or company owners. A difference between LCA and SLCA exist when looking at system boundaries because in LCA all "non"-stages are normally zero, but in SLCA this is not always the case. If a company decides to shut down the production then the environmental impacts will be zero, because no emissions will then be created. On the other hand the social consequences can be quite severe for the workers and local community due to the shut down and the social impacts are therefore not zero in this case.

Table 1: An overview of social impacts included in Social LCA approaches (28). There is no link between the columns.

Worker related issues	Society related issues	Product user related issues
Non-discrimination	Corruption and bribery	Integration of customer health and safety concerns in product
Freedom of association and collective bargaining	Development support and investment in society	Availability of product information to product users
Child labour, incl. hazardous child labour	Job creation	Ethical guidelines for advertisements of product
Forced and compulsory labour	Local community acceptance of company	
Level and regularity of wages and benefits	Company commitment to sustainability issues	
Physical working conditions - Working time and wage payment - Disciplinary actions - Health and safety of employees		
Psychological working conditions		
Training and education of employees		

Table 1 shows some examples of social aspects that can be included in a SLCA. There exist different approaches of how to assess the most important social impacts. The most used approach is to include general agreed upon important factors based on international conventions related to working conditions (29). Another approach has been to evaluate the importance of different social impacts from theoretical frameworks. The last approach is to identify social impacts relevant to the SLCA through participatory processes including stakeholders affected. However, if opinions vary among the individual stakeholders then it is hard to summarize impacts across life cycle stages using this last approach. Different approaches for data collection has also been proposed and some of the most common are site-specific data, national and regional regulatory frameworks, monitoring agencies, and socio economic conditions.

The different social impacts in a SLCA can supplement Porter's five competitive forces. An increase in the availability of production and product information to users could lead to a change in buyer power. This could be e.g. child labour or health and safety procedures at the site. Another example could be that the company on the basis of either a social or environmental LCA considers to change supplier, the supplier power could be affected as a result of stricter demands from the company. This could have both positive and negative social consequences for the workers at a supplier site whether or not the supplier decides to comply with these new demands. Factors such as corruption, bribery or local acceptance of a company can in the same way affect the "treat of entry" and "industry rivalry" categories. SLCA is related to the social factor in the PEST analysis, and it is a factor that can affect all five competitive forces.

2.7.Life Cycle Management

In continuation of LCT a concept called life cycle management (LCM) has emerged which incorporates the three pillars of sustainability. A definition of LCM from United Nations Environmental Programme (11):

"Life Cycle Management (LCM) is a product management system aiming to minimize environmental and socio-economic burdens associated with an organization's product or product portfolio during its entire life cycle and value chain."

In order to utilise LCM relevant stakeholders, processes, factors and effects will have to be addressed. The purpose is to manage and make decisions not only for environmental impacts as e.g. in a LCA analysis, but also for economic and social impact related to the life cycle of a product or service. There is no dedicated theory or dedicated LCM methods, and so far LCM is comprised of many tools and methods for different LCM areas where LCA is one of the tools (11).

Another similar concept termed life cycle sustainability management (LCSM) also aims at improving all the three pillars of sustainability at the same time. LCSM is defined as (30):

"a strategic management system which aims at minimising an organisation´s negative impact on the natural and social environment by its products or services along the entire product/service life cycle and value chain, to warrant that natural, social and economic resources are sustained for future generations."

Here the word strategic has been added to the concept of LCM. Strategy is understood how a company can have a valuable position, plan or ploy contributing to a sustainable development.

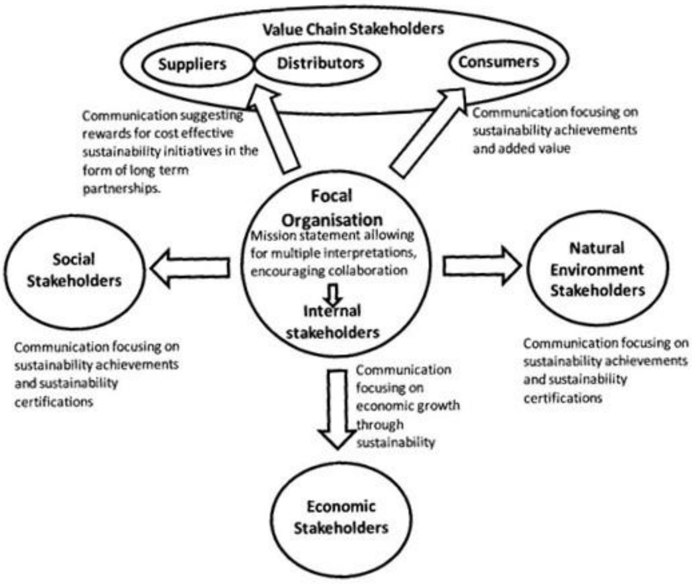


Figure 9: Framework for sustainability stakeholder management in a LCSM context (31).

Scandelius and Cohen (31) describe how communication with stakeholders with diverse interests can be made if an organisation wants to implement LCSM. Scandelius and Cohen recognise that in order to achieve LCSM all the stakeholders along the product chain must collaborate even though there might be tensions.

They further suggest five categories of sustainability stakeholders needed to be managed to develop a sustainable strategy (see Figure 9).

LCM and LCSM both wants to incorporate life cycle thinking into management to obtain sustainability through the involvement of stakeholders. Where LCM is product orientated LCSM is focused on the company's sustainable strategy.

2.8. Combination of Strategy and Sustainability

As mentioned in the previous sections theoretical models exist for how a company can analyse its business environment. Different frameworks for incorporating sustainability in the decision making process exist with LCA as one of the tools to estimate physical environmental impacts. Even though the two fields use different terms with strategic management using words like power, force, rivalry, and competition and life cycle thinking using words like sustainability, stakeholder, communication and functional unit an attempt to combine the two will be made.

In the following it will be described how a LCA study can supplement Porter's five forces when analysing the present strategy of a company. The similarity between Porters five forces and LCA lies in that both methods can be used to evaluate a product system. Where Porter is focused on the manmade social effects of competition, the LCA focuses on physical processes and impacts on the environment.

One of the competitive forces is supplier power where a supplier can be described as someone delivering raw materials or other input to a company. Supplier power is described as the power relationship between a supplier and a company i.e. how easy it is to switch from one supplier to another or how many suppliers exist on the market. The quantitative sustainability of a raw material from a given supplier can be analyses and evaluated by means of a LCA and be used to assess the supplier power. If for instance a company wishes to pursue a more sustainable business strategy a LCA can identify environmental hot-spots in the supply chain. The company can then evaluate how this will affect the power relations with its suppliers. The hot-spot identification can affect supplier power by putting stricter demands related to emission or environmental impacts on the supplier. However, if the given supplier is one of few who produce a certain environmentally friendly product or service such demand would increase supplier power. An analogy between the use phase in LCA and buyer power between e.g. a shipyard and a ship owner can be made in a similar way (see Figure 10).

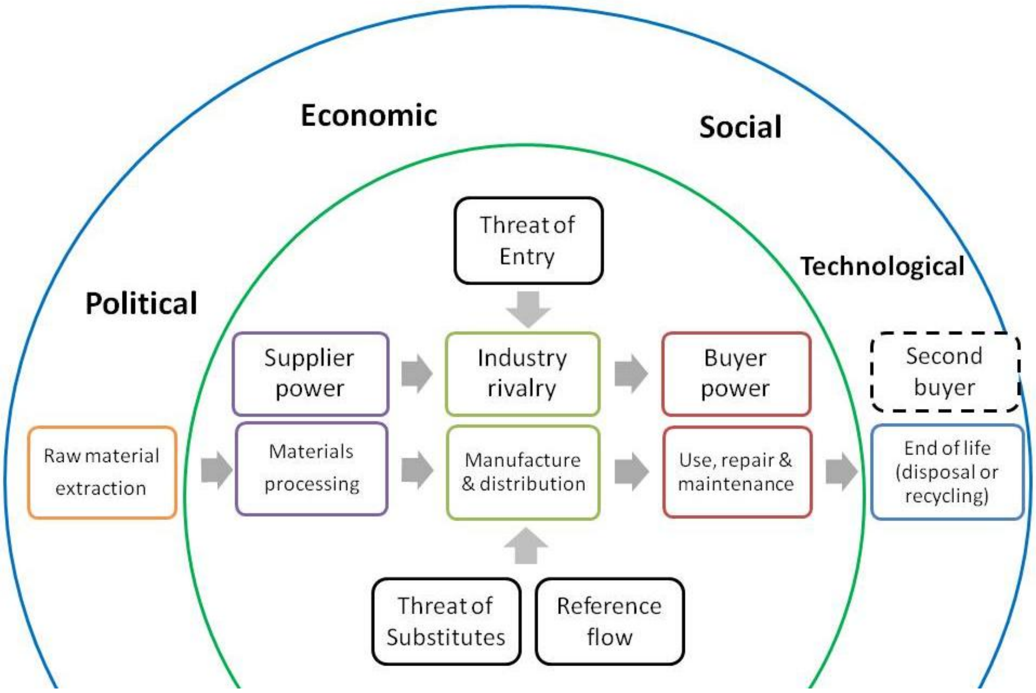


Figure 10: The link between LCA and Porter's five forces. The green circle illustrates the industry environment and the blue circle illustrates the macro environment. The PEST factors are randomly placed in the macro environment.

For the company itself the analogical link between LCA and Porter's five forces lies in the connection between the production phase and industry rivalry. If the LCA identifies environmental hot spots within the company´s own production process an elimination of these hot spots might differentiate the product from competitors and increase the level of profitability. If an LCC analysis is done showing a cost saving by switching to a less effective and less polluting material this will also affect competition among companies inside the industry.

In the LCA methodology the final phase in a product chain is called end-of-life (EOL), where remaining waste of a product re-enters the ecosphere. Porters five forces do not describe what happens with a product once a consumer is done using it. It can be that Porter just saw the product entering into the macro-environment or that waste treatment was someone else's problem. However, if a company wants to pursue a sustainable strategy it has to consider what happens in the end-of-life phase when the product or service is disposed. If recycling or waste treatment is handled by a third party this could be seen as a second buyer in the Porter methodology (32).

A forth force named threat of substitutes can be related to reference flow in LCA terminology. In this study the two reference flows are a ferry build in aluminium with a specific weight versus a ferry build in CFRP with a specific weight. In Porter's model these would be seen as two substitute products fulfilling the same function or need.

The fifth competitive force is threat of entry. The threat of entry can be reduced by using the LCA in a marketing perspective and hence increasing the company´s own brand values. This will demand a critical review of the LCA and will mainly work if the surrounding society appreciates environmental products. If a LCA were made mandatory for all products sold in a given industry this would affect the threat of entry, because new entrant would have to make a LCA on all their products before entering the market. Making a consequential study, i.e. analysing what changes in the surrounding economy if a company changes it way of doing business could be evaluated together with the threat of entry. Lastly new materials or technological inventions could also affect threat of entry.

Rarely does production exists (see Figure 6), were raw materials goes into one single company and fully consumer ready products comes out. More often production of a consumer product goes along a production chain with many smaller companies, being supplier and buyers to each other. Still from a company´s point of view all suppliers of semi-manufacture can be seen as delivering the company´s input materials. Production upstream can be considered as materials and suppliers, and downstream the stakeholders can be considered as buyers in the use-phase.

In Figure 10 a blue circle illustrating the macro environment can be seen. As mentioned earlier a PEST analysis will be used to get an overview of the macro environmental factors. In the LCSM-methodology (see Figure 9) the sustainability stakeholders can be categorized into value-chain-stakeholder, social stakeholder, Natural Environment stakeholders and economic stakeholder. The values-chain stakeholders correspond to the stakeholders in Porter's model; supplier, industry and buyer (20). The Social stakeholders relate to the social factor of the PEST, the economic stakeholders relate to the economical factor of the PEST, and finally the natural environment stakeholders relate to all categories in the PEST. Scandelius and Cohen (31) talk about how a company communicates its sustainable strategy to the different type of sustainability stakeholders while a PEST analysis specifies the factors from the macro-environment that can impact a company (21). The categories or factors that the two methods look at are the same, but the difference is the way the impacts are directed either to or from a company.

A few examples will be given showing the relation between macro environmental factors and sustainability. Political factors are related to governmental policies or regulations that can have significant influence on all phases in the life cycle and their related costs. Governments or regulatory bodies can support a sustainable development by taxing pollution and toxic materials or by subsidising sustainable solutions. The technological factor relates to all phases as well since technological inventions and progress can affect many different stages in the life cycle. It can increase efficiency of a product in the use phase or lower material use in the manufacturing phase. Technology is an important and inevitable factor to consider when discussing strategic analysis and sustainable development coherently (23).

Sustainability and strategy is combined because most quantitative sustainability assessment methods have a focus on current environmental impacts and don't include ways of planning for the future. Here the strategic methods can help in analysing possibilities and barriers for sustainability development. This interdisciplinary method can suggests which actions are needed to become sustainable.

2.9.Design for Sustainability

Examples of previous research combining strategy and sustainability will be presented. This has been done in studies related to design thinking and below three sources related to design for sustainability is presented.

The first source is an article by Anastas and Zimmerman (23) that presents twelve principles of green engineering. It is a framework for understanding and representing the engineering techniques that are being used to become more sustainable. The twelve principles should not be considered rules or inviolable standards, but instead a set of guidelines for thinking in terms of sustainable design that can aid in achieving sustainability. According to this article green engineering needs to include life cycle consideration and multi scale applications when looking at design for sustainability. A couple of the twelve principles will be referred to later in this report.

A second source is an interview with Steven D. Eppinger (33) about design for environment. According to Eppinger the implementation of sustainability is crucial, but it is more than just reducing waste or improving energy use. He points out that product design is important because this is where the materials decisions are made. According to Eppinger sustainability is fundamentally a material problem, since there is only so much one can do in operations. Very often the bad stuff that is happening in operations and production like toxins or wastes originates from the design of the product, and to solve this you need product redesign. It is not a question about how much material you use, but more a matter of what materials you use and what happens to them after you have used them.

In Figure 11 an illustration of the two different life cycles a material goes through is found. According to Eppinger there is nothing inherently bad with the industrial life cycle except the disposal step, and if managed right this can be a good cycle. Companies need to take responsibility for the materials throughout the entire product life cycle and limit themselves to use only materials that can be recovered, recycled or reused without degradation. The illustration is a bit similar to the approach used in this study where the natural bio life cycle is investigated using a LCA analysis and the product industrial life cycle is investigated using Porter's five forces model. Eppinger is a bit critical about the use of a LCA analysis, because as he says such an analysis does not reduce anything, it just tells you how bad it is. The trouble is that if people think that a detailed assessment like LCA is needed before any improvement can be made this might hamper some really opportunities to make improvements in the right direction.

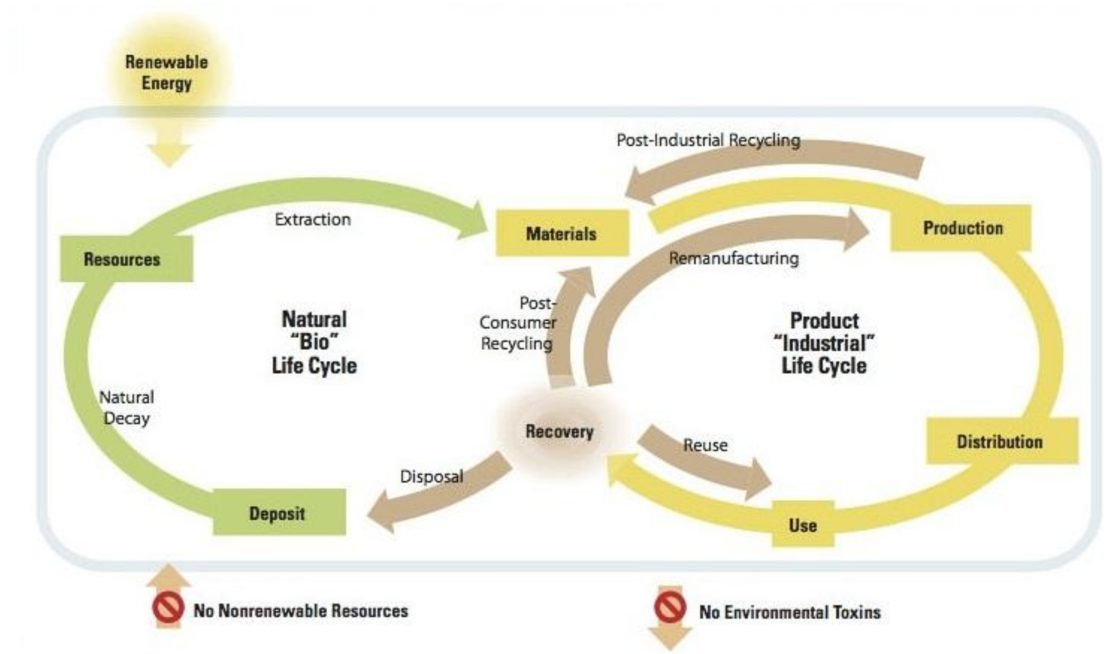


Figure 11: illustration of the life cycles a material travel through first in a biological life cycle and then an industrial life cycle (33).

A third source found is a project funded by the Danish Environmental Protection Agency which looks at the integration of sustainable development and value creation into the design of new products and services (34). The project adopts a life cycle approach consisting of seven steps, which demonstrate how to tackle the environmental challenges in product development. According to the authors approximately 80% of a product's environmental profile is fixed under concept creation in product development (34). The life cycle approach in this project tries to incorporate environmental concerns into a strategy and therefore have similarities with the approach in this report.

Chapter 3 Methodology

This chapter will include a presentation of the research methods used and argumentation for the usability of these methods. The case studied is Tuco Marine Group ApS and their activities with a particular focus on three Norwegian high speed catamaran CFRP ferries build around 2009-10 named Kistefjell, Sollifjell and Fløyfjell.

The case study will be an instrument to gain insight into the link between sustainability and strategy. The environmental effects of sustainability will be described through a LCA. The link between business strategies and the environmental concerns will be analyses using Porter's Five Forces and PEST. By looking at the Danish composite shipbuilding industry it will be described how business strategies and environmental concerns can supplement each other to achieve sustainable development.

The LCA analysis was conducted following the guidelines in the ILCD handbook (22) and for data and impact calculation a software program called Gabi 4.4 with the EcoInvent 2008 database was used. In the strategic analysis the qualitative methods of Porter's five forces and PEST was used.

Qualitative methods were relevant to use because a business environment is a social reality. The data collection consisted of interviews with relevant stakeholders, observations, literature research, participation in events and background material. During the study relevant knowledge was documented by transcription of interviews and notes taken at conferences or other observation settings (see appendix 1-18). Interviewees were found through networks and recommendations both inside and outside DTU. The interviewees were selected based on their relevance and connection to the case or if they belonged to the Danish Maritime sector and had knowledge or experience with composite or aluminium ferries.

The collection of data for both the qualitative and quantitative aspects were found to support each other, since some of the interviewees with information regarding the quantitative data also had information relevant for the qualitative parts. This was especially the case for Kai Nielsen, Steinar Mathisen and Christian Berggreen.

3.1.Data Collection

The authors of this study attended three events which all concerned the Danish maritime sector. The first event "Cheap Green Ferries" was a one day conference in Middelfart hosted by Marcod, which is a maritime centre for optimization and operation. It was about cheap and green lightweight ferries with a particular focus on new ways of designing and building ferries in Denmark. The second event called "Composite Materials and Reality" held in Copenhagen was about composite materials and their relevance and potential in the shipbuilding industry. This conference was hosted by the Engineering union IDA and Ship-technical Society (Skibteknisk Selskab). Finally the annual meeting of Danish Maritime held in Copenhagen was attended.

Below a list of the three events with original titles and dates:

- Billige Grønne Færger, Middelfart, 23th of January 2013 (Appendix 16)
- Komposit Materialer og Virkeligheden, København, 11th of March 2013 (Appendix 17)
- Danske Maritimes Årsmøde, København, 18th of April 2013 (Appendix 18)

A two days field trip to Tromsø in Norway was arranged as part of the data collection work. The economic resources for the trip came as a scholarship from Skibteknisk Selskab. The three catamaran ferries were operating in the area of Tromsø and during the trip interviews with various stakeholders were made together with pictures and observations obtained during the ferry ride from Tromsø to Harstad and back again. The field trip took place between the 29th and 31st of May 2013.

Tuco has been visited at total of three times. First visit was in December 2012 prior to the start of the thesis to start up the cooperation, the second visit was a two day trip in March 2013 to gather information and the third trip was in June 2013 to follow up on information and receive feedback. In addition ongoing communication with Tuco was done by e-mail and phone.

3.2.Interviews

During the research several interviews were conducted. In Table 2 is a list of interviewees and their relevance for the study can be found.

Table 2: A list of the interviews conducted during the study. The first part consists of the most relevant interviews, and the last part consists of less relevant interviews.

Most relevant interviews			
Name	**Occupation**	**Relevance to the study**	**Focus of the interview**
Kai Nielsen (See Appendix 1)	Production manager at Tuco Marine Group	Responsible for production and procurement and with extensive knowledge about the hull production of the three catamaran ferries	Data collection for the quantitative LCA analysis, relationship to suppliers and designers, history of the company, competitive advantage and organisational structure
Jonas Pedersen (See Appendix 2)	CEO and founder of Tuco Marine Group	Initial contact. Knowledge about the strategy and marketing, taking care of customer contacts and decisions	The future of the company, market segments, customers, competitors, durability of CFRP, cooperation and political agenda.
Kristoffer Jensen (See Appendix 6)	COO at Danish Yacht	Employee at another shipyard building in composite materials	Industry rivalry, suppliers, customers and market potentials
Torsten Arnt Olsen (See Appendix 3)	Chief surveyor at the Danish Maritime Authority	Works with regulation on a daily basis and knows the barriers for building ferries in CFRP	IMO, SOLAS and EU regulation, fire safety, challenges of CFRP, and alternative design.
Steinar Mathisen (See Appendix 10)	Daily operation manager at Boreal Transport Nord	Been part of the project from the first day of the CFRP ferries as manager at Boreal	History and experiences with the CFRP ferries, maintenance and service.
Anonymous (See Appendix 5)	Naval architect at Danish ship design company	Many years in the business and point of view from this part of the industry	The way of doing business, and knowledge of CFRP

Name	Occupation	Relevance to the study	Focus of the interview
Christian Berggreen (See Appendix 4)	Associate professor at DTU Mechanical Engineering	Expert in composite materials and properties	Technical properties of composite materials
Grunde Jomaas (See Appendix 8)	Associate professor at DTU Civil Engineering	Expert in fire test and safety	Concepts of fire regulations
Arne Bløger (See Appendix 10 and 13)	Full time employee at Tuco Marine Group	Has done repair work and service on the CFRP ferries	Amount of maintenance and repair work
Michael Bruhn Rasmussen (See Appendix 9)	Commander at the Danish Navy	One of few with experience in maintenance and service of composite ships	Use and maintenance of glass fibre reinforced polymer ships
Less relevant interviews			
John Hansen (See Appendix 10)	Captain at the catamaran ferry Sollifjell	Immense experience in sailing and operating one of the CFRP ferries	Opinion of the ferries and manoeuvre capabilities
Unknown name (See Appendix 10)	Captain at the catamaran ferry Fløyfjell	Immense experience in sailing and operating one of the CFRP ferries	Opinion of the ferries and manoeuvre capabilities
Kjetil Vik (See Appendix 11)	Journalist at the local newspaper iTromsø	Written a lot of articles about the three ferries	The public opinion in Tromsø of the three CFRP ferries
Anders Schmidt (See Appendix 12)	Project manager at Force Technology	Involved in research about recycling of composites	Reusability and recycling of carbon fibre and CFRP
Henrik Dam (See Appendix 14)	Naval architect at Grontmij Denmark	Knowledge about the Danish maritime industry	The way of doing shipbuilding business
Michael (from Lithuania) (See Appendix 15)	Foreign subcontractor	Works part time at Tuco on different projects	Foreign supply of workforce.
Claus Bo Jenstrup (See Appendix 7)	Surveyor at Det Norske Veritas (DNV)	Knows the role of a classifications society	A general talk about DNV and rules

All interviews were structured beforehand with a list of subjects and questions for each interview respectively. The actual conduction of an interview was less strict with some questions omitted and new included which in some cases gave room for an open discussion about the research topic. Minutes and transcription from most of the interviews can be found in appendix 1-15.

Chapter 4 Descriptive

In this chapter descriptive sections needed to understand the context of the study will be presented.

4.1.Steps for Building a Ship

A list of the different steps needed before a ship can be built, from the initial dialogue between the ship owner and the naval architect until the complete manufactured ship at the shipyard, is seen below. The list is made based on interviews with Kristoffer from Danish Yacht and a Danish naval architect (see Appendix 5 and 6).

1. Early assessment where a ship owners comes with an intention or idea for a new ship to a naval architect.
2. The naval architect comes up with a conceptual proposal and an outline project.
3. A number of project prices from various shipyards are collected based on the outline project and a shipyard is chosen.
4. The next phase is a very close collaboration between the shipyard, the naval architect and the ship owner, where a basic design is made.
5. A naval architect continues with the calculation of the weight based on the specifications of the basic design and in the meanwhile a more precise price is calculated by the shipyard.
6. A point is now reached where everyone agrees about what to build and commits to a speed, a weight and a price.
7. In the next phase the naval architect makes class drawings while the shipyard makes production drawings and initiates the procurement process with suppliers.
8. Then the ship is built with a continual collaboration and communication between all three parties.

4.2. The Blue Growth Plan

On Wednesday the 12th of December 2012 the Danish government announced the first part of its blue growth plan called “Den Blå Vækstplan” (2). The plan concerned the maritime industry in Denmark and had a whole section related to shipbuilding in lightweight materials. The section stated that shipbuilding in new materials like carbon fiber or other lightweight materials had both growth- and environment potential. The potential was especially high for passenger ferries or ships since considerable savings on operation cost and environmental benefits could be achieved when operating a ship that was around 71% lighter than a ship of steel (5). The weight reduction would result in lower fuel consumption and reduced emissions of CO_2, SO_x and NO_x. According to “Den Blå Vækstplan” the public sector had a central role since they could be a potential buyer of lightweight ferries. However, it was outlined that a number of technical conditions such as fire safety needed to be clarified before lightweight ships could be competitive against metal ships.

In the latest governmental budget from spring 2013 20 million DKK has been earmarked for green maritime solutions with special focus among other on new ship types. The money are among other for demonstration projects related to retrofit of existing ships, alternative fuels and shipbuilding using new lightweight materials like composites (35).

4.3.High Speed Craft Code

A general philosophy behind conventional ship safety relies on a ship being built in steel and with all necessary emergency equipment being carried on board. The High Speed Craft (HSC) code (36) recognizes that safety can be enhanced by the infrastructure associated with regular service on a particular route. The code was introduced in 1996 by the IMO. One of the reasons behind was that numerous new designs of marine vessels had been developed and put into service during the last couple of years. Though some of these designs did not comply with regulation related to ships build in steel they demonstrated an ability to operate at an equivalent level of safety when engaged on restricted voyages under restricted operational weather conditions and with approved maintenance and supervision schedules. The HSC code has a functional approach allowing for the use of other non-conventional and combustible materials like composites, provided that a safety level at least equivalent to conventional ships is achieved. These non-conventional materials also need to meet strict criteria related to fire reaction divided into six different space categories (see HSC code description (36)). The application of the HSC code is limited to passenger ships on voyages not further than 4 hours from place of refuge. A high speed craft is defined as a craft capable of reaching a speed equal to or exceeding:

$$3.7\ \nabla^{0.1667} (\mathrm{m/s})$$

Here ∇ is the displacement corresponding to the design waterline measure in m^3. Maximum speed of the three CFRP catamaran ferries is 33 knots (≈17 m/s) resulting in a displacement of maximum 9390.5 m^3.

4.4.History and Properties of Carbon Fibre

Compared to aluminium and steel carbon fibre is a new material for use in shipbuilding. In the following the history, the physical properties and production application of carbon fibre will be described.

Figure 12 : A close-up picture showing the carbon fibre laminate structure (37).

Carbon fibre is not a new material for use in commercialized products. In the beginning of the 1970s it was used in spacecraft and military applications with a price of 150 US dollar per pound of carbon fibre (38). Through the 1970s, as a result of more efficient production methods, the price decreased to around 65 USD per pound and applications of carbon fibre in the military and aerospace industry expanded. In the following decades application in other areas like sporting goods, construction and car manufacturing has been introduced and today the price of one pound of carbon fibre is 5 US dollar (3). The manufacturer capacity is expected to double in the next 10 years going from 97.500 tonnes in 2011 to 186.000 tonnes in 2020 (38). Carbon fibre has reached a stage where the cost of production is low enough and the capacity high enough to make it desirable for new applications like shipbuilding.

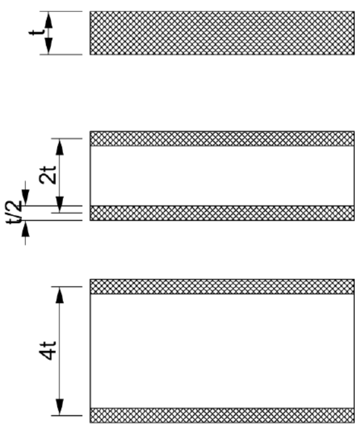
Table 3: Basic properties of fibres and metals (HS – high strength, HM – high modulus, GPa – gigapascal) (39).

Material Type	Density [kg/m^3]	Tensile Modulus [GPa]	Tensile Strength [GPa]	Fibre Cost of 300g/m^2 [£/m^2]
Carbon HS	1800	160 - 270	3500	14
Carbon HM	1800	325 - 440	3500	N/A
Aramid HM	1450	120	3100	9
Glass E-Glass	2500	69	2400	2
Glass S2-Glass	2500	86	3450	7
Mild Steel	7850	205	450	
HS Steel	7850	197	1241	
Aluminium	2700	1069	400	

In Table 3 the basic properties and cost of different fibres, steel and aluminium can be found. Tensile modulus is a measure of the stiffness of an elastic material while tensile strength is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking (40). Carbon fibre does not react as well on strong impacts as glass (especially S2-Glass) or Aramid fibers but properly engineered laminates can utilize carbon very well for impact loads such as slamming in power and off shore boats (41).

4.5.Sandwich Structure

Composites are often used in a sandwich structure to achieve stiffness. Figure 13 shows the difference in rigidity and strength for a single skin structure and for two sandwich structures with different core thickness. The weights of the three structures are almost the same, but the properties are different with both of the sandwich structures being stronger than the single skin structure. There exist various kinds of core materials, but some of the most used are balsa wood, polyurethane foam and PVC foam (42).



Weight	Flexural Rigidity	Bending Strength
1	1	1
~1	12	6
~1	48	12

Figure 13:"Sandwich Effect" showing the difference in stiffness and strength of using a sandwich structure. The numbers has no unit and are just used for comparison (43).

To make a sandwich structure the fibers are affixed to a core material using adhesive. Figure 14 shows the manufacturing of a sandwich structure.

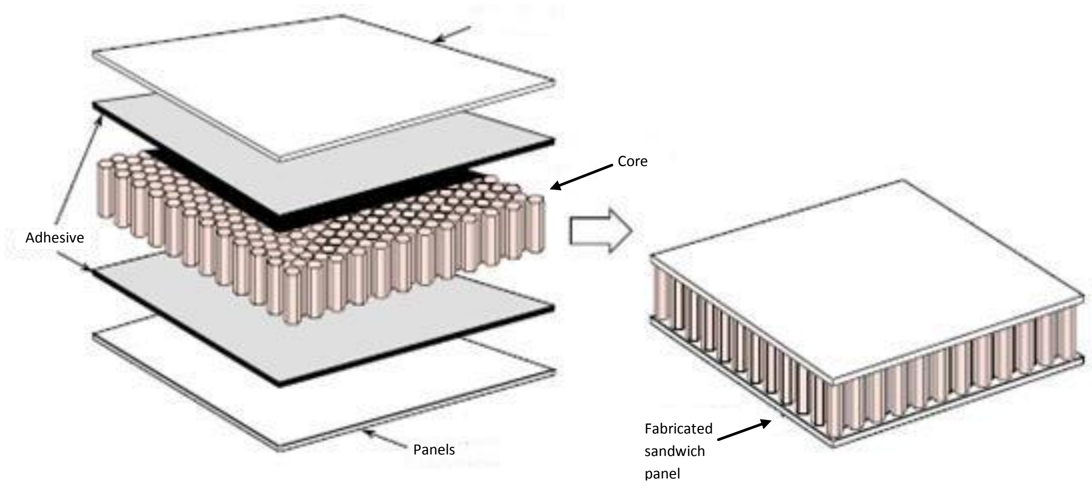


Figure 14: Manufacturing of a sandwich panel in this case using an adhesive layer (43).

The fibre panels are adhesively bonded to the core to obtain the strength and stiffness of the sandwich structure, and only as long as the bonding between the fibre and core is contained the sandwich will keep its strength. A peak laminate strength is achieved when the Fibre Volume Fraction (FVF) is around 60-70 % (43). FVF is the ratio between fibre percentage and resin percentage of a laminate.

4.6.Manufacturing Technique

Manufacturing sandwich structures in pre-designed shapes can happen in the production method called Vacuum Assisted Resin Injection Moulding (VARIM) sometimes also named VARMT.

The main steps in the VARIM technology are (44):

1) Mould preparation and fabric lay-up
2) Sealing the mould and creating a vacuum
3) Resin preparation and degassing
4) Resin impregnation
5) Cure of fabricated panels

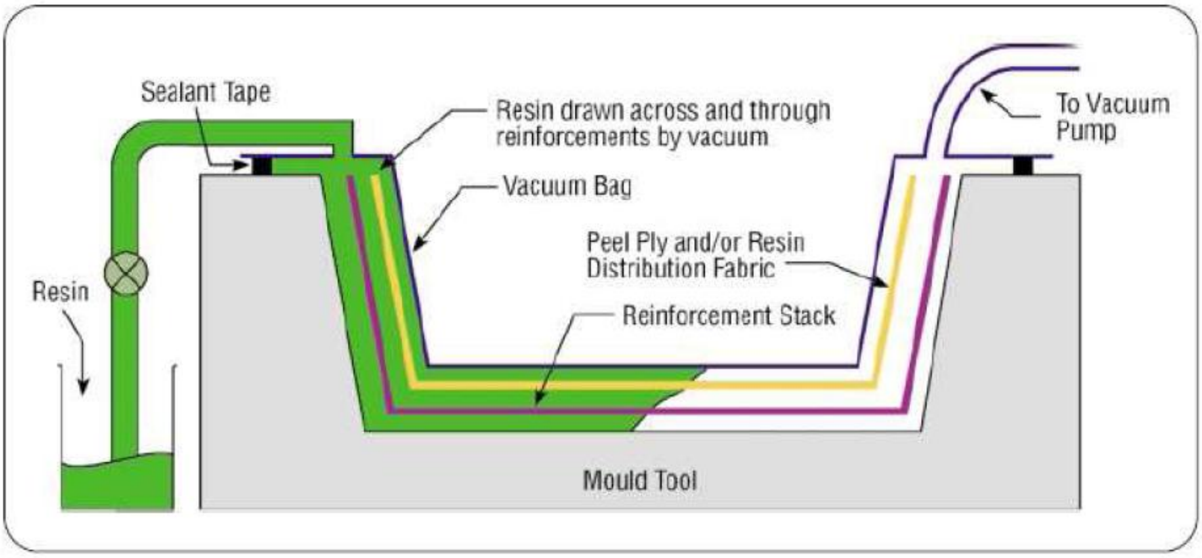


Figure 15: Principle of vacuum infusion in this case using a she mould (45).

Figure 15 shows the manufacturing technique VARIM, a low-cost manufacturing method, which injects resin into fibre fabrics using vacuum with a one-side mould (46). Instead of adding the resin by hand it is injected via a vacuum pump. The whole structure is sealed with tape and a vacuum bag and the resin is then drawn across and through reinforcements by vacuum. After injection the resin needs to harden at room temperature for around 24 hours. A thin layer of porous release material is used between the mould and the resin for easy removal of the hardened composite panel. One advantage of using injection is the high content of fibers in the final product (FVFs up to 50-60%) compared to the content of fibers obtained when adding the resin by hand (FVFs ~40%) (43).

On Figure 16 two different types of moulds is illustrated. The u-shaped she-mould is one way of producing composite hull structures and the other is a he-mould. Tuco mainly uses a he-mould which means they builds the structure on the outside of the mould instead of inside the mould, since this method is less time consuming and demand a smaller mould (Appendix 1). A he-mould method can however sometimes demand more fill work.

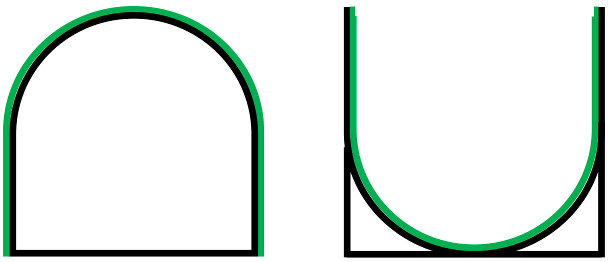
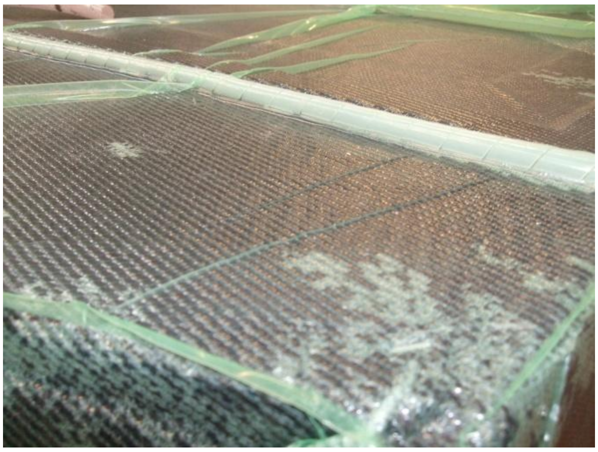
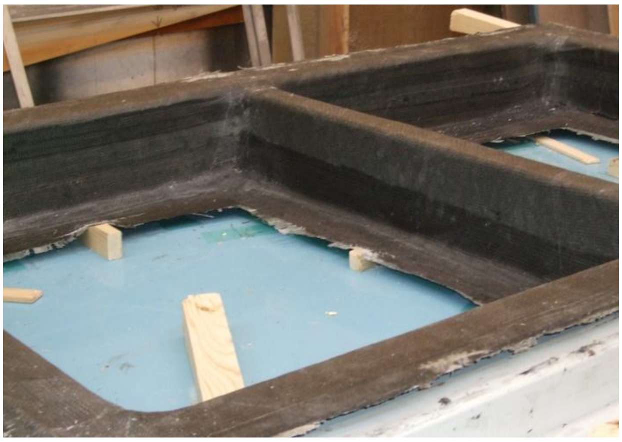


Figure 16: Left: he-mould, right she-mould. Black is the mould, green is the sandwich polymer structure.

Below is some pictures taken from the production hall at Tuco to illustrate the different steps of the manufacturing technique. Figure 17 shows an element placed on a he mould ready for resin infusion which will end up becoming a part for a safety vessel. The element is covered in green plastic and underneath and above lays plastic tubes to distribute the resin. Under the tubes and the green plastic is a white layer called peel ply which is a parting agent material that ensure the plastics do not bond with the laminate in the hardening process. On Figure 18 the resin has been infused.

Figure 17 : Tuco production hall, the piece is ready for resin vacuum infusion. The person on the left is production manager Kai Nielsen.





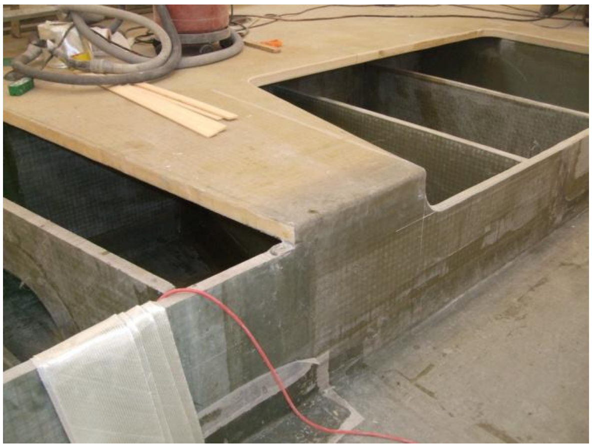


Figure 18: The first picture shows a structure which has been filled with resin. The second picture shows a hardened part. The third picture shows part of a composite hull which is nearly finished.

4.7. The Shipyard Tuco

Tuco Shipyard was founded in 1998 by the two 22 years old boat builders and entrepreneurs Jonas Pedersen and Jakob Frost (47). At that time the company's primary products were speedboats and turnkey yachts both luxury yachts and smaller yachts mainly for private customers. The company had facilities to build boats up to 80 foot with sales prices up to 25 million DKK. In the beginning of the 20th century Tuco Shipyard was the first Danish shipyard to be able to build in aluminium and won in 2005 the Danish Industry's enterprise award for the company's strong entrepreneur spirit (48). In 2008, as the global economy experienced recession the market for yachts also experienced decreasing sales, which lead to a bankruptcy in 2008 for Tuco Shipyard. After the bankruptcy the owners and employees re-evaluated the strategy and formed a new company called Tuco Marine Group ApS. As a result the workforce went from being around 50 full-time employees with 10 people working in the administration to becoming a company of only 11 full-time employees with 4 of these working in the administration (Appendix 1). As part of the new strategy sub-contractors from Eastern Europe were hired on contracts based on projects in the order book. The focus of Tuco Marine Group became to build ships in carbon fibre and glass fibre for the commercial market. This new focus on commercial ships came after Tuco Marine Group had received an order for manufacturing of the three CFRP hulls for the Norwegian ferries investigated in this study.

At present Tuco Marine Group has a management consisting of the director and co-owner, Jonas Pedersen, a technical expert and second co-owner, Jacob Frost, a production manager, Kai Nielsen, and a designer, Jakob Rasmussen. Once a week an external accountant uses about half a day to do the financial and account work. Besides the management there are five permanent employees and two apprentices organized under the production manager Kai Nielsen. The main part of the permanent employees has been in the company for more than 10 years and the newest employee was hired two years ago. The apprentices are boat building students and background of the other employees is farmer, plast processing technician, carpenter, auto mechanic, and boat builder respectively. In Figure 19 the organisation diagram is illustrated.

Some of the permanent employees have been given supplementing responsibilities as for example project management and purchase of materials. However, it is mainly the younger employees who are interested in additional responsibility (see Appendix 13).

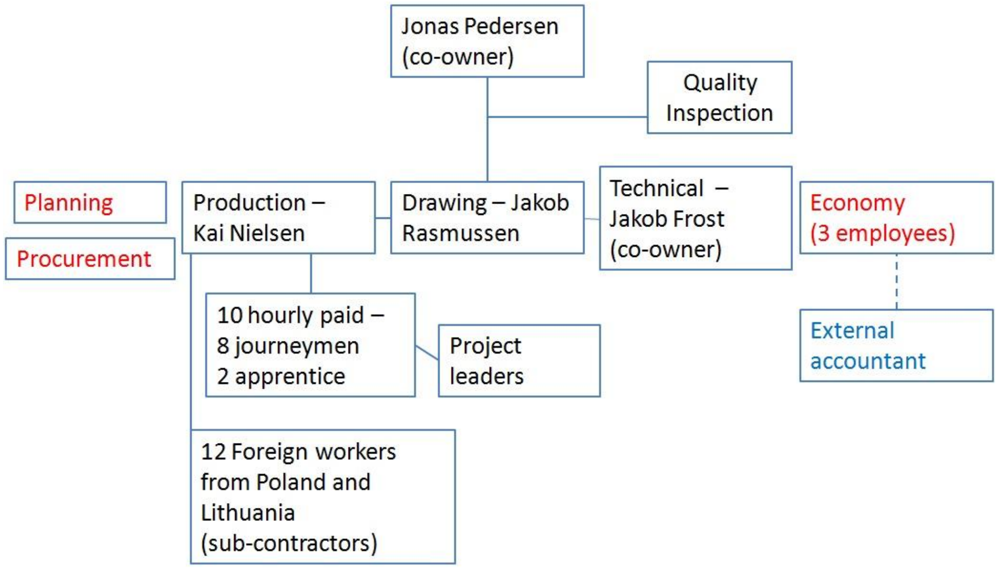


Figure 19 : Organisation diagram of Tuco as of June 2013. Red text marks departments existing before the bankruptcy in 2008

When Tuco receives a big order they hire a foreign sub-contractor to aid in the production process because it is cheap and skilled labor. In Marts 2013 sub-contractors from shipyards in Poland and Lithuania are working on different projects at the Danish shipyard. Many of the subcontractors have worked at Tuco in previous projects and are well-know with working at the shipyard. The foreign employees has to comply with the same rules and safety standards as the Danish employees and at least one of the foreign employees must be able to speak English and act as an interpreter for the others.

Tuco cannot plan further ahead than their order book, which can be booked from one week to one and half year into the future (Appendix 2). Within the company they try to plan 3 to 5 years in advance for example by maintaining good relations to their customers. At the shipyard they do not manufacture turnkey ships, but focuses on being specialized in manufacturing of high quality carbon fibre hulls for assembly at other shipyards. They do not make calculations of the sandwich structures, but with their experience and know-how they can see when something is e.g. oversized or a design can be optimized. In the future they would like to be able to communicate this kind of evaluation of the design of the structures to the naval architect and act as a consultant partner in the design phase. Today Tuco has competencies and permission from the Danish maritime authorities to build in carbon fibre, glass fibre and aluminium.

4.8.Case Study of Three Norwegian Catamaran Ferries

In 2008 the municipality of Troms decides that three of its ferry routes should be put out to tender. One of these routes “route 2” covered transportation by sea between Tromsø, Finnsnes and Harstad. In the tender documents it was specified that the company given the contract should operate the route in the period 1.1.2010 to 31.12.2019 (49). The conditions given by the contracting authority which in this case was the municipality of Troms were dated 11.06.2008 and offers from the operating companies were received October 2008. The company given the contract ends up being Veolia Transport Nord AS which in 2011 was bought by another operating company called Boreal Transport Nord AS (Appendix 21).

Route 2 had previously been covered by two high speed catamaran ferries called “MS Fjordkongen” and “MS Fjorddronningen” both build in aluminium in 2005. One of the reasons for replacing these relative new ferries was a focus of the municipality to make the ferry service even more environmental friendly and reduce fuel costs. The intention was to move the passengers away from using their own car or taking a plane and instead start travelling with the more environmental friendly fast ferries (Appendix 21). This can also be seen in the tender documents where emissions from CO_2 and NO_x are weighted 80% and price is only weighted 20% in the decision. All the tenderers therefore had to specify what their calculated yearly emissions in tonnes and price of the solution would be. Each tenderer was then assigned a score given as:

$$Score = \frac{n - r_p}{n} \cdot 0.2 + \frac{(n - r_{e1}) + (n - r_{e2})}{n} \cdot 0.8$$

Where n is the sum of tenderers, r is the rank of either price p or emission e in relation to the other offers. The tenderer with the highest score would then be given the contract. There was an exception that only offers which were less than 20% more expensive than the cheapest offer would be considered and get a score. The offer from Veolia Transport Nord consisted of three catamaran ferries build in carbon fibre composite material with a weight of 79 tonnes, length of 35 meter, width of 10.5 meter and passenger capacity of 250 people. The ferries would be built by a shipyard called Umoe Mandal AS (also known as Båtservice Mandal) and had to comply with the high speed craft code with a maximum speed of 35 knots and only one passenger deck (49). The ferries would have five employees on board consisting of a captain, a ship’s mate, a chief engineer, a seaman, and one servicing the kiosk. A total contract price for the three ferries of 160 million NOK was signed. The total distance sailed each year by all three ferries was calculated to be 351,656 km with a more precise distance between the five stops on route 2 given by (49):

Tromsø – Finnsnes: 69.524 km

Finnsnes – Brødstadbotn: 30.570 km

Finnsnes –Harstad: 81.887 km

Brødstadbotn – Engenes: 27.506 km

Børdstadbotn –Harstad: 54.667 km

Engenes – Harstad: 28.137 km

Figure 20 : Route 2 from Tromsø to Harstad (Google Maps).

In 2007 the route had a total number of passengers of 236,239 which gave around 120 passengers per trip from Tromsø to Harstad with 19 of these trips per week (49). The fuel tank on all three ferries had a capacity of 3500 Liter which made it possible to take one round trip between Tromsø and Harstad per full fuel tank since the ferry consumed 16 liter per nautical mile (NM) (8.64 L/km).

When the project group around the three ferries had to find a company to manufacture the CFRP hulls, there was no capacity at the existing Norwegian shipyards. One of the project members had on a previous occasion ordered a private CFRP boat from Tuco and knew their competencies to build in carbon fibre. He therefore recommended using Tuco to manufacture the hulls (Appendix 1). Tuco won the contract for manufacturing of the hulls in competition with a French and Swedish shipyard (47).

The contract with Tuco Marine Group was signed in the spring 2009. The contract contained manufacturing of three hulls with first delivery in November 2009 and last delivery in February 2010. After a CFRP hull had been manufactured at Tuco it had to be transported by cargo ship around 700 km to the shipyard in Mandal where it would be assembled with engine, screw, and so on. The first hull to be assembled into a complete ferry was Sollifjell which left the yard in Mandal on 24th of March 2010. This was almost three month later than specified in the contract where the period of operation should have started on 1st of January 2010. The delay was caused by a court case of who should get the contract. However, this did not extend the period available for building the ferries, and therefore it was not possible to have them ready for operation on 1st of January 2010.

On her maiden voyage after leaving the yard on the 24th of March 2010 the brand new CFRP ferry Sollifjell experienced damages to the tunnel with some of the laminate plates falling off due to slamming. This gave the ferry a tough start with a lot of negative press coverage and in May 2010 weeks of criticism resulted in the municipality trying to terminate the contract with Veolia (Appendix 21). At the same time CFRP experts from both the Swedish company DIAB and the accident commission agree that the accident was due to an error in the design and not due to wrong production methods. The second ferry Kistefjell supposed to be delivered in April 2010 was delayed due to the accident and in June 2010 the shipyard in Mandal decided to rebuild certain parts on all three ferries in order to strengthen the material and modify some of the design of the tunnel.

Almost a year after the accident on 10th of March 2011 the second and third ferry Kistefjell and Fløyfjell respectively finally got approved by the Norwegian maritime authorities, while the first ferry Sollifjell was still being repaired at a shipyard in Aalesund. Shortly after the municipality again investigated whether it was possible to break the contract with Veolia, but it was shown to be too expensive so nothing happened. In the beginning of May 2011 the ferries Kistefjell and Fløyfjell were in operation for the first time, which was more than a year later than planned. However, only three days later they were taken out of service because the fittings on the docks and the gangway were not adapted to these new ferries and were unsafe for the passengers. The modification to the docks and gangway took nearly two month and cost 4 million NOK, but on the 1st of July 2011 the ferries re-enter operation. On 11th of August Sollifjell was carrying its first ever passengers after being repaired and approved. In the next couple of months the ferries were sailing regularly with some minor problems duo to diapers in the vacuum toilets, a wood sticks or otter in the screw and minor engine problems which delayed some of the departures. On request of the captains and after numerous collisions with the docks the maneuver power on all three ferries were improved in August 2011 by doubling the effect of the two auxiliary engines making it easier to enter and exit docks.

All the negative stories were still affecting the image of the ferries and in September 2011 a survey showed that only 1 out of 10 people in the Troms region wanted to keep the three catamaran ferries also supported by the fact that the number of passengers for August was 10% lower compared to the year before. The confidence from the business people was also low with only 39% using the ferries with the main argument that there was not enough room to work on the ferries. On the positive side in December 2011 it was concluded that after the three ferries was put into operation in the beginning of July 2011 and up to the end of November 98.2% of the departures had been completed and 94.7% had been completed in accordance to the schedules. The attitude among the passengers was improving with 8 out of 10 now claiming they were satisfied with the precision of arrivals and departures and the number of daily trips. At the end of 2011 Boreal Transport Nord, which had bought Veolia Transport Nord, published a press release stating that DNV had made measurements showing a reduction in fuel consumption of 57% and NO_x emission of 66% compared to the previous aluminium ferries Fjordkongen and Fjorddronningen.

In January 2012 all three ferries were out of service after damages to the hull. The damages happened due to collisions with the docks in Harstad and Tromsø duo to the harsh and windy winter weather and Boreal was considering whether the limit for when the ferries could sail should be changed. The municipality was still not satisfied with the service delivered by Boreal and send the 3rd of February a written notice to get out of the contract. The reasons was lack of regularity, repeated incidents of hull damage, inadequate control for detection of damages, violation of the requirements in the tender contract for maximum speed, and the accident on Sollifjell. During the winter months February and March bad weather hindered operation a number of times and statistic showed that 12.300 passengers most of them being commuters choose either car or airplane instead of the ferries in this period. In May 2012 the day to day manager of Boreal said the company was now better prepared to operate the ferries since the crew had gained experiences with the ferries which were completely unfamiliar for them in the beginning.

A survey made in June 2012 among the passengers show that 7 out of 10 were satisfied with punctuality, almost 10 out of 10 were satisfied with service and hospitality, and 3 out of 10 were satisfied with the price while 4 out of 10 were not. In general the passengers were also satisfied with cleaning, comfort, and information about safety procedures. Later it was published that the number of passengers for August 2012 were 12% higher compared to August 2011 and also higher than the number for 2010. After a relative quiet winter compared to the previous year the ferries had an increase in passengers in January and February 2013 and in the spring only two incidents with an engine and a gearbox respectively affected the schedule.

Chapter 5 Life Cycle Assessment

In order to assess the sustainability of composite shipbuilding the environmental effects occurring under production, operation and disposal of a CFRP ferry will be assessed and compared to a relevant reference. The environmental concerns will be evaluated by the use of a life cycle assessment (LCA) which is a quantitative analysis tool. A LCA describes the impact from the techno sphere on the eco sphere and in which phases of the life cycle these impacts occur.

This chapter contains goal and scope of the LCA, a description of the data used in the modelling (LCI), presentation of the LCIA results together with a sensitivity analysis, and finally an interpretation and evaluation of the validity of the results.

5.1.Goal

The purpose of the LCA is to answer the second sub-question:

"Which environmental effects occurs under production, operation and disposal of a ferry build in carbon fibre reinforced polymer and how are these effects compared to a relevant reference?"

This question is related to the goal of the LCA which is to assess how sustainable carbon fibre reinforced polymer (CFRP) is when used in the shipbuilding industry by looking at the environmental performance of passenger ferries. The degree of sustainability will be interpreted by a comparison with the environmental impacts of an aluminium passenger ferry of around similar size. The reason for using an aluminium passenger ferry as a reference flow stems from the strategic analysis (see section 6.1.5), where aluminium was identified as a substitute product and shipyards building ferries in aluminium as industry competitors. The choice of reference flow increases the relevance of the results for the shipbuilding industry since aluminium is a well-known point of reference.

Results of the LCA will be a supplement to the strategic analyses and contribute to an understanding of how the competitive forces influence sustainability and vice versa (see Chapter 2). By comparing both the environmental impacts and the strategic forces and factors along the product chain the main question about the sustainability of CFRP for shipbuilding will be answered.

The target audience is Tuco and the results are intended to evaluate their current practises and suggest new ways for them to conduct business in the future. Another reason for carrying out the study is to calculate whether the estimated fuel savings and reduced emissions hereby of a lighter CFRP ferry will offset any potential impacts from the production and disposal stage of CFRP compared to aluminium.

A critical review is needed when a LCA study is going to be published and it has to follow the ISO-14044 standards (5, 50). This report is a student assignment and the results are meant for the company in question. Hence critical review will not be needed. However, Tuco has expressed an interest in using the results in marketing and branding of the company and in this case a formal critical review will be needed. The authors will strive to ensure documentation, consistency and reproducibility of the study to make the results credible and useful for further studies. In addition the LCA study will be reviewed by

Stig Irving Olsen, supervisor on this master thesis, but nonetheless the study should not be used for decisive comparative assertions.

5.2.Scope

The LCA study will compare an existing CFRP high speed catamaran ferry to an existing ferry built in aluminium. Both ferries can operate on route 2 in Norway between Harstad and Tromsø. The CFRP ferries in focus are three identical catamaran high speed ferries with the names “Fløyfjell”, “Kistefjell” and “Sollifjell” all serviced by the Norwegian public transport operator Boreal Transport Nord. The aluminium reference ferry “Renøy” is also operated by Boreal Transport Nord.

In the maritime industry little is presently known about the performance of CFRP ships (Appendix 3 and 5). The main focus of the study is the CFRP ferries, and getting detailed descriptions of them. Data for the aluminium ferry will be based on mainly generic data, supplied with assumptions and estimations where needed. In case of estimations for the aluminium ferry relatively benign environmental effects will be assumed e.g. it is assumed that 100% of the aluminium hull can be recycled in the end-of-life phase and power and heat in the production stage of the aluminium hull is not included.

Through the comparative analysis superiority, inferiority or equality of a CFRP high speed ferry will be covered in relation to an aluminium high speed ferry. Any potential differences in impact categories will be identified and the source located. For the CFRP-ferry processes or hot-spots with significant environmental impact will be identified.

5.2.1. Flows and Functions

The primary service of a ferry is to transport people and/or vehicles from point A to B across a body of water. The functional unit is defined as:

1/3 of 30 years ferry service on the route between Harstad and Tromsø with a capacity of at least 150 passengers and an average minimum speed of 30 knots following the requirements set by the municipality in Troms (49).

To cover 1/3 of ferry service the ferries each have to sail approximately 110.000 km yearly. By assuming all three CFRP are exactly identical only data representative for one of the CFRP ferries will be compared to one aluminium ferry. The functional unit is only 1/3 because the route is serviced by three similar CFRP ferries. Table 4 contains basic information on the ferries which has been in service on route 2 in the last couple of years.

Table 4: Data for present and past ferries servicing route 2 from Tromsø to Harstad (51, 52). Fuel consumption was obtained during the interview with Steinar from Boreal.

Name	"MS Fløyfjell" "MS Kistefjell" "MS Sollifjell"	"MS Fjordkongen" "MS Fjorddronningen"	"MS Renøy"
IMO	9563172, 9563160, 9562996	9328998, 9328986	9199725
Material	CFRP	Aluminium	Aluminium
Passenger capacity	250	350	180
Car capacity	0	0	4
Speed (knots)	32.4	33.4	32.9
Building year	2011	2005	1999
Gross tonnage[1]	329	787	308
Width x length (m)	10.5 x 35	11 x 45	10.2 x 30
Fuel consumption (L / NM)	16	40	22

To be able to fulfil the functional unit the ferries must have some obligatory properties, while positioning properties can differentiate one ferry over another (see Table 5).

Table 5: Showing the obligatory and positioning properties of a ferry servicing route 2 from Tromsø to Harstad. On this route ticket price and docks in service are specified by Troms Flykeskommune and are therefore not listed under positioning properties.

Obligatory properties:	**Positioning properties**
Known route. Must be movable to deliver the service. Floating. Stable in accordance to given weather-conditions and sea state. Predictable and regular timetable. Room for at least 150 passengers. Able to safely load/unload people at a dock. Professional crew for the operation. Comply with legislation and HSC code Toilets depending on travel time	Excess passenger capacity Speed and transport time Lifetime of the ferry Noise level during operation Comfort, size of chairs and stability Additional service like food and beverages Leisure activities (Wi-Fi, television, etc.) Sleeping facilities Interior design Service level of crew members Able to accommodate specified types of vehicles/trains. Trainee positions for e.g. seaman Emissions (NO_x, SO_x, CO_2) Business commuter facilities

Originally it was considered to use "Fjordkongen" and "Fjorddronningen" as reference flows. However, the average number of passengers per trip is around 120 passengers (Appendix 21) so the extra capacity

[1] Measure of volume see dictionary on page IV

and size of “Fjorddronningen” and “Fjordkongen” and in continuation hereof the extra weight and fuel consumption of these ferries would give the CFRP ferries an unfair advantage. Instead the smaller aluminium high speed catamaran ferry “Renøy” with a more comparative capacity of 181 passengers and four cars was chosen to get a better comparison based on the service delivered. “Renøy” is serviced by Boreal and used on route 2 as a reserve vessel when a least two of the CFRP ferries are being serviced (Appendix 10).

5.2.2. Framework

The basic descriptive LCA is going to be attributional since the product system is unlikely to have any consequences affecting other product systems on a larger scale. Attributional approaches also tend to look back in time and assess the environmental impacts which a product or service is responsible for (22). The study relates to existing ferries where the life cycle stages until end-of-life are known. In the analysis and modelling of the end-of-life phase different scenarios will be made including landfill, incineration and recycling. In attributional modelling the background processes are typically represented by average data for e.g. power or transport and this will also be the case in this model (22). The extraction of raw materials is described in the background processes in this LCA study.

The product system of CFRP ferries is still a niche product on the market for high speed ferries. If the product however is shown to change the market a consequential LCA could be considered where the consequences of these changes on different processes or systems should be identified.

5.2.3. System Boundaries

The system boundaries define which parts and processes of the life cycle belong to the analysed system, i.e. are required for providing its function as defined by the functional unit. They hence separate the analysed system from the rest of the techno-sphere. At the same time, the system boundaries also define the boundary between the analysed system and the eco-sphere, i.e. define across which boundary the exchange of elementary flows with nature takes place. A definition of elementary flows from (22):

“single substance or energy entering the system being studied that has been drawn from the ecosphere without previous human transformation, or single substance or energy leaving the system being studied that is released into the ecosphere without subsequent human transformation”

5.2.4. Limits

The study is limited to a comparison of the hull and engine on the two reference ferries. The size and weight of hull and engine are directly correlated to the use of a lighter material. Because a comparison is made between two ferries build in respectively aluminium and CFRP the processes or flows which do not contribute to a relevant degree to the differences between the systems will be ignored or cut off (22). This is also possible since the total overall impact is not required to be analysed in this study. Processes to be cut off will be the paint, electrical and mechanical parts, zinc anodes, and insulation. Zink-anodes are used on both aluminium and CFRP ferries, but there is fewer on a CFRP ferry due to the missing corrosion risk of the hull. Due to lack of data on insulation it is assumed that the same amount of insulation is needed on both ferries, even though this might not be correct in real life. In real life a CFRP ferry might have more insulation due to stricter demands for fire safety. CFRP on the other hand do not need the same extent of thermal insulation as aluminium (53).

The present study is limited on the maintenance work throughout the lifetime of the ferries simply due to lack of data. During the field trip to Norway an interview at the mechanical repair shop in Harstad with an employee from Tuco (see Appendix 10) gave an estimate of the number of repairs “Fløyfjell” have had within the last year. Combining this with a later interview with the production manager at Tuco gave an estimation of the amount of material used. However, no similar data for maintenance work on the aluminium ferry “Renøy” could be found. A number of literature studies have shown that maintenance cost for aluminium ferries is higher compared to CFRP ferries mainly due to corrosion and metal fatigue (53).

There might be differences between amount of insulation and mechanical parts like screw, fuel tank and propulsion system on the two ferries. However, none of these differences is expected to contribute significant to the final results of the study as can also be seen from the Eco Island ferry project (5).

The limitations of the study are lack of information of the production phase of an aluminium ferry. Assumptions related to welding length and amount of aluminium used for the hull had to be made. Limitations related to transport in both models are also present since exact origin of some supplier materials and transportation method and route were unknown. Transport of waste has not been modelled, due to lack of data. Plastic helpers used in maintenance is not modelled either due to lack of data. Finally processes related to the production of combined heat and power from waste incineration has been ignored to simplify the modelling.

5.2.5. Back and Foreground System

The foreground system is defined as those processes of the system that are specific to it. This is typically processes that cannot be replaced by market average data or generic data. However, generic data can sometimes for a case be suitable for a foreground system process. The background system is then those processes where average or generic data can be assumed to appropriately represent the respective process. Background processes are therefore never specific data, while foreground processes can be either specific data or generic data depending on the case (22). Furthermore from a management perspective the foreground processes are those that are under direct control of the producer or operator or where he has direct influence. The use-phase and end-of-life phase can therefore both be part of the foreground system if e.g. the product developer influences these processes. The background system contains the processes that are outside the direct influence of the producer or service operator of the analysed system e.g. processes at tier-two suppliers and beyond. The foreground and background system interact with each other by exchanging goods or services.

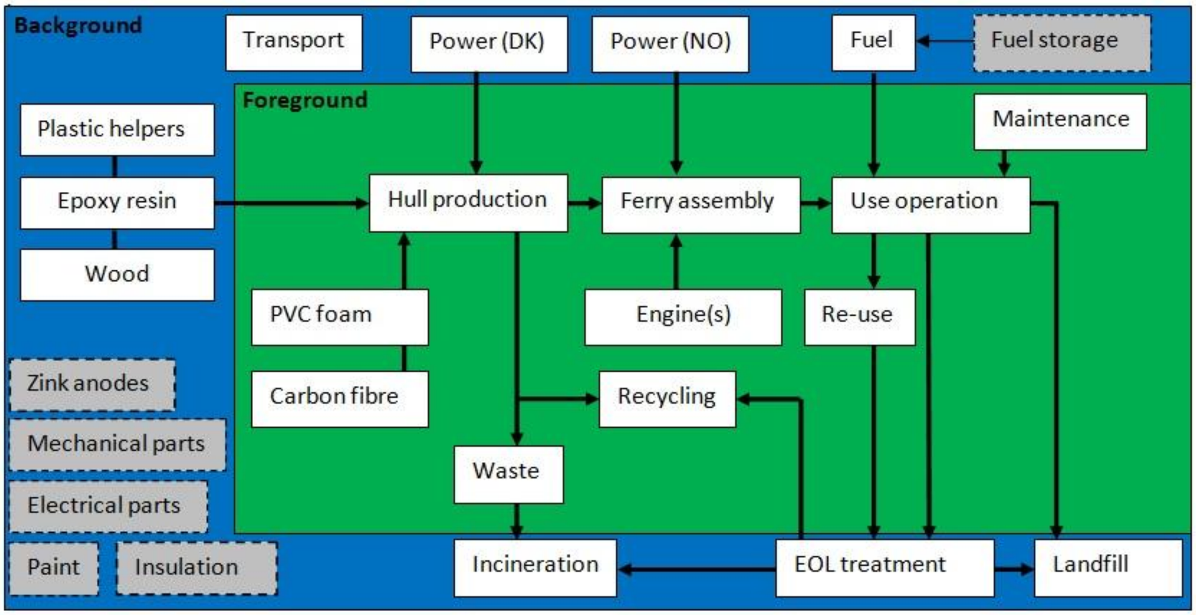


Figure 21: An illustration of foreground and background system for a ferry built in CFRP.

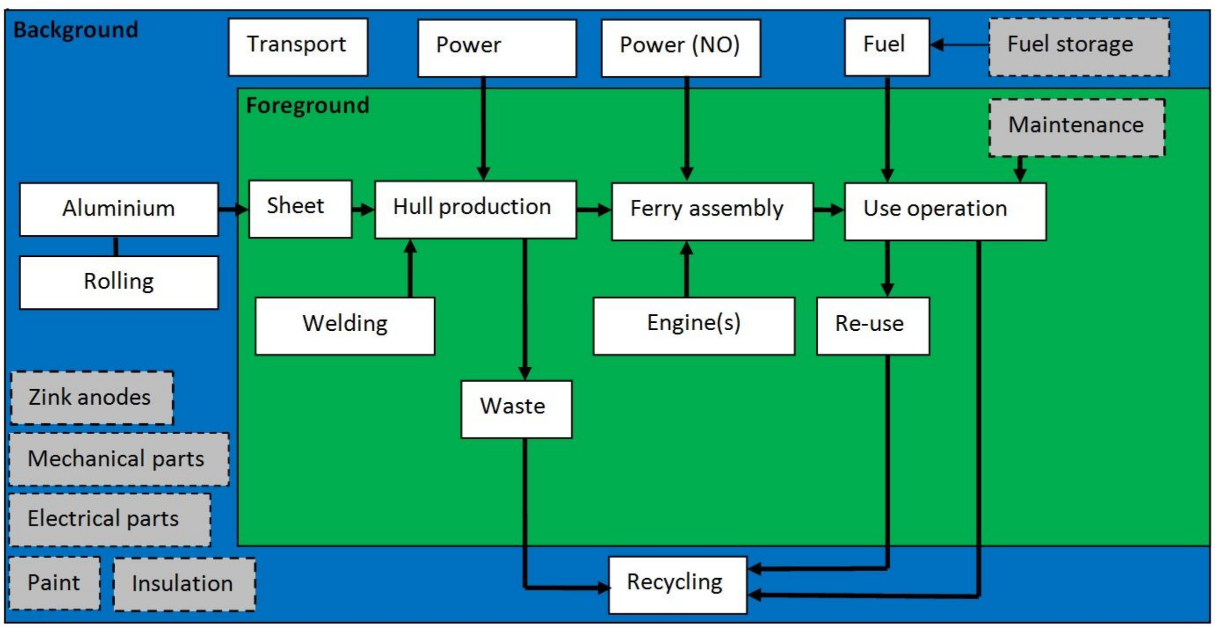


Figure 22: An illustration of foreground and background system for a ferry built in aluminium.

Figure 21 and Figure 22 illustrate the foreground and background systems of a CFRP and an aluminium ferry respectively. A grey box with dotted lines represents a limit. The white boxes represent the modelled processes. Processes in the blue background area are generic processes, where the amount of input and output are specified. The processes in the green foreground area are specific for the model.

The suppliers to the hull production are generally placed in the background system since none of them are suppliers of purchased made-to-order goods or services and none of them are expected to be influenced by Tuco's choice or specification. Generic data will therefore be used for these processes.

However, generic processes do not exist for PVC foam production and carbon fibre production, and these processes are modelled in the foreground system based on the Eco island ferry project (5). Some processes and their correct regional origin were not possible to find in the EcoInvent database and in these cases assumptions or best estimates were made.

5.2.6. Geographical Scope

Three main raw materials is used for production of a carbon fibre sandwich structure namely carbon fibre laminate, core material and resin. Carbon fibre laminate is mainly produced at one of the big factories in USA, Japan or Korea (see section 6.1.2) however in this study the supplier of carbon fibre laminate is Norwegian. Core material is produced in Sweden and resin is produced by a German company with headquarter in the USA, but with manufacturing facilities in Norway, UK, France and Holland. In addition to the three raw materials a number of plastic materials and parts are sold by a Danish contractor, but are expected to be produced in Germany. The origin of the wood for the moulds are unknown, but is assumed to come from the forests in Sweden. Raw materials to the production of resins, carbon fibre, core material and other plastics are assumed to come from the global market.

The hulls of the three CFRP ferries were produced by Tuco in Denmark, while assembly took place in Norway. The manufacturing of engines took place at MTU in Germany, while other mechanical parts are produced in Norway at Servogear Ecoflow (47), (also see BOM list in section 5.3). Recycling options for CFRP do not exist as of present (Appendix 4), but it will be assumed that disposal took place in EU either as recycling, incineration or landfill.

“Renøy” was built in Leivik in Norway by Oma Baatbyggeri, which included production of the hull and assembly. The manufacturing of engines took place at MTU in Germany (54). The production of aluminium is assumed to take place in Europe, while extraction and mining of bauxite comes from the global market like Australia (55). Recycling options for aluminium do exist and it will be assumed that all aluminium is recycled in the European region.

5.2.7. Time

Expected lifetime of a CFRP ferry is assumed to be 30 years since no documentation or records exist on precise lifetime of a ferry built in this kind of material. For other composite materials such as glass fibre the experiences has supported a lifetime of this order (Appendix 9). The lifetime of a composite material like carbon fibre is depend on the use phase and related wear and tear since the composite structure itself do not degenerate over time (56). A quote from an interview with Christian Berggreen underpins this (Appendix 4):

> “Carbon fibre itself does not deteriorate over time, but it is most likely the joints and bonds between different layers and small damages that spread in the construction that will limit the overall lifespan of a ship.”

In the Eco Island ferry project (5) the lifetime of a CFRP ship is assumed to be 40 years. Ships in general have a lifetime of about 30 years (5) and since all other fittings on the CFRP ferries are standard, it will be assumed that all the fittings are designed to the general lifetime of a ship, making 30 years a valid estimation of the lifetime of a CFRP ship. The aluminium ferry is expected to have a similar lifetime of 30 years (57).

Since the contract runs from a period of 10 years it can be relevant to illustrate this in the model. In Norway it is often seen that ferries in operation are quite new (Appendix 10) and the short contract period underpins this. A comparison of the two reference ferries based on 10 years of operation will also be made.

5.2.8. Impact Categories

The life cycle impact assessment (LCIA) method ReCiPe will be used in this study. The method comes from Netherlands and is chosen because the organization behind is independent and not assigned to industry interests. ReCiPe is chosen because it is a widely used method and because of recommendation from Associate Professor Morten Birkved from DTU. The cultural perspective Hierarchist will be used for midpoint and endpoint.

5.2.9. Representativeness

The technological and geographical representativeness of the results are specific to a European context. The available real life data stems from the period 2009 to 2013, while the processes are taken from ecoinvent database last updated in 2008 except the process for production of PAN precursor fibres taken from the professional PE database. The data used for the LCI will be dependent on available processes in the ecoinvent database. Certain processes which are not described explicitly in the database like production of carbon fibre fabrics or PVC foam will be modelled based on equivalent studies (5). The representativeness will be more thorough described in the LCI (see section 5.3).

Processes are as far as possible selected based on nationality to get the best possible approximation to reality. Nationality based selection is possible for electricity processes. When no specific nationality processes exist regional European processes (RER) or Swiss processes (CH) are chosen. In some cases like transport Global processes (GLO) are used.

5.2.10. Special Requirements

The LCA will be categorized so the different life cycle phases correspond to the forces in Porter five forces (20). The end-of-life scenarios will be used to initiate a discussion in the strategic analyses about future technological inventions in relation to recycling. Having in mind that technological development might occur before the ferry needs to be disposed in 30 years or more. The modelling will be done using Gabi-software version 4. However, Morten Birkved has informed that the characterisation to endpoint for the “fossil depletion” is a factor of 10^2 times to high and the “Ionising radiation” is a factor of 10^6 to high. Hence separate calculations will be made to compensate for these two errors (see Appendix 27). The results will be documented in form of a master thesis and through an executive summary for Tuco (see Appendix 30).

5.3. Life Cycle Inventory

The data gathered in the LCI phase are input to the subsequent LCIA phase. The inventory phase involves the collection of data for elementary flows, product flows and waste flows. LCI work means to collect, obtain and develop data for the different processes and model the system so that it is providing the functional unit.

The data will be organized according to the product chain. First the relevant production data will be represented, and then operation data and end-of-life related data. Lastly background and generic data will be presented for example transport and engine size. Presentation of the production data will start with specific CFRP production, then specific aluminium production, and finally assembly data.

5.3.1. Production of CFRP Hull

Specific for the CFRP is the bill of material (BOM) which is listing the materials used for the production of one CFRP hull. In Table 6 the BOM list can be found together with a representation of the process used for each material input. Finally LCI data for processes that had to be modelled separately will be presented (Appendix 26).

Table 6: Materials used for the production of one CFRP hull as informed by production manager Kai Nielsen (Appendix 22)

Material inputs	Amount	Unit	Producer/ source	LCI data / Gabi process	Representativeness
Carbon fibre	8985	Kg	AMT Devold Norway	Carbon fibre (modelled process, see Appendix 26)	No process exist in ecoinvent, but an identical process is used in Eco island ferry project (5)
Norpol 177 (polyester resin)	1050	Kg	Reichhold	Polyester resin, unsaturated, at plant/RER (ecoinvent 2008)	There was a polyester resin process in ecoinvent that could be used.
Norpol 184 (epoxy vinyl ester)	665	Kg	Reichhold	Epoxy resin, liquid, at plant/RER (ecoinvent 2008)	Norpol 184 and the two Dion products are all epoxy based vinyl ester resins. Liquid epoxy resin was a good match and the same process was used in the eco-island ferry project.
Dion 9100-700 (epoxy resin)	5310	Kg	Reichhold	Epoxy resin, liquid, at plant/RER (ecoinvent 2008)	
Dion 9102-683 (epoxy resin)	12500	Kg	Reichhold	Epoxy resin, liquid, at plant/RER (ecoinvent 2008)	
Norpol Peroxide 24 (hardener)	535	Kg	Brøste Denmark	Cumene, at plant/RER (ecoinvent 2008)	Only 50% of the content in Norpol peroxide 24 is cumene, but this process was the best found estimate
H Core	8165	Kg	DIAB Sweden	PVC foam (modelled process, see Appendix 26)	No process exists in eco-invent, but an identical process is used in Eco island ferry project (5)

Material inputs	Amount	Unit	Producer/ source	LCI data / Gabi process	Representativeness
Letspartel NM 206	575	Kg	Rockidan Denmark	Acrylic filler, at plant/RER (ecoinvent 2008)	Filler is the English word for “spartel” and acrylic filler was the only available filler process.
Jotacote UNI Primer	700	Kg	Jotun Denmark	Paint (ignored - same as aluminium)	
Acetone	800	Kg	Unknown	Acetone, liquid, at plant/RER (ecoinvent 2008)	Same process, but unknown origin
Wood for moulds	833	kg	Unknown	Plywood, indoor use, at plant/RER (ecoinvent 2008)	2-3 tonnes wood was used for the moulds for all three ferries. The quality of the wood was birch plywood. (see Appendix 1)
El - 7 months	60000	kWh	Denmark	Power mix/DK (ecoinvent 2008)	The following conversion factor is used (1 kWh = 3.6 MJ)
Natural gas for heating – 7 months	35000	m^3	Denmark	Natural gas, burned in industrial furnace low- NOx > 100 kW/RER (ecoinvent 2008)	Only a RER process was available in ecoinvent for natural gas burned in furnace (assumed 38.7 MJ pr. m^3 gas)
Tacky tape MESM 1310	6.750,00	meter	Bodotex Composites	Polystyrene, general purpose, GPPS, at plant/RER (ecoinvent 2008)	Plastic helpers are what the production manager at Tuco called this category of products. These products are needed in order to make vacuum infusion of resin. Even though Bodotex was contacted no product specification could be found, and hence all products were assumed to contain the same mixture of plastics. The total mass of all these plastic products were assumed to be 3 tonnes.
Bagging film PO 120 8 M	4.000,00	m^2			
Infusion net Dianet 100 mm	1.500,00	m^2			
Peel ply PA 80 1280mm	3.000,00	m^2			
L connector Acilf 25 - 3/4S	1.000,00	stk.			
I-connector ½"	500,00	stk.			
I-connector 3/4"	500,00	stk.			
T connector Acit 16S	800,00	stk.			
T connector ACIT-20S	400,00	stk.			
Ventil ACIV 20	1.500,00	stk.			
Plastic Spiral SP-12	5.000,00	meter			
Infuserings profil IP-50	560,00	meter			
Infusion Box IB-80	1.200,00	stk.			
Armeret slange ½"	800,00	meter			
Armeret slange 3/4"	500,00	meter			

The material inputs are given by Tuco, but whether an input like power mix or natural gas for heating went specifically and solely to production of one CFRP hull is hard to say, since other projects could have been done simultaneously in the production hall. However, it is expected that the majority of power and gas have been used for production of the three CFRP hulls.

5.3.2. Production at Tuco

Table 7: Production at Tuco with inputs and outputs and a waste percentage estimated to be 25% on all input materials on the list below except acetone which is emitted to the air.

Exchange	Unit	Amount	Process name	Notes
INPUT				
Carbon fibre	kg	6738,75	Carbon fibre production	
Polyester resin	kg	787,5	Polyester resin	
Epoxy resin	kg	13856,25	RER: epoxy resin, unsaturated, at plant	
Cumene	kg	401,25	RER: cumene, at plant	
PVC foam	kg	6123,75	PVC foam production	
Acrylic filler	kg	431,25	RER: acrylic filler, at plant	
Acetone	kg	800	RER: acetone, liquid at plant	
Natural gas	MJ	1354500	RER: natural gas, burned in industrial furnace low NO_x > 100 kW	
DK: electricity mix	MJ	216000	DK: power mix	
Transports	tkm	42346	RER: transport, lorry 16-32t, Euro5	Range: 20000-50000tkm, type uncertain (see Table 16)
OUTPUT				
acetone	kg	800	Emission to air	
hull	kg	28000		

Table 8: Production waste from Tuco is sent to three different processes listed in the table as inputs. Output is the waste from production with a negative amount because this is the modelling procedure in Gabi.

Exchange	Unit	Amount	Notes
Output			
carbon fibre	kg	-2246,25	
Polyester resin	kg	-262,5	
Epoxy resin	kg	-4618,75	
Cumene	kg	-133,75	
PVC foam	kg	-2041,25	
Acrylic filler	kg	-143,75	
Plastic helpers	kg	-3000	
plywood indoor	m^3	-1,67	Density of plywood is assumed to be 500kg/m3 Range 480-600 kg/m3 (58)
Input			
CH: disposal polyethylene, 0,4% water, to municipal incineration	kg	10405	Same disposal process as used in (5). The amount is a sum of carbon fibre, polyester resin epoxy resin, cumene, acrylic fuller and plastic helpers form the "output" part.
CH: disposal, polyvinylchloride, 0,2% water to sanitary landfill	kg	2041,25	PVC is not desirable to incinerate in Denmark, and is therefore sent to landfill (59).
CH: disposal, wood, untreated, 20% water, municipal incineration	kg	833	Range 480-600 kg/m3

Initially Tuco informed that they had a waste percentage of around 10-15% (Appendix 1). After comparing the weight of the input materials with the weight of the final hull the waste percentage was calculated to be around 25%. Using 10% waste would give a final hull weight of 34 tonnes, but according to Tuco the final hull only weighted 28 tonnes.

Based on Eco island ferry project (5) the carbon fibre production and the PVC foam production were modelled. In the eco-invent database no process were found for carbon fibre so a specific process based on Polyacrylonitrile (PAN precursor fibres) were made. One modification was made under energy use where “CH: power mix” replaced "electricity, medium voltage, Europe" (See Appendix 26).

Several processes for PVC existed in the database however in Eco island ferry project (5) a specific PVC core production process was modelled separately. To make the two LCA studies as comparable as possible the same PVC process is used in this study with some modification. Two modifications were made “SE: Power mix“ replaced "Electricity, medium voltage, Sweden” and “Ch: disposal, polyvinylchloride, 0.2% water, to municipal incineration” replaced a waste incineration process in Denmark with bi-production of heat and power (See Appendix 26).

In addition to the PVC and carbon fibre production, all Plastic helpers were modelled separately. The intention was to use one type of plastic to represent all Plastic helpers. However, it was not possible to obtain product information from the retailer, and all Plastic helpers were therefore assumed to be “RER: polystyrene, general purpose, GPPS, at plant” (See Appendix 26).

5.3.3. Production of Aluminium Hull

The aluminium used for shipbuilding is an alloy containing Magnesium (60). Table 9 and Table 10 show the data for aluminium rolling and aluminium hull making respectively. The hull making process includes welding which in Gabi is measured in distance. The estimation was 5 km of welding based on a comparison with the catamaran high speed ferry Leonora Christine which had 53 km of welding (61).

Table 9: Aluminium rolling process for the making of 1 kg aluminium sheet. For the production of Renøy a total of 57 tonnes of aluminium alloy is needed and all the numbers should therefore be multiplied by 57.000. The final weight is only 37 tonnes because 35% of the aluminium is production waste (see Table 10).

Exchange	unit	amount	Notes
INPUTS			
Aluminium Alloy AlMG3 , at plant	kg	1	(60)
OCE: transport, transoceanic freight ship	tkm	20	90% of Bauxite comes from other continents than Europe (62) Range : 15,000 – 25,000 km
RER: sheet rolling aluminium	kg	1	
OUTPUT			
Aluminium sheet	kg	1	

Table 10: Aluminium hull making process for the construction of 1 kg aluminium hull listed as output product. Renøy weights 37 tonnes and in this case all the numbers in the table should be multiplied by 37.000.

Exchange	unit	amount	Notes
INPUTS			
Aluminium sheet	kg	1,54	
RER: welding, arc, aluminium	m	0,13	Total welding estimated to 5 km Range for total welding 1-20 km
OUTPUT			
Hull	kg	1	
RER: aluminium, secondary, from old scrap, at plant (inverted)	kg	0,54	Assumed 35% scrap (53). Estimated range 30-40%

5.3.4. Assembly Data

The aluminium sheets had to be transported from an aluminium producer to the shipyard in Norway. This is assumed to be done by transoceanic freight ship due to the infrastructure in Norway and the low environmental impacts from ship transport. The total amount of aluminium sheet transported to Norway is 57 tonnes when including the 35% aluminium scrap that is sent to a recycling plant.

Transportation of the CFRP hull from Faaborg harbour to Mandal in Norway was done on a general cargo ship (see Figure 23) and the distance was measured to be 700 km using Google Maps. All transport calculation can be found in Table 16.

A comparison of the assembly data for both ferries can be found in Table 11. Only the weight of the motor and amount of iron used to build it is of relevance. The functionality and output of a motor is related to the operation stage and fuel consumption.

Table 11: The assembly data and processes for the CFRP ferry and the aluminium ferry

Exchange	Unit	CFRP	Aluminium	Notes
INPUTS				
Gas motor 206 kW/RER (ecoinvent 2008)	pieces	7.2	10	A gas motor was chosen as the best engine option in ecoinvent based on the Eco island ferry project (5). The weight of one gas motor was estimated to be 1400 kg (see Table 17).
Transport barge/RER	tkm	19600	0	The most representative process for this type of cargo ship transport was a barge. Assuming a distance of 700 km Range 18000 -21000 tkm (see Table 16)
Hull	kg	28000	37000	Mass of the aluminium hull is estimated on the assumption that aluminium is 30% heavier than CFRP, range 30-50t (see page 63 for validity).
OUTPUT				
Ship	kg	38080	51000	The total weight of hull and engines

5.3.5. Operation

This section contains first Table 12 about the operation phase, then Table 13 about the modelling of the fuel burning process and finally a rough estimate of the maintenance for one of the CFRP ferries.

Table 12: Operation data for both ferries in Norway

Exchange	Unit	CFRP ferry	Aluminium ferry	Notes
INPUTS				
Lifetime	year	30	30	See section 5.2.7
Total weight	kg	38080	51000	Sum of hull and engines
CFRP hull scrap	kg	28000	0	Used as input to disposal option process
Disposal, building, bulk iron, to sorting plant/CH	kg	10080	14000	Recycling of iron from the engines
Yearly diesel fuel converted to Energy	MJ	34317254,6	4718225,1	For calculations see Appendix 29
Maintenance	Year	30	0	For CFRP see Table 14. No data was obtained about maintenance of aluminium.
OUTPUT				
RER: aluminium, secondary, from old scrap, at plant/RER (inverted)	kg	0	37000	Assuming 100% recycling of the aluminium hull after the lifetime

Table 13: The diesel burning process is modelled using the ecoinvent process from 2008 called "GLO: diesel, burned in building machine <u-so>" and by removing "RER: building machine [machines]" as input to the process. The same amount and type of lubricating and mineral oil is needed for the two reference ferries based on conversations with Steinar Mathisen.

Exchange	unit	Amount
INPUTS		
CH: disposal, used mineral oil, 10% water to hazardous waste	kg	0,000514
RER: diesel, at regional storage (fuels)	kg	0,0234
RER: lubricating oil, at plant (organics)	kg	0,000514
OUTPUT		
GLO: diesel, burned in building machine(machines)	MJ	1

Data and calculation for maintenance in Table 14 is based on conversations with Arne Bløger from Tuco taking place in Harstad, Norway (Appendix 10). During 2012 Tuco had been in Norway eight times to repair the CFRP ferries. This gives around three yearly visits per ferry. At the latest yearly main service check on Fløyfjell taking place in May 2013 the number of damages was 12. It can be expected that the majority of repairs are done at the yearly main service check and therefore a total of 15 repairs per ferry per year are assumed. Each repair is assumed to demand 1 m^2 carbon fibre with a thickness of 2 mm and density of 1800 kg/m^3. A good resin infusion gives a resin/carbon ratio of around 40/60 while a less good resin infusion gives 60/40 (Appendix 1). In this study a ratio of 50/50 has been assumed since resin is added by hand and air is absorbed by vacuum when Tuco is doing repair work. After consulting the production manager at Tuco the total weight estimate for maintenance materials was reduced to a total of 50 kg per year.

Table 14: Maintenance of CFRP hull based on interviews with Tuco

Exchange	unit	Amount	Notes
INPUTS			
Carbon fibres (plastics)	kg	25	range 15-50 kg
Epoxy resin (plastics)	kg	25	range 15-50 kg
Ch: disposal, polyethylene, 0,4% water, to municipal incineration	kg	13	Around 25% waste
OUTPUT			
Maintenance work	Year	1	

Figure 23: The left picture is taken at the yearly maintenance of Fløyfjell. The box holding the drive shaft had begun to show small cracks and got reinforced (black triangular shapes). The picture is taken from inside the engine room. The right picture shows one of the CFRP hulls placed on board a cargo ship which would later sail to Norway (63).

5.3.6. End of life

In the end-of-life stage the aluminium hull is assumed to be recycled 100%. All engines are assumed to be recycled as scrap iron. The reason for complete recyclability is that recycling options exist today for both aluminium and iron (64, 65). In reality the recycling percentage might be lower, but in this model an approximation of 100% is valid.

The disposal option for CFRP today is restricted to landfill (Appendix 12) and 100% landfill is therefore assumed in the LCA analysis. However, research is being conducted to make composite materials recyclable. When the CFRP ferries are to be scraped there might exists recycle options, and different disposal scenarios of CFRP are therefore included in this LCA study.

Table 15: Different disposal options for CFRP. If only a fraction of the CFRP is recycled the rest is split into two equal sized parts sent to incineration and landfill respectively, which is the same approach used in the Eco-Island ferry project.

Scenarios		100% landfill	100% incineration	100% recycling	50% recycle	
INPUTS	Unit	Amount				Notes
Ch: disposal polyethylene, 0,4% water to municipal incineration	kg	0	100	0	25	
Ch: disposal polyethylene, 0,4% water to sanitary landfill	kg	100	0	0	25	
DK: electricity mix	MJ	0	0	-100	-50	electricity used
RER: polyethylene, HDPE, granulate, at plant	kg	0	0	100	50	
OUTPUT						
Waste solid	kg	100	100	100	100	

5.3.7. Transport

Table 16: Transports used in previous processes

Material / product	Country of origin	Producer and destination	Distance (km)	Range min	max	Type of transport	Amount (kg)	tkm	Range min	max
Transport to Tuco										
PVC	Sweden	Tuco at Fyn	500	300	1000	lorry	8165	4082,5	2449,5	8165
carbon fibre	Norway		1400	1200	1600	lorry	8985	12579	10782	14376
plastics	Germany		1000	500	1500	lorry	3000	3000	1500	4500
resins and paints	Germany		1000	200	1000	lorry	21435	21435	4287	21435
wood	Sweden (mid)		500	200	1000	lorry	2500		500	2500
Total								42346,5	20000	50000
CRFP Transport to Norway										
Hull	Denmark (Fyn)	Båtservice Mandal in Norway	700	650	750	regional ship Europe	28000	19600	18200	21000
Aluminium Transport to Norway										
Aluminium sheet	Global	Leirvik in Norway	20000	15000	25000	ship				

Transport of the hull from Tuco to Båtservice Mandal was conducted as a single transport on a general cargo ship (see Figure 23 right). Distance was found using Google maps and assuming a route through Great Belt and East of Anholt.

5.3.8. Engine

To simulate the material flow going into the production of an engine the process "Gas motor 206 kW/RER" is chosen based on Eco-Island ferry project (5). The weight of one engine is estimated to be 1400 kg based on the sum of input masses of the chosen process in Ecoinvent. It is found that the weight of an engine is not always proportional to the engine's output see (Appendix 26). Table 17 below shows the data given as basis for the modelling of the engines.

Table 17: Engine LCI data for both ferries. Mass and power of each engine was found on the producer's homepage (66), (67), (68).

<table>
<tr><th>Engine type</th><th>Power (kW)</th><th>Amount (pieces)</th><th>Producer/ retailer</th><th>Producer specification</th><th>Mass (kg)</th><th>Total (kg)</th><th>Number of gas motors 206 kW</th></tr>
<tr><td colspan="8">CFRP ferries Kistefjell/Sollifjell/Fløyfjell</td></tr>
<tr><td>12V 2000 M72</td><td>1080</td><td>2</td><td>MTU</td><td>Main engine</td><td>4600</td><td rowspan="2">10074</td><td rowspan="2">7,2</td></tr>
<tr><td>4045DFM Diesel Engine</td><td>63</td><td>2</td><td>John Deere</td><td>Auxiliary Engine</td><td>437</td></tr>
<tr><td colspan="8">Aluminium ferry Renøy</td></tr>
<tr><td>12V 2000 M70</td><td>788</td><td>4</td><td>MTU</td><td>Main engine</td><td>3500</td><td>14000</td><td>10</td></tr>
</table>

This concludes the data used in modelling of the life cycles of the three CFRP ferries and the aluminium ferry.

5.4. Life Cycle Impact Assessment

According to the ILCD handbook (22) a life cycle impact assessment (LCIA) must be performed when doing a comparative LCA study because the final LCIA results are an important component of the basis for the interpretation phase. Furthermore conclusions and recommendations must be based on the outcome of the LCIA results.

The final outcome of the LCIA results are three damage endpoints related to ecosystems, human health and resources. The damage values or units for these endpoints (sometimes termed endpoint level indicators) are (69):

Ecosystem diversity (species.yr): loss of species in a certain area due to the environmental load during a year.

Human Health (DALY): Disability Adjusted Life Years which is a combination of years lived with disability and years of life lost.

Resource availability ($): Indicating the quality of remaining mineral and fossil resources and related increased cost for future extractions.

Before being able to calculate the damage endpoints one needs to calculate midpoints (see Figure 7). In this study seventeen midpoints are calculated which each have a link to an endpoint, for more info see

(69, 70). To compare the relevance of the three endpoints a hierarchist perspective is used were ecosystems is weighted 40%, human health 30% and resources 30%.

5.4.1. Overall Life Cycle

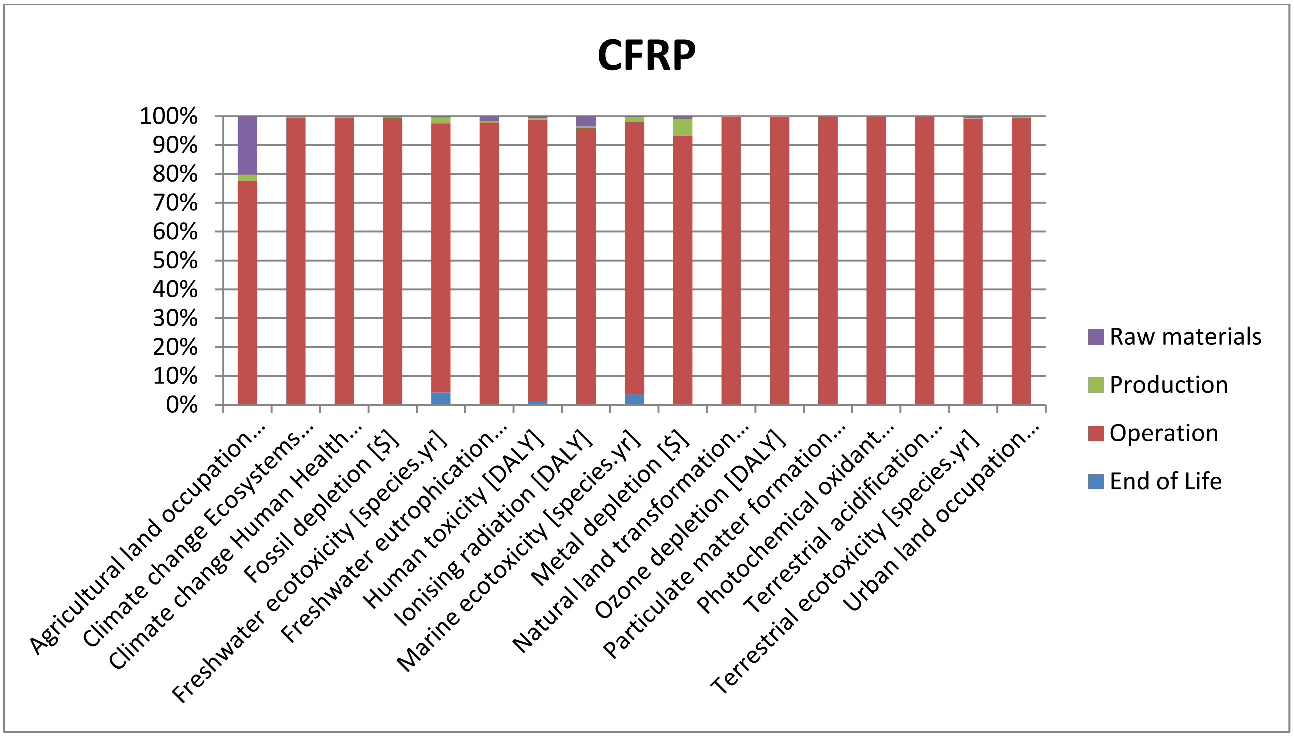


Figure 24: Results for 17 midpoints for the CFRP ferry with an estimated lifetime of 30 years and 100% landfill as end-of-life scenario. The results are split into the four life cycle stages namely raw materials, production, operation and end-of-life.

On Figure 24 the seventeen midpoints impact indicators for the life cycle of the CFRP ferry can be found. Each impact indicator is split using the percentage contribution from each of the four life cycle stages. Operation is seen to dominate all indicators. In agricultural land occupation the use of almost one tonnes plywood in the raw material stage though also has an impact. For the midpoint indicator metal depletion in the production stage were found to have an impact, which origins from the use of 10 tonnes iron in the engines.

The end-of-life stage is causing small impacts to freshwater ecotoxicity, marine ecotoxicity and human toxicity as a result of landfill of polyethylene with 0.4% water content. However, it should be noted that the full environmental impacts of using landfill may not be completely described, and hence using a landfill process will show too benign environmental impacts in the end-of-life phase (71). To summarize the operation stage given by the long life time and extensive fuel consumption dominates the results.

Similar calculations were done for the aluminium ferry with an identical life time of 30 years and a recycling rate of the aluminium of 100%. The results can be found on Figure 25.

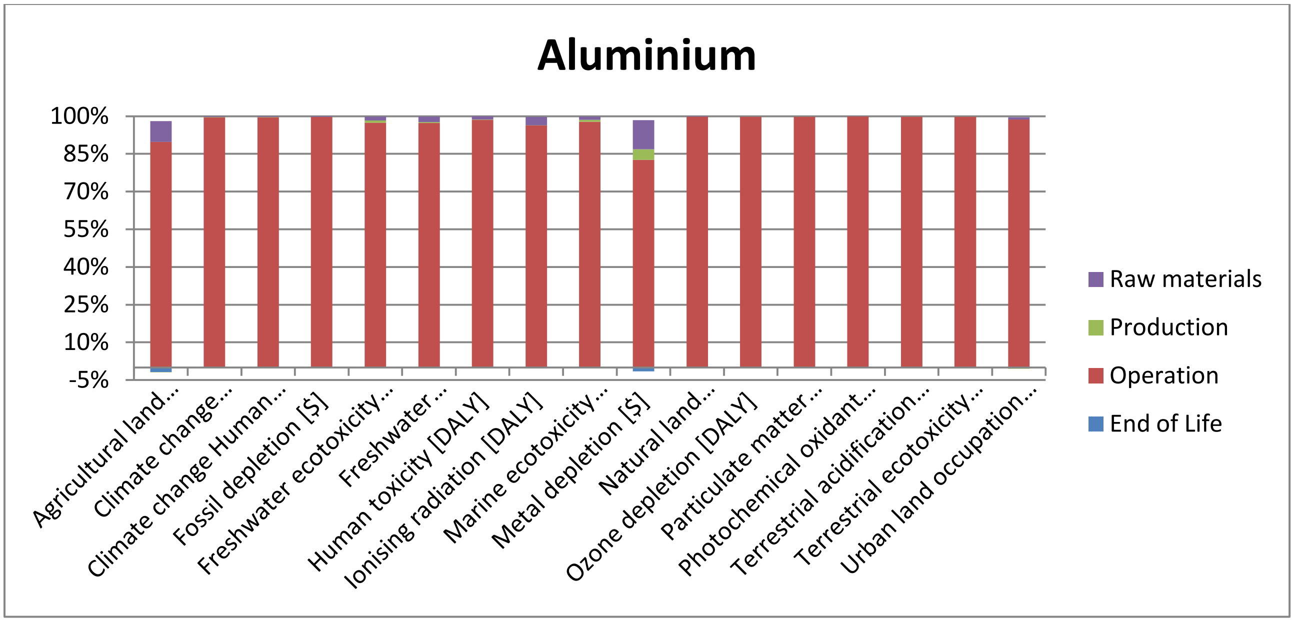


Figure 25: Results for 17 midpoints for the aluminium ferry with 30 years of estimated operation time and 100% recycling in end of life phase. The results are split into four life cycle phases.

Operation is dominating all 17 midpoint indicators and production is mainly affecting metal depletion as a result of the 14 tonnes iron used for the engines. "Agricultural land occupation" and "metal depletion" is both less than 100%, because recycling of aluminium in the end-of-life stage is beneficial for the environment.

Comparison of the two types of ferries can be found on Figure 26 and Figure 27 below.

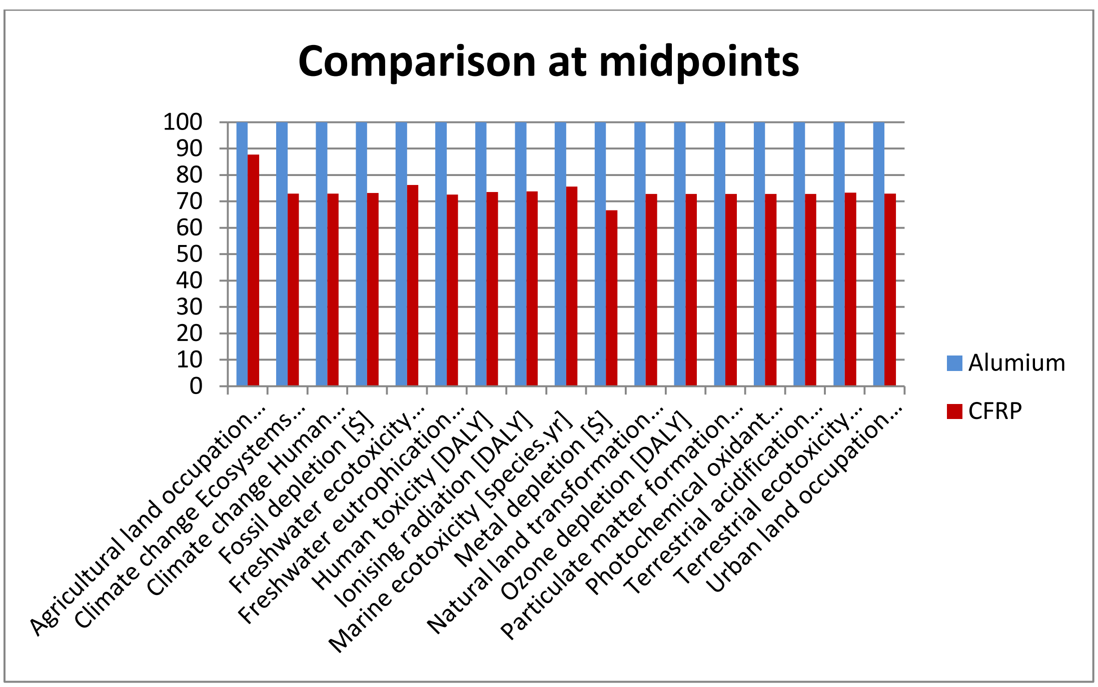


Figure 26: Comparison at midpoints for CFRP and aluminium

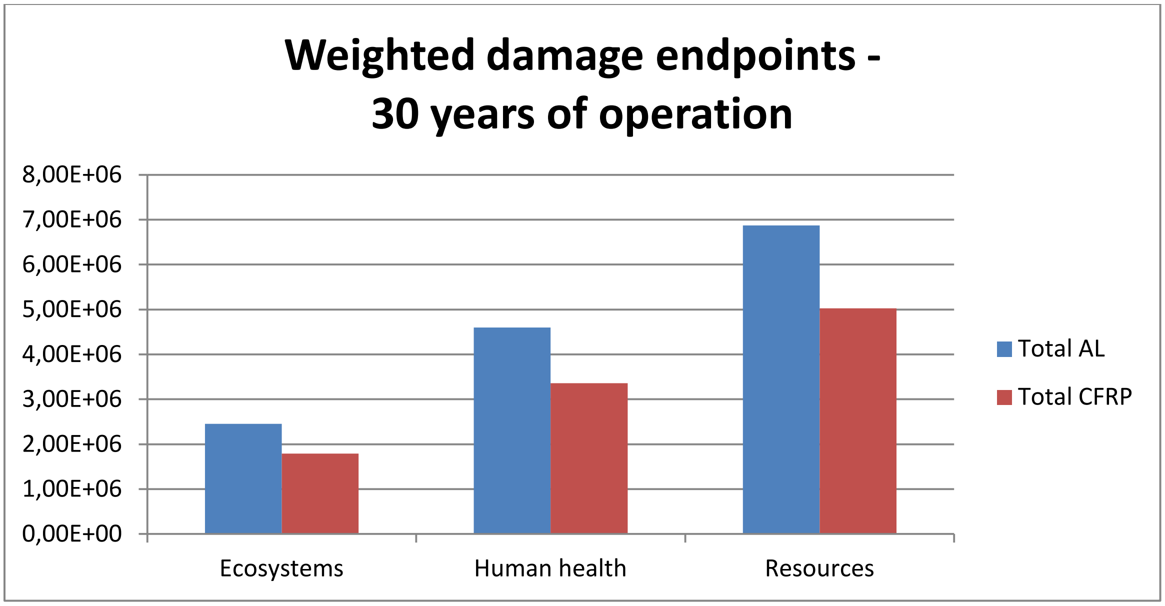


Figure 27: Weighted damage endpoints for the CFRP and aluminium ferry respectively.

Figure 26 shows that the aluminium ferry is more harmful in all midpoints categories, and Figure 27 shows the same for the weighted damage endpoints. It was found that the proportion between the CFRP and the aluminium ferry in all three damage endpoints is close to $\frac{22}{16}$, which corresponds to the difference in fuel consumption of the two ferries. So this figure underpins that fuel consumption during operation is the decisive parameter.

5.4.2. Construction

Since operation clearly dominates the results, it could be interesting to compare the impacts caused by the construction phase i.e. raw material phase plus production phase.

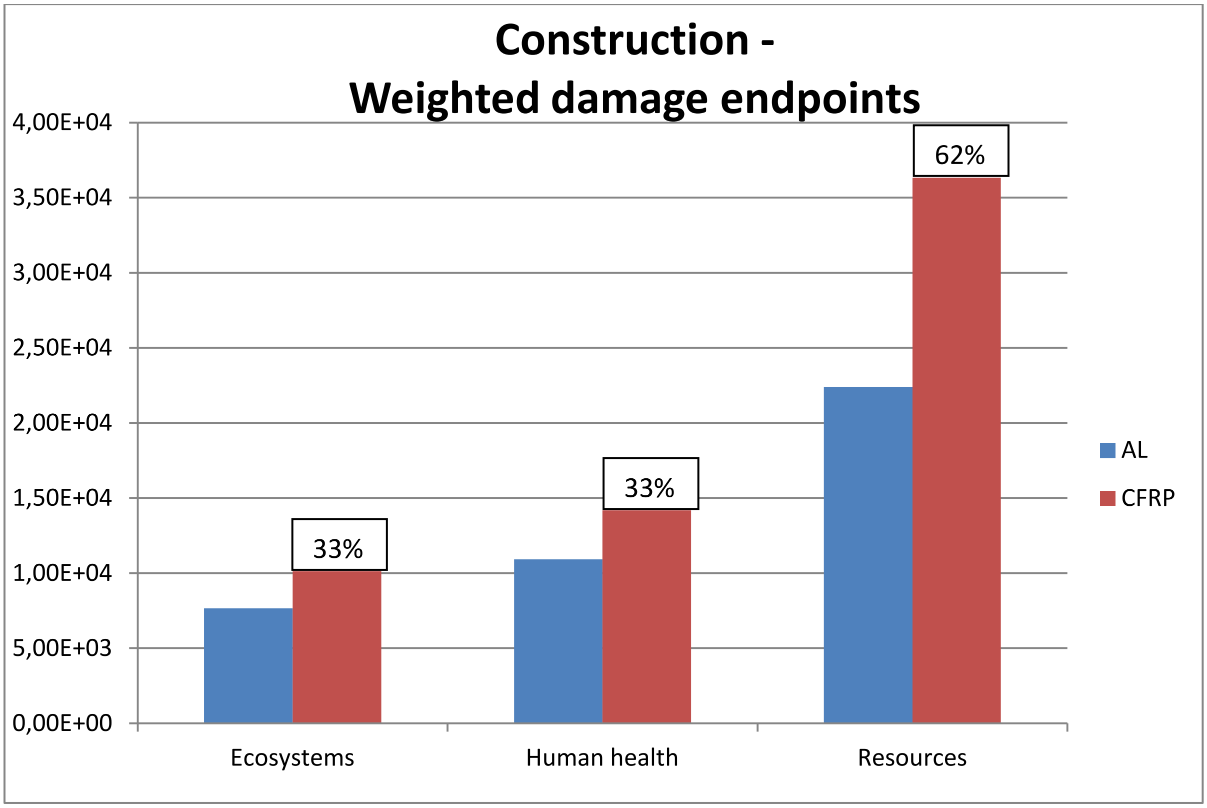


Figure 28: A comparison of the construction phase of the aluminium and the CFRP ferry. The construction phase is here a summation of the two life cycle stages raw materials and production. The percentage numbers in the white squares indicates that CFRP have 33% higher impact in ecosystems and human health than aluminium and 62% higher impact in resources.

From Figure 28 it is found that construction of the CFRP ferry creates higher environmental impacts than construction of the aluminium ferry. To get an impression of the fuel consumption needed before the CFRP ferry have the same environmental impacts as the aluminium ferry an environmental break-even point analysis is made (see Table 18).

Table 18: Showing environmental break-even points for the Aluminium and CFRP ferry (for calculations see Appendix 31).

Damage category:	Break-even (full month):
Ecosystems	2
Human health	1
Resources	3

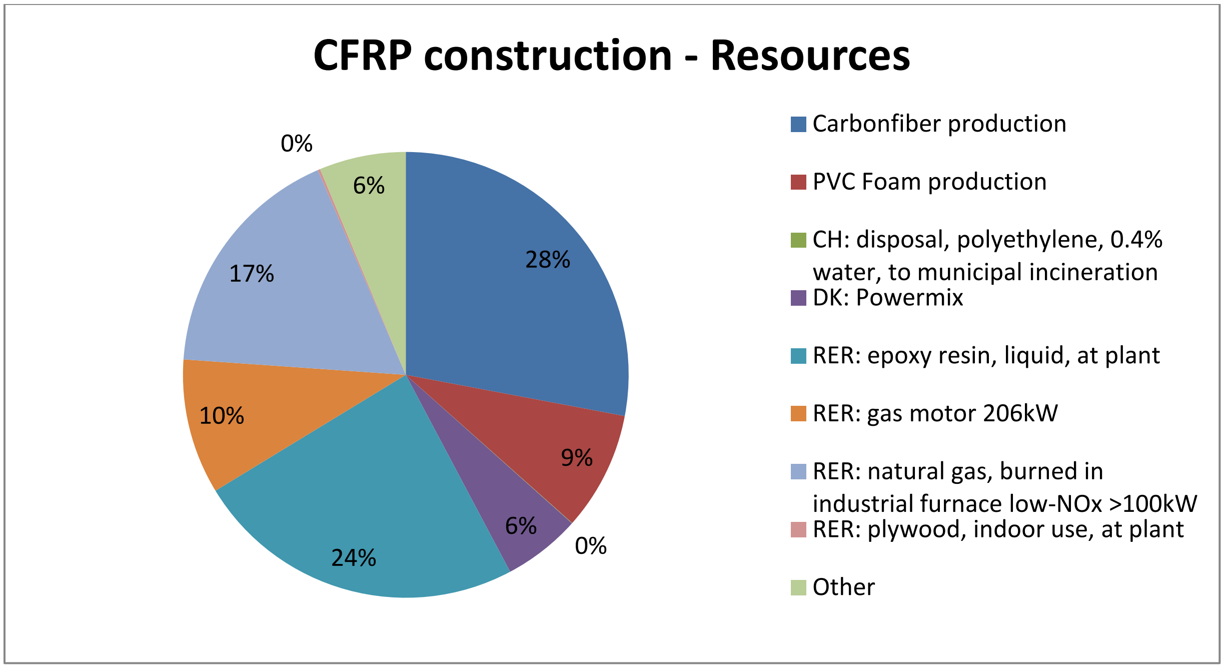
It is found that after only three months of operation all three damage endpoints have reach break-even. From that point and forward the aluminium ferry will cause higher environmental impact than the CFRP ferry for the rest of its lifetime. In Table 19 the amount of diesel fuel used during three months of operation for the two ferries can be found.

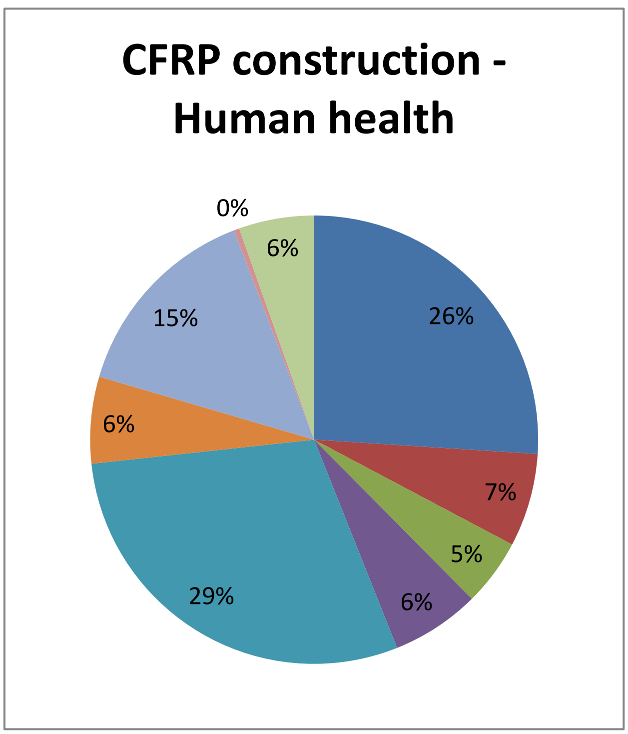
Table 19: The amount of diesel used after 3 months of operation

Ferry:	Fuel consumption (liter):
CFRP	237.581
Aluminium	326.674

The differences between the two numbers are 89.093 liter, meaning that the extra impact caused in the construction phase of the CFRP corresponds to nearly 90.000 liter diesel for the resources indicator, while it corresponds to around 30.000 liter for the human health indicator and 60.000 liter for ecosystems.

On Figure 29 the percentage contribution from each of the construction processes to the three damage indicators can be found. The biggest contribution on all three figures comes from the processes carbon fibre production, liquid epoxy resin, and natural gas (for heating of production hall) which together account for 65-70% of the impacts.





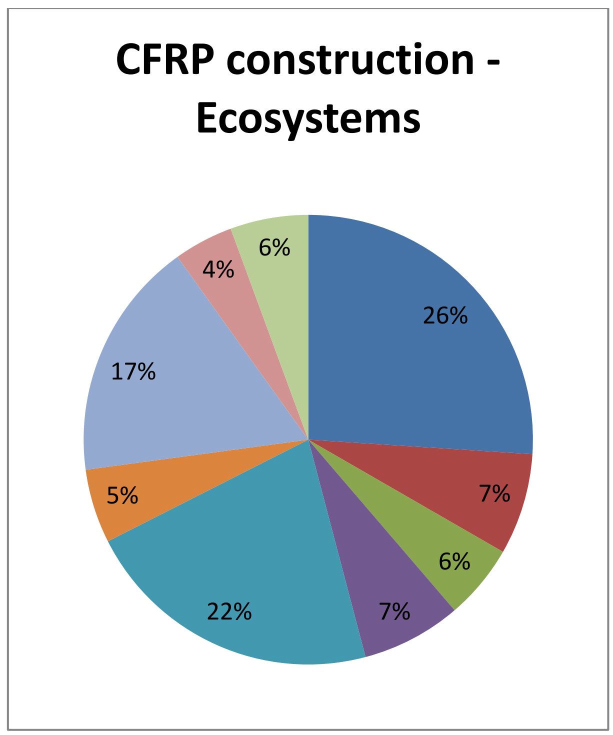


Figure 29 : Weighted damage endpoints for the construction of a CFRP hull and engine. Top shows the contribution of each process to the resources category. The bottom left show the same for damage to human health and the bottom right shows the same for ecosystems. Only processes with an impact of 4% or above in any category is outlined.

5.4.3. End of Life

CFRP is still a new and rather unproven material in the commercial maritime industry (Appendix 3, 4, 5 and 6) and no recycling options does presently exist (Appendix 12).

A comparison between end-of-life scenarios for an aluminium ferry and a CFRP ferry has been made and the results can be found on Figure 30.

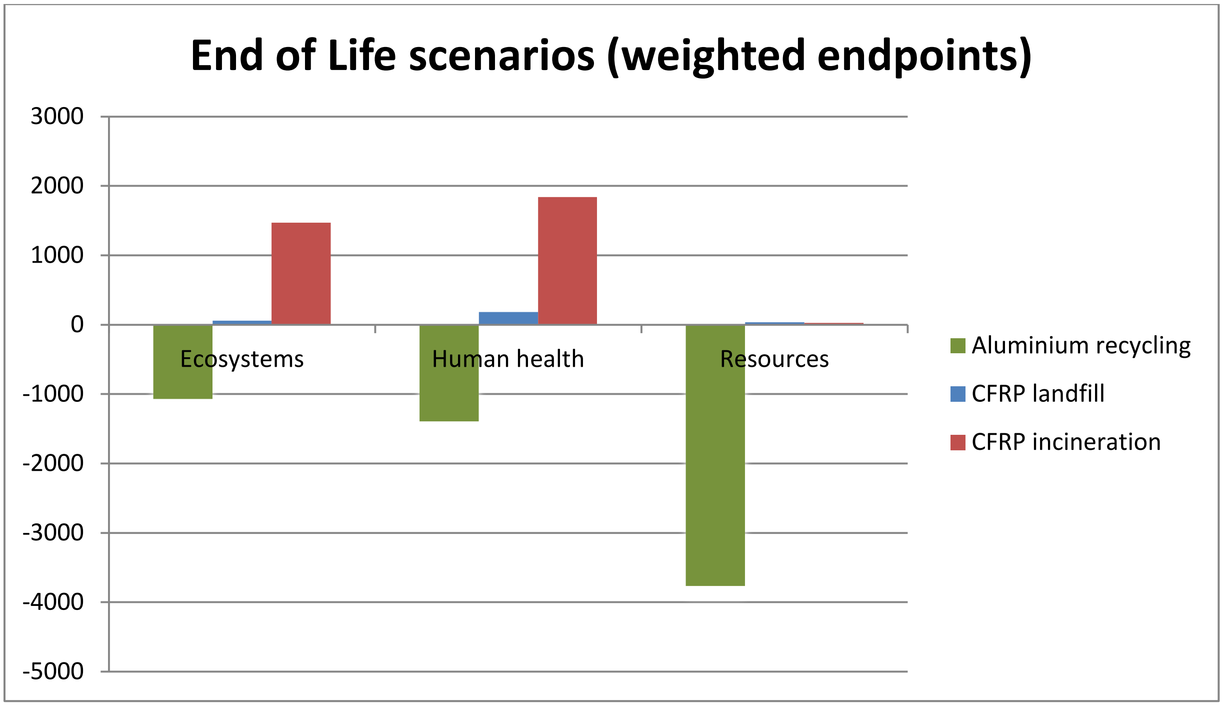


Figure 30: Three different end-of-life scenarios divided into three damage endpoints. The results are normalized and weighted. The CFRP incineration process does not contain recovery of energy or heat in this case.

Recycling of aluminium is beneficial for the environment. For CFRP the landfill option is found to be less harmful than incineration. However, this could be due to uncertainties in the impacts known and accounted for in a landfill process like e.g. impact to soil and groundwater or number of years at landfill (71, 72). A different modelled land fill process might give another result. Incineration of CFRP might be less damaging if the incineration takes place at a combined heat and power plant, but such an approach is not considered in this study.

Future technologies and methods might emerge making it possible to recycle an amount of the CFRP material and therefore three scenarios with different recycling rates are made (see Figure 31).

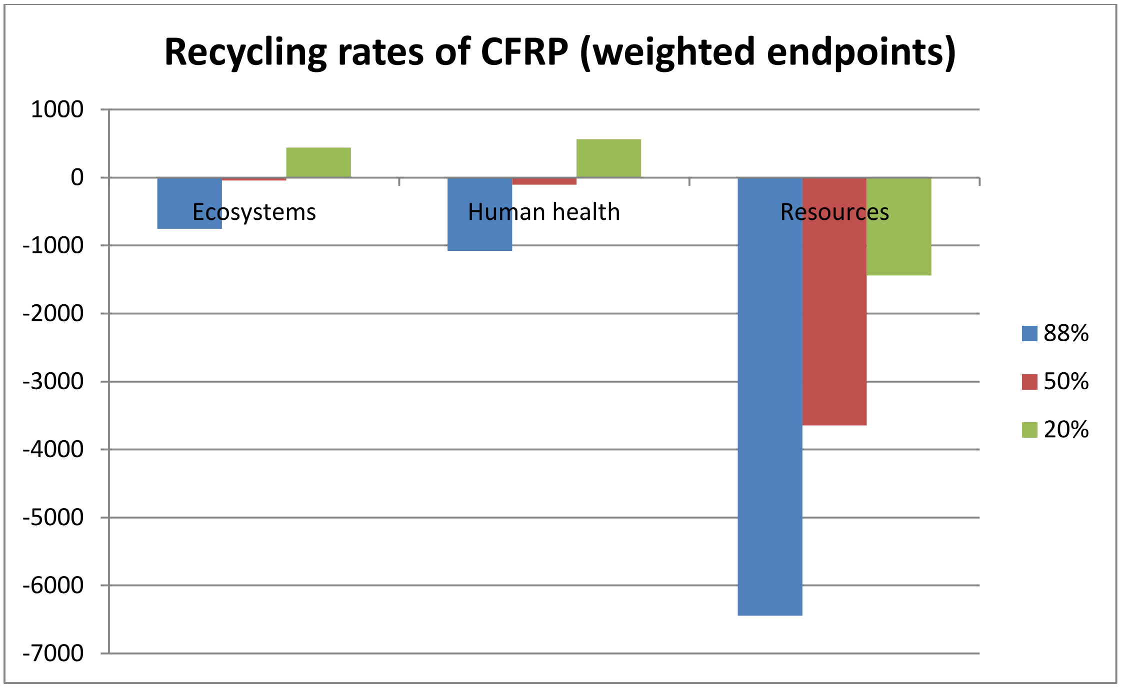


Figure 31: Damage endpoints for three future scenarios of recycling of CFRP with recycling rates of 80%, 50% and 20%.

In all three scenarios the amount of CFRP which is not recycled is split into two equal sized parts. Each part is sent to incineration and landfill respectively (similar to Eco-island ferry project (5)). It can be seen that even with 50% of the CFRP recycled all three damage endpoints show negative impact. Making recycling a possible disposal option in the future will improve both the life cycle cost as a source of income and be beneficial for the environment even with a 50% recycling rate. Comparing Figure 30 and Figure 31 the recycling of aluminium is better for both ecosystems and human health compared to all three CFRP recycling scenarios. For the resources the comparison with aluminium depends on the recycling rate of CFRP.

5.4.4. Sensitivity

Since the contract for the three ferries with Troms municipality is valid for 10 years a sensitivity analysis will be made to see the effect of a shorter operation time. Furthermore sensitivity analyses will be made on various alternatives in the uncertainty ranges and alterations to the basic deterministic scenario.

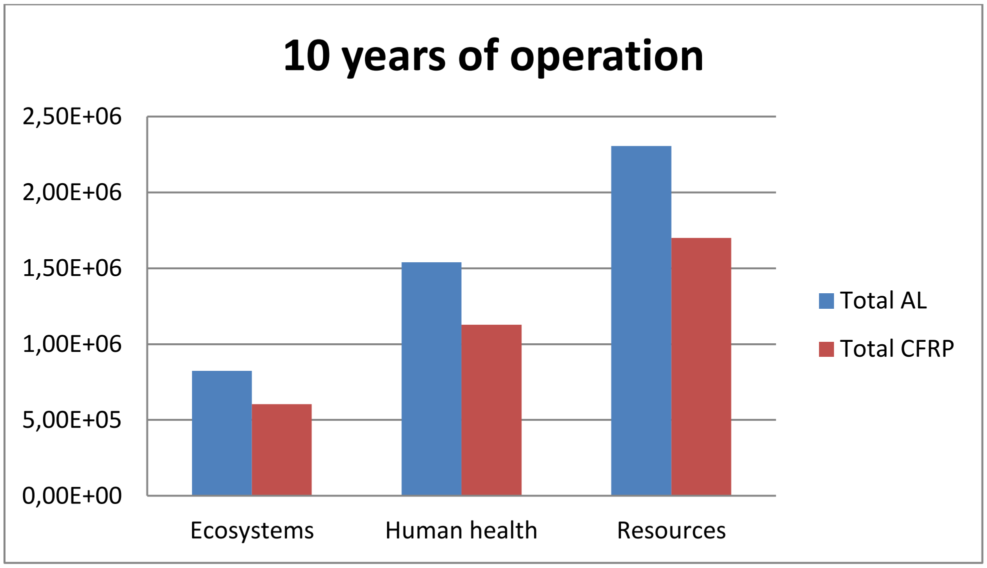


Figure 32: Weighted damage endpoints after 10 years of operation.

On Figure 32 the proportion between CFRP and aluminium is $\frac{16}{22}$ indicating that fuel consumption is still the dominating parameter even for the shorter 10 years of operation. It does not matter whether the ferries operate the route for 10 or 30 years in relation to comparative environmental impacts.

Table 20: Four sensitivity analysis of the aluminium model for 30 years of operation. In the basic model the aluminium hull weights 37 tonnes and transport is set to 20.000 km.

Scenario (30 years of operation)		Ecosystems	Human health	Resources
Aluminium basic scenario	Construction	7646	10919	22376
	Total	2455865	4600602	6875664
hull weight: 30 tonnes	Construction	-17,06%	-16,79%	-14,74%
	Total	-0,04%	-0,03%	-0,04%
hull weight: 50 tonnes	Construction	31,69%	31,18%	27,37%
	Total	0,08%	0,06%	0,07%
Transport: 15.000 km	Construction	-0,80%	-1,27%	-0,76%
	Total	0,00%	0,00%	0,00%

Table 21: Sensitivity analysis of CFRP for different scenarios. Basic production time was 7 months, lorry transport was set to 42,346 tkm, waste process was polyethylene, production waste was 25%, 3 tonnes of plastic helpers and 866 kg of plywood was used for each CFRP ferry.

Scenario		Ecosystems	Human health	Resources
CFRP - basic scenario	Construction	10133	14177	36324
	Total- 30 Y	1792192	3354515	5025540
Replace epoxy with polyester	Construction	3,70%	-5,35%	-0,98%
	Total- 30 Y	0,02%	-0,02%	-0,01%
2,5 month of production time	Construction	-11%	-9%	-11%
	Total- 30 Y	-0,06%	-0,04%	-0,08%
Lorry transport 20.000 tkm	Construction	-0,69%	-0,64%	-0,60%
	Total- 30 Y	0,00%	0,00%	0,00%
PVC waste process	Construction	-1,10%	-0,82%	1,15%
	Total- 30 Y	-0,01%	-0,01%	0,01%
Only 10% production waste	Construction	-10,76%	-11,59%	-9,32%
	Total- 30 Y	-0,06%	-0,05%	-0,07%
1 tonnes plastic helpers	Construction	-2,26%	-2,14%	-1,77%
	Total- 30 Y	-0,01%	-0,01%	-0,01%
5 tonnes plastic helpers	Construction	2,26%	2,14%	1,77%
	Total- 30 Y	0,01%	0,01%	0,01%
1000 kg plywood for the mould	Construction	0,90%	0,12%	0,04%
	Total- 30 Y	0,01%	0,00%	0,00%
No maintenance	Operation	-0,02%	-0,02%	-0,02%
	Total 30 Y	-0,02%	-0,01%	-0,02%

The construction phase mentioned in Table 20 and Table 21 is the sum of raw materials and production. As the tables illustrate different scenarios and uncertainties have an impact on the final results. Note that a negative percentage indicates an environmental benefit compared to the basic descriptive scenario.

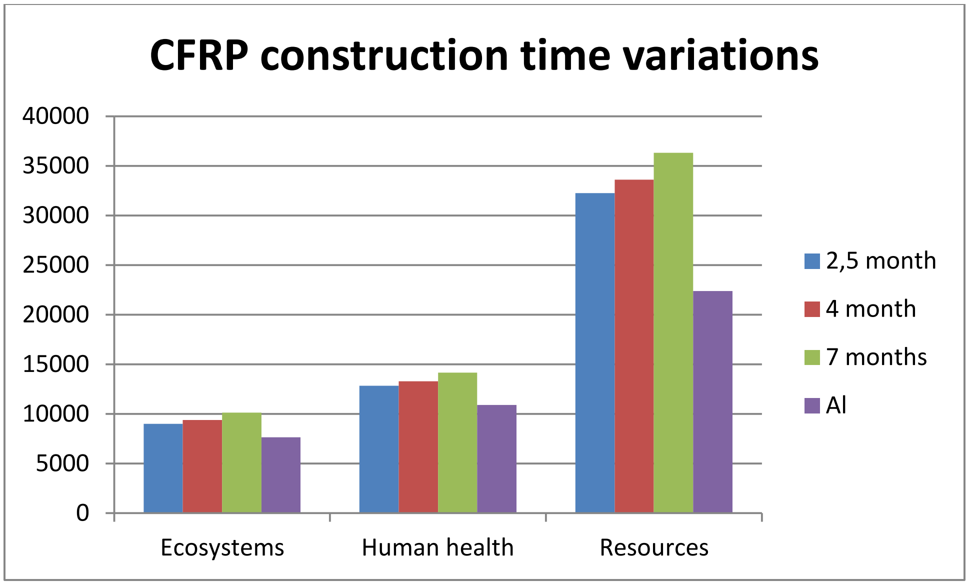


Figure 33: The effect of having a shorter production time of a CFRP hull than the original 7 months used in this LCA analysis. The only parameter changed is the amount of natural gas used for heating during production. Aluminium has been included as a reference point.

In Figure 33 it is shown how a reduction in construction time will influence the damage endpoints. Natural gas for heating is the only parameter changed, since the production hall must have a minimum temperature of around 19 degrees Celsius in order to achieve the optimal hardening process (Appendix 1). A prolonged production time means Tuco needs to keep their production hall warm longer. However, it has to be noted that a minimum production time is needed for all the hardening processes to take place. The time of year also plays a role when calculating the amount of natural gas used, and it is evident that more gas is needed for heating during a cold winter than during the summer. An interesting fact from the production manager Kai Nielsen at Tuco was that during some of the coldest periods of the year they could use 50,000 DKK per month for heating (Appendix 1). As he mentioned this could partly be due to bad insulation of their present production hall, and said it could be interesting to do a cost-benefit or break-even point analysis of investing money in better insulation. The amount of electricity used is assumed to be the same no matter the duration of production, since a specific amount of work related to power equipment is assumed to be needed for a given hull. The conclusion of the sensitivity analysis for production time is that slight changes do occur and for all three time variations the CFRP ferry gets a higher score in all damage endpoints than aluminium.

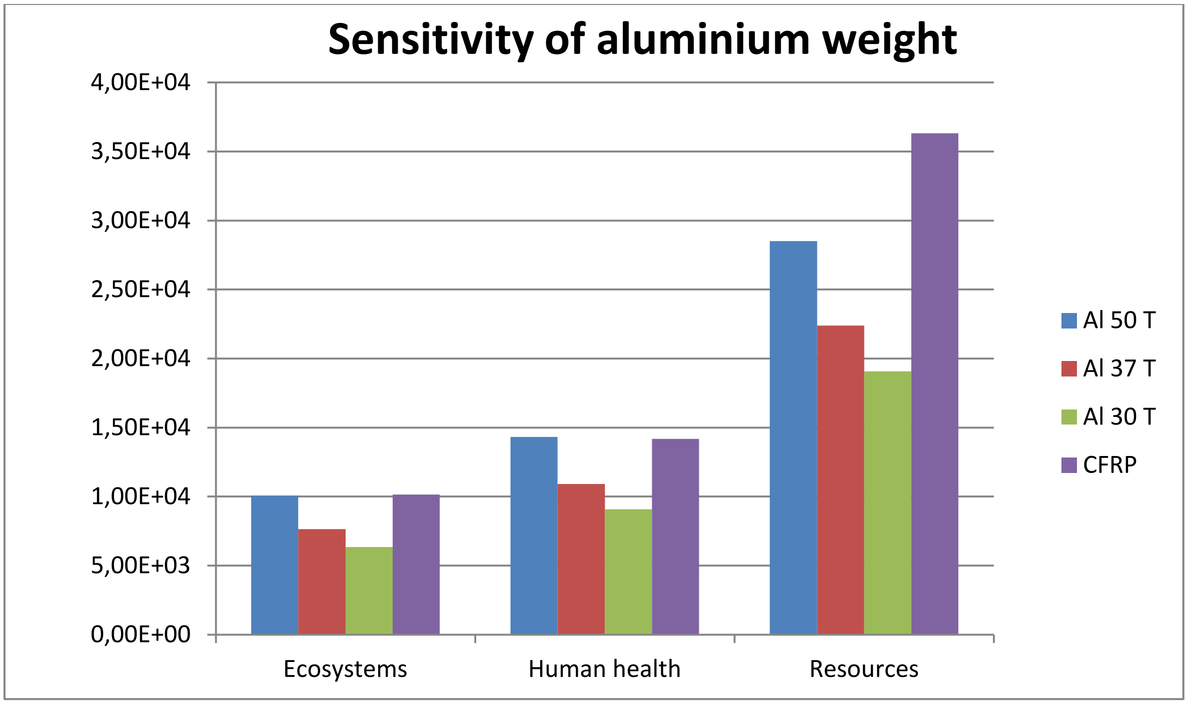


Figure 34: Scenarios of different weights of the aluminium hull with an assumed waste percentage of 35% during production. The red column is the basic deterministic weight. The CFRP hull weights 28 tonnes.

Sensitivity of the amount of aluminium used for hull production can be found on Figure 34. In this LCA analysis the aluminium hull is estimated to weigh 37 tonnes, which is around 30% more than the CFRP hull. This number is estimated and the actual weight could be either lower or higher for the aluminium ferry Renøy. Variations in the amount of aluminium used for hull production have a significant impact on all three damage categories. Even for an aluminium hull weight of 50 tonnes the construction phase is equal to or less harmful than CFRP for the all three damage endpoints. The precision and validity of the results in this LCA study would be improved if the exact aluminium hull weight was known.

5.5. Life Cycle Interpretation

The goal of the LCA was to find which environmental effects occurred under production, operation, and disposal of a ship build in carbon fibre reinforced polymer compared to a relevant reference. The main results, recommendations and validity will be discussed.

5.5.1. Results and Recommendations

The results showed that three processes namely carbon fibre production, epoxy resin and natural gas used for heating accounted for around 65-70% of the impact associated with the construction of a CFRP hull. While the first two are depending on the design, the size of the hull and waste percentage the latter one natural gas can be decreased through different initiatives. The amount of natural gas used during the winter could be significant and one way to reduce this is by improving insulation in the production hall. Insulation would cost money, but it might be offset by lower future expenses to natural gas.

By comparing the numbers given by Tuco of the input materials used for production and the total weight of the complete hull it was found that 25% of the input materials went to waste. This number is higher than the 10-15% Tuco thought they had. Reducing these numbers would decrease the environmental impacts by approximately 10% in the construction phase.

The major environmental impact for the overall life cycle is found to be fuel consumption in the operation phase. Fuel consumption is related to the engines power output, which is dependent on the total weight and speed of the ferry. To limit fuel consumption future ferries should be designed as light and fuel efficient as possible. Furthermore a reduction of the weight will decrease the amount of carbon fibre, epoxy resin and PVC foam used in the construction stage and result in lower impacts from this stage. A lower speed will decrease the environmental impacts as well.

According to the end-of-life scenario it could be environmental beneficial to find alternative disposal options to landfill and incineration. One option would be to recycle the composite materials, because it would limit the amount of new virgin composite products to be produced in the future.

5.5.2. Validity of CFRP Model

The time of year is a decisive factor related to the amount of natural gas used for heating. It is evident that more heat is needed during the winter than the summer. Results and impacts from the construction phase will therefore be seasonal dependent. However, better insulation will decrease seasonal dependency and natural gas consumption.

The number of times a mould is re-used influences the reproducibility of the LCA analysis. In this case study all three ships are made using the same mould and therefore the amount of plywood used per ferry can be divided by three. Often when a ferry route is put to tender only one ferry is needed and in this case the amount of plywood needed will be higher since one mould will corresponds to one ferry.

In the modelling it was considered to use waste incineration processes for PVC instead of Polyethylene. For both the end-of-life disposal process and the production waste process the same incineration process of polyethylene was used, as in Eco-island ferry project (5). A scenario analysis of the two incineration processes showed that incineration of PVC was more beneficial in two of three damage endpoint categories (see Table 21). The decision to use the polyethylene incineration process was therefore kept.

A restriction to the modelling relates to the processes available in the ecoinvent database. PVC foam and carbon fibre were not found in ecoinvent, but were modelled on the basis of the eco island ferry project (5). The input material Norpol Perioxide 24 was a harder containing 50% cumene and 50% of other ingredients. These ingredients could not be found in ecoinvent and Norpol Perioxide 24 was modelled using a pure cumene process (see Table 6). The Norpol material only contributes with 1.4 % of the final weight of the hull, so the estimate was considered adequate.

As mentioned in the LCI, it was not possible to obtain data for the plastic helpers and the numbers used for maintenance were rough estimates based on little empirical basis. However, the impact from resources used for maintenance was negligible in relation to the overall impacts (see Table 21).

5.5.3. Validity of Aluminium Model

The three CFRP-ferries were compared to the aluminium ferry Renøy. Renøy was built in 1999 and there is a chance that better and more efficient hull design for aluminium ferries has been developed which could reduce engine power and decrease fuel consumption for an aluminium ferry. The possible improved design of hull and propeller could change the amount of fuel used per year and might result in another outcome of the LCA analysis. On the other hand the capacity of MS Renøy is 181 passengers and four cars which is less than the 250 passengers a CFRP ferry can carry and this might offset the around ten years gap in technological development.

Collecting data for the aluminium model in Gabi was difficult and assumptions had to be made. Only the fuel consumption was known. Many of the processes in the production phase including weight of input materials and transportation distances had to be best estimates. However, it was attempted to favour the aluminium ferry by only including known processes like aluminium alloy, sheet rolling and welding in the production phase even though there might be other processes in manufacturing of an aluminium hull. The amount of energy used for e.g. tools and machines or heat for the production hall was not included in the aluminium model and it was assumed that 100% of the aluminium could be recycled after 30 years of operation. The amount of aluminium alloy used for production was one of the most decisive input materials and in this case it was difficult to know whether the estimated amount had been in favour of aluminium or not. The weight of the aluminium ferry Renøy was estimated to 37 tonnes. The estimate was found after several attempts based on various techniques listed below.

1. According to Friis, Andersen and Jensen (73) the outfit (interior, furniture etc) weight is linear to the length × width of a ferry. If this applies the hull on Renøy will weigh 24 tonnes if made in CFRP. However, Renøy is made of aluminium and according to Hjørnet (4) the overall structure weight of aluminium is around 55% heavier than CFRP. This will result in a hull weight of Renøy around 36-38 tonnes.

2. The fuel consumption was another technique used to estimate the hull weight of Renøy. The fuel consumption on Renøy is 22 L/NM and on Sollifjell it is 16 L/NM. Renøy therefore uses 37.5% more fuel than the CFRP ferries per sailed nautical mile. If assuming the same percentage difference in hull weights the hull weight on Renøy would be 38.5 tonnes.

In the end it was estimated that the aluminium hull on Renøy properly weighed between 35 and 40 tonnes, hence 37 tonnes were decided as the deterministic value.

In the sensitivity analysis it was shown that even if the aluminium hull weight was increased to 50 tonnes, the damage endpoint “resources” for CFRP would be 27% larger than Aluminium, while ecosystems and human health were more or less the same, when only considering impacts from the construction phase.

If the exact amount of aluminium alloy could be obtained this would improve the aluminium model. Such information could be obtained by contacting the shipyard who built Renøy or a naval architect with experience in aluminium shipbuilding. These persons could probably also describe the production method of an aluminium hull more detailed. The fuel consumption was found to be the dominating parameter and this number was known for certain.

Even though there was uncertainties about the input data to the aluminium model the use of Renøy was still the best possible option, since Renøy could sail the same route as the three CFRP ferries and have approximately the same passenger capacity and speed. In this study it had been attempted to avoid favouring the CFRP ferries, by having a simple aluminium model with a high recycling rate. Whether the environmental impacts calculated for the aluminium model was too benign was hard to say, since one of the most important input materials namely amount of aluminium alloy was unknown.

5.5.4. Validity of Impact Assessment Method

One purpose of the LCA analysis was to use the results in strategic analyses to determine sustainability in the composite shipbuilding industry. In that respect it could be considers which type of impact assessment method would be most valid. In the present study the ReCiPe hierarchist method has been used, but other methods could have been used. ReCiPe has three perspectives of impact assessments, egalitarian, hierarchist and Individualist. Each perspective is based on the values of stakeholders where the egalitarian has a long term perspective based on precautionary principles, while the individualist prioritize short term needs and believes technology can avoid many problems in the future (74). The hierarchist is somewhere between the two others and are often considered to be the default model. Comparing the industry's own time horizon and values, an individualist impact assessment would properly reflect the conservativeness and cost focus of the industry (see section 6.1). However, when comparing to macro environment factors like governments or institutions a more egalitarian impact assessment would properly be more valid (see section 6.2.1). To make the best possible impact assessment all stakeholders from the strategic analyses could be interviewed about their values and priorities.

5.5.5. Summary

The LCA has been used to point out which processes or materials could be changed or optimized. Recommendations about lower consumption of natural gas and less waste are in line with the principles of lean and principle two in green engineering (23) in the cases of over processing (too much heating) and overproduction (waste percentage).

The result of this LCA analysis is in line with the results found in the Eco-island ferry project where the majority of the environmental impacts occur in the operation phase. The Eco-island ferry project (5) was done on a fictive traditional ferry with slower speed (9.5 knots), but the conclusion was the same that it can be beneficial to limit fuel consumption in the operation phase by having a lighter ferry. This conclusion is the same even though the Eco-island ferry project considered a fully outfitted fictive ferry while this report considered only the hull and engines of a real life ferry.

The construction phase of a CFRP ferry does not include some special environmental friendly processes compared to the aluminium construction. However, when the design and lighter weight enables fuel savings in the operations phase the saved fuel outweighs the extra impact caused in the construction phase in less than 3 months.

5.6. Life Cycle Cost

An economic calculation of buying a CFRP ferry compared to an aluminium ferry can be done using a life cycle cost (LCC) analysis. The economic aspect is relevant to consider in relation to the strategic part where the competitiveness of CFRP is related to the price and cost relative to aluminium. A LCC analysis incorporates the cost of ownership through the whole life cycle of the product from purchase of the product, maintenance and fuel cost during operation to disposal or resale of the product. It is often used to compare two different investment possibilities in order to select the most profitable one.

A rough LCC analysis will be made since data related to maintenance cost was difficult to obtain. The maintenance cost for the CFRP ferry is estimated based on interviews with Tuco while maintenance cost of an aluminium ferry is estimated to be around twice as high based on Eco-island ferry project (26). The estimations include maintenance costs of the hull during the whole life time of the ferries, while maintenance cost of machinery, paint and outfitting (interior) is expected to be the same even though different engines is installed on the two ferries (Appendix 10). Furthermore the cost for downtime is not included in the analysis. The maintenance cost is assumed to be 0.1 million NOK per year for the CFRP ferry and 0.2 million NOK per year for the aluminium ferry. These numbers is based on three yearly services on each CFRP ferry and that each service cost approx. 33,000 NOK (Appendix 1).

A lifetime of 30 years will be assumed and therefore operation and maintenance costs during 30 years of operation will be used. It is assumed that the ferries will maintain the same level of operation and distance sailed per year as currently present on route 2 from Tromsø to Harstad during the whole lifetime. Disposal cost either sale, recycling or waste treatment is still involved with uncertainties since end-of-life scenarios of especially the CFRP ferry could change during the next 30 years. In this LCC analysis landfill will be used for the CFRP ferry inducing a cost when disposing of the ferry. A price of 500 NOK per tonnes that is put to landfill is assumed (75). For the aluminium ferry 100% recycling is assumed inducing a profit when disposing. The income from selling the aluminium scrap is 2000 NOK per tonnes scrap (55, 64).

The investment needed for buying the three CFRP ferries is 160 million NOK (49) which equals 53.3 million NOK per ferry. This investment is assumed to include both design and manufacturing. The investment needed for buying an aluminium ferry like "Renøy" could not be obtained, but it is assumed that a CFRP ferry is 20% more expensive than a similar aluminium ferry (Appendix 1). This gives a price of 44.4 million NOK for an aluminium ferry. So in a short time perspective the aluminium ferry is a cheaper investment than the CFRP ferry.

5.6.1. Operation Costs

From Table 22 the difference in fuel cost per year is calculated to be 2.32 million NOK. The difference will depend on fluctuations in fuel price and according to daily operation manager Steiner Mathisen from Boreal Transport Nord the price varies between 6-7 NOK per liter diesel fuel.

Table 22: Data related to the operation cost of the two ferries.

	CFRP ferry	Aluminium ferry
Distance sailed per year (km)	110,000	110,000
Distance sailed per year (NM)	59,395	59,395
Fuel consumption (L/NM)	16	22
Price of fuel (NOK/L)	6.5	6.5
Fuel cost per year (mio. NOK)	6,17	8,49

A life cycle cost analysis was made based on the data above and the result can be seen on Figure 35.

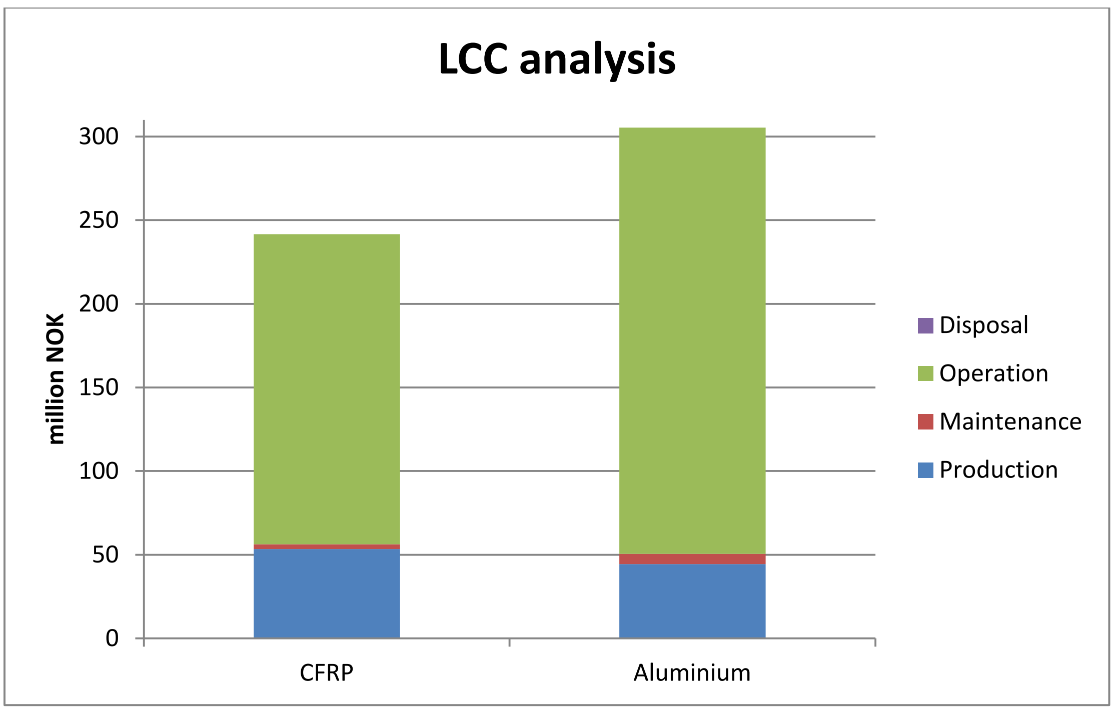


Figure 35: The accumulated life cycle costs of a CFRP ferry and an aluminium ferry divided into contributions from production, 30 years of maintenance and operation, and disposal.

Total life cycle cost for the two ferries is calculated at current prices and inflation rate and interest rate is not included in this LCC analysis. Figure 35 show that the CFRP ferry has the lowest accumulated costs at current prices. From the figure it can be seen that fuel cost during operation account for the largest share of the life cycle costs. Production cost has a visible share as well, while maintenance and disposal account little in the overall score. A break-even point is calculated and can be seen on Figure 36.

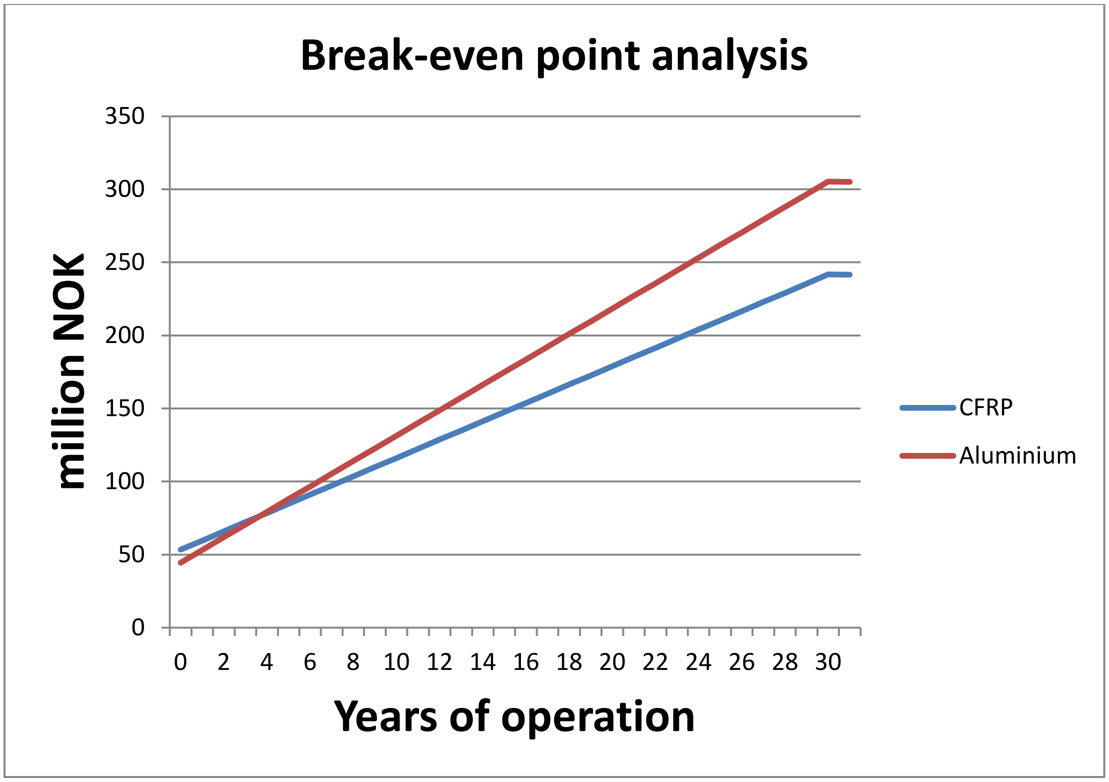


Figure 36: The graph is showing the break-even point and the accumulated cost per year.

The break-even point takes place after 4 years of operation and from that point the cost savings of the CFRP ferry compared to the aluminium ferry continue to increase until the ferry is resold or disposed. In case of 30 years of operation on route 2 from Tromsø to Harstad the total cost saving becomes 63.52 million NOK. If the ferries only operate for 10 years the cost saving will be almost 15 million NOK.

5.6.2. Sensitivity Analysis

As found in the LCC analysis the majority of costs steams from the operation phase. The effect of changing variables related to this phase will be investigated in this section. The fuel consumption is fixed and specified for both ferries, but distance sailed per year, years of operation and fuel price can be changed.

If years of operation and fuel price are kept constant and only distance sailed per year is changed, the sensitivity of distance can be investigated. Doing this shows that the investment of a CRFP ferry is still profitable compared to an aluminium ferry if the ferry sails 10,000 km or more per year (see Table 23). In case of 10,000 km sailed per year a small cost saving would be made after 30 years of operation and break-even would occur after 29 years.

As a reference point the Tun Island ferry is sailing 25,200 km per year (5). If the lifetime was set to 20 years of operation the CFRP ferry would be profitable when sailing 16,600 km or more per year. However, it should be noted that a high speed catamaran ferry is unlikely to operate on shorter routes where saved travel time is less significant. A traditional ferry probably made of steel with completely different fuel consumption and capacity would most likely be used as a reference. The results of some other distance per year are found in Table 23.

A higher distance sailed per year favours the CFRP ferry since it has the lowest fuel consumption. An increase in distance sailed and hence operation time could increase the amount of maintenance work as well, but this is not included in the analysis. Since the price of the aluminium ferry is estimated the sensitivity of price difference between the two reference ferries for various yearly distances can be found in Table 23.

Table 23: Showing break-even point analysis for alternatives in investment price and yearly sailed distance. Numbers in brakes are total life cycle savings in million NOK. The basic deterministic values are 83% and 110,000 km respectively.

Distance per year km) / Price of Al ferry (% of CFRP)	10,000	25,000	50,000	100,000	110,000 (basic value)
50%	89	43	24	13	11 (45.74)
75%	43	22	12	7	75 (59.07)
83% (basic value)	29 (0.34)	15 (9.82)	8 (25.61)	5 (57.20)	4 (63.52)
90%	18	9	5	3	3 (67.07)

The numbers calculated in Table 23 is based on the assumption that maintenance cost per year is 0.10 m NOK for a CFRP ferry and 0.20 m NOK for an aluminium ferry. The fuel price is set to 6.50 NOK per liter and the price of a CFRP ferry is set to 53.33 m NOK. Fuel consumption for the two ferries is still 16 L/NM and 22 L/NM.

Assuming an aluminium ferry is cheaper than a CFRP ferry then a higher price difference will extent the time period before break-even and lower the total savings during the life cycle. Even with sailing distance of 110,000 km and a price difference of 50% meaning the price of a CFRP ferry is twice the price of an aluminium ferry the net savings during 30 years of operation will be a little less than 46 million NOK. The break-even point occurs after 11 years of operation. However, given contracts generally are signed for a period of 10 years a shorter break-even point might be preferred for the operator.

A fluctuation in fuel price could favour the CFRP ferry and according to the Eco-island ferry project (26) a yearly increase of 3% in addition to inflation can be expected. Break-even point for fluctuations in fuel price can be found on Table 24.

Table 24: Changes in fuel price and related break-even point and difference in total life cycle costs. The initial fuel price is 6.5 NOK per liter and all other parameters are the same as in the deterministic study.

Yearly change in fuel price	Break-even point (years of operation)	Total difference in life cycle costs (m NOK)
-10%	5	56.57
-3%	4	61.43
3%	4	65,60
6%	4	67.69
25%	3	80.89

It can be seen that small fuel price fluctuations does not affect the break-even point much, but it do affect the savings during the lifetime of the ferry.

A variation in the yearly maintenance cost between 50,000-500,000 NOK did not alter the break-even point from being 4 years. Changing the cost of CFRP disposal using an incineration cost of 300 NOK/ton and a recycling profit 2000 NOK/tonnes did not change the break-even point either.

5.6.3. Summary

From an economical point of view the CFRP high speed ferry has a lower life cycle cost compared to the aluminium ferry even when accounting for uncertainties. The break-even point happens after 4 years of operation and since the contract with the municipality is valid for 10 years it is economic beneficial on this route. However, when a ship owner decides whether to invest in a CFRP ferry he should consider the difference in investment price between CFRP and aluminium together with the distance sailed per year. The yearly savings related to lower fuel consumption is depending on the specific route in focus. It is not possible to say which alternative is the cheapest because it depends on different factors like investment price, fuel consumption, yearly trips, and distance between ports. It is though certain that more kilometres sailed yearly is in favour of the lighter CFRP ferry due to the lower fuel consumption. The task is to find the limit defining when investment in a CFRP ferry is profitable during a given time frame. When comparing two ferry alternatives one should put particular focus on the operation phase and the share fuel costs have out of the total life cycle costs. The ratio between production costs, operation costs including maintenance and disposal cost or income needs to be considered. In this study the maintenance and disposal costs are small compared to the total life cycle costs, but for a different route or ferry the results might be different.

Chapter 6 Strategic Analyses

A strategic analysis will be made to answer how the competitive parameters influence a sustainable development. First the industry environment will be analysed by using Porter's Five Forces (20) while drawing in results from the LCA analysis. Second a PEST analysis will be made to look at the macro environment and the factors influencing the industry. The results and limitations from the strategic analyses will be discussed at the end of this chapter.

6.1. Porter's Five Forces

The focus of this study is on a sustainable development and the way Porter's Five Forces are used might be different than in a pure business context. Porter's five forces are intended to determine the attractiveness related to overall industry profitability. The five forces are in this study used to assess how attractive the industry is related to a sustainable development. The perspective is therefore different and this affects the way the analysis is conducted.

The analysis will start with a definition of the industry and then the disposition will follow the life cycle of a product starting from the supply chain and supplier power, over production and industry rivalry to the use phase and buyer power. The buyer power section will be supplemented with buyer experiences and a possible future secondary buyer market. Lastly the analysis will be rounded off with threat of entry and threat of substitutes.

6.1.1. Definition of Market

The market analysed will be the lightweight ship market where lightweight ferries is a subpart. Lightweight ships are built using materials like aluminium or composites e.g. carbon fibre and glass fibre, most often to obtain high speeds. There is a discrete difference between a shipyard building in composite materials and a shipyard building in aluminium. The craft for building in composite materials are related to plastic-makers, while aluminium requires smith craft. Therefore the two types of shipyards have to draw on different types of knowledge and different suppliers.

Only minor distinction is made between shipyards building in carbon fibre composite and in glass fibre composite. This became clear after a conversation with Christian Berggren, an expert in composite materials from DTU, who pointed out that it is basically the same issues one has regardless of using carbon fibre or glass fibre in shipbuilding since the design will be almost identical (Appendix 4). According to Christian Berggreen the only difference between carbon fibre and glass fibre is the fibre system and the single fibre. This means that the amount of fibre needed will be a little bit different when building a ship in one of these two composite materials.

6.1.2. Supplier Power

Four main supplier groups exist when manufacturing a hull in sandwich composite. The first group is the suppliers of core material to be used in the sandwich construction between the fibre laminates. Different kind of materials can be used for this purpose, and examples of core materials are PVC, balsa wood, and honeycomb (42). The second group is the suppliers of composite material mainly carbon fibre or glass fibre. A third group is the suppliers of resin, where the most used resins are epoxy, vinyl ester, or polyester (76). The fourth group is suppliers of all auxiliary materials such as wood for the moulds, plastic sheets, adhesive tape, and tubes for vacuum infusion used in the production phase. In addition to these four groups there are the regional suppliers of power and natural gas.

One of the biggest suppliers of core material is the Swedish company DIAB which has a large selection of products specific for sandwich structures in the maritime industry. Ten years ago DIAB almost had a monopoly on delivering core materials, but this is not the case anymore (Appendix 6). Today other companies like Gurit, used by Danish Yacht, are present on the market. The environmental impacts of using PVC foam as core material was calculated in the LCA analysis and from Figure 29 it can be seen that PVC foam production account for 7-10 % of the impact in the construction phase. If a more environmentally friendly core material than PVC is used it would have some influence on the total impacts in the construction phase, but not a significant influence. If incineration was the end-of-life scenario PVC would have a higher environmental impact.

Tuco used the Norwegian company AMT Devold as their supplier of carbon fibre for the three ferries. Globally there exist around twelve major suppliers of carbon fibre (see Figure 38). The demand for carbon fibre in 2011 can be seen in Figure 37.

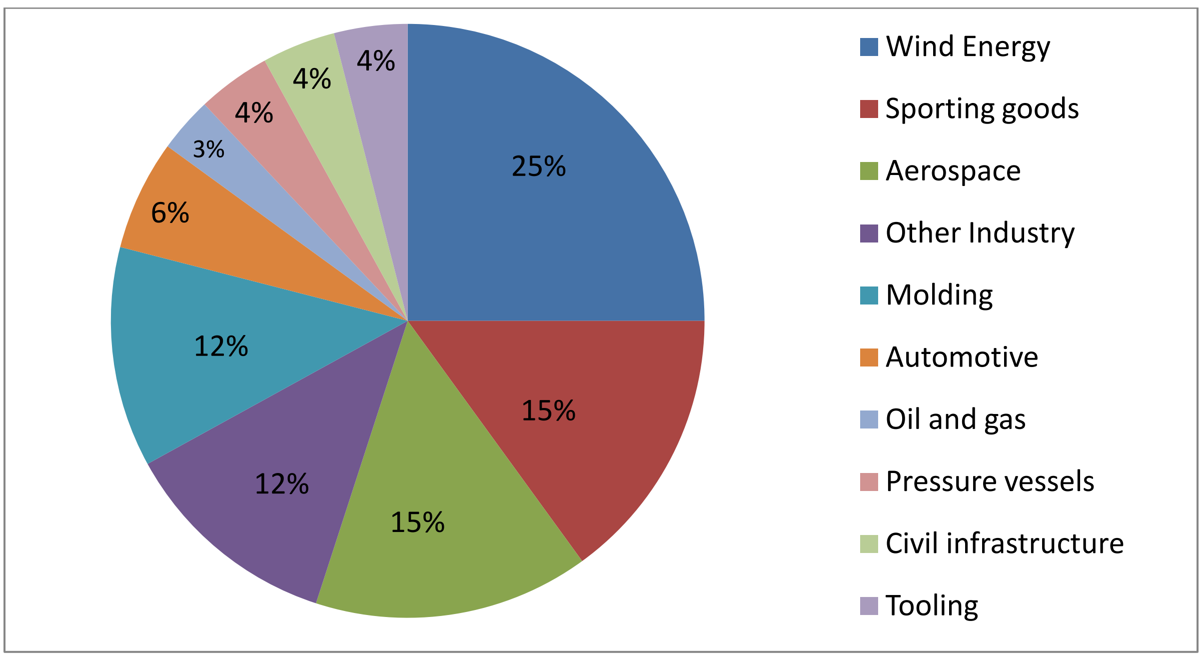


Figure 37: The demand for carbon fibre in 2011 (38).

The producers of carbon fibre do not depend on the maritime industry since the majority of the demand comes from other industries like wind energy, sporting goods and aerospace. The dependency from these industries is expected to increase and in 2020 the demand from the wind energy sector is expected to be five times higher and aerospace three times higher than the 2011 levels (see Figure 38).

Table 1	PAN-based Carbon Fiber, Manufacturer Nameplate Capacity, metric tonnes		
	2011	2015	2020
Toray	19,000	21,000	21,000
Zoltek	14,000	16,000	18,000
Toho	13,900	13,900	13,900
Mitsubishi	13,000	13,000	13,000
China (combined)	9,200	10,000	10,000
Hexcel	7,500	8,500	8,500
Formosa Plastics	8,000	8,000	8,000
SGL Carbon	7,900	10,000	10,000
Cytec	2,300	4,000	4,000
AKSA	1,800	3,600	4,000
Hyosung	<1,000	2,000	8,000
Others	<1,000	1,000	1,100
SABIC	0	1,500	5,000
Totals:	97,500	112,500	124,500

Table 2	PAN-based Carbon Fiber, Manufacturer ESTIMATED ACTUAL Capacity*, metric tonnes (based on 2011 market share)		
	2011	2015	2020
Toray	19,000	23,000	31,000
Zoltek	14,000	17,000	23,000
Toho	13,900	18,000	22,000
Mitsubishi	13,000	15,000	20,000
China (combined)	9,200	11,000	18,000
Hexcel	7,500	9,500	12,500
Formosa Plastics	8,000	9,000	11,500
SGL Carbon	7,900	14,500	18,000
Cytec	2,300	5,000	6,000
AKSA	1,800	5,000	6,000
Hyosung	<1,000	3,000	8,000
Others	<1,000	1,500	5,000
SABIC	0	1,500	5,000
Totals:	97,500	133,000	186,000

Table 3	Carbon Fiber Demand Forecast, Aerospace and Defense, metric tonnes		
	2011	2015	2020
Commercial aircraft	4,300	7,910	13,290
Military fixed-wing	500	770	1,000
Rotorcraft	370	400	460
Business Aircraft	240	590	720
General Aviation	600	1,000	1,250
Jet engines	380	1,660	1,930
Space and launch	450	520	550
Carbon-carbon	160	240	500
Total:	7,000	13,100	19,700

Table 4	Carbon Fiber Demand Forecast, Industrial, metric tonnes		
	2011	2015	2020
Wind energy	12,280	37,600	67,400
Oil and gas	1,380	2,700	10,650
Molding compounds	5,750	7,700	10,170
Industrial rollers	450	700	820
Pressure vessels	1,650	7,250	12,520
Automotive	2,700	4,000	5,600
Civil infrastructure	1,900	2,900	3,900
Pultrusion	1,300	2,200	3,710
Misc. energy	180	500	1,520
Medical/prosthetics	240	320	440
Tooling	2,000	2,700	3,960
Total:	29,830	68,570	120,690

Table 5	Carbon Fiber Demand Forecast, Consumer, metric tonnes		
	2011	2015	2020
Sporting goods	6,840	7,180	7,860
Marine	800	1,600	2,190
Misc. consumer	1,380	2,010	3,240
Total:	9,020	10,790	13,290

Table 6	Total Global Carbon Fiber Demand, metric tonnes		
	2011	2015	2020
Aerospace	7,000	13,100	19,700
Industrial	29,800	68,600	120,690
Consumer	9,000	10,790	13,290
Total Demand:	45,800	92,490	153,680

*Represents Roberts' estimates of actual capacity (greater than manufacturer's estimated nameplate in Table 1 by 2015) if suppliers maintain current competitive market share in response to growing demand (Table 6).

Figure 38: Estimated capacity and demand forecast for carbon fibre from 2011 – 2020 (38).

Most of the carbon fibre plants are located in industrialized countries like China, Japan or USA. Since Tuco is only buying the amount of material that is needed for a given order their switching cost is low. However, it is a prerequisite that the material from a new supplier of carbon fibre can be approved by a classification society. If not it will require time and effort to test the new material and get it approved. An increased demand will affect the supply of carbon fibre as well, meaning that either existing suppliers will increase their supply or new suppliers will enter the market. To summarize the carbon fibre producers have some power, since the shipbuilding industry is not the primary purchaser of carbon fibre and an eventual shortage of carbon fibre supply would probably hit small and less powerful purchasers like shipyards first. On the other hand the competition among the carbon fibre producers together with low switching cost give some bargaining power to the shipbuilding industry. Fluctuations in price due to changes in demand and supply can also affect the power relations. Since the shipbuilding industry in focus is anyone building in composite materials the supplier power of carbon fibre would change if this industry chooses to shift from carbon fibre to another fibre material.

The LCA results showed that carbon fibre production accounts for 27-31% of the impacts related to the construction stage. This is for the production of carbon fibre alone and excluding the power and natural gas needed for vacuum infusion and the subsequent hardening process. A change to another composite material could therefore be a possibility to improve the environmental impacts.

Suppliers of resin are the largest supplier group based on mass since resins account for almost half of the weight in the final hull. Many different companies exist on the market since resin is used in other industries like automotive and electronics (77). Tuco is using a German supplier called Reichhold, while Danish Yacht is using the global company Gurit. The main part of the resin used at Tuco consist an epoxy based vinyl ester resin and from the LCA analysis it was found that around 23-32% of the impacts related to construction is caused by the use of epoxy resin. A sensitivity analysis was made where polyester resin was used instead of epoxy resin and this resulted in lower impact for human health, but higher impact for ecosystems. The supplier power for resins is low, but significant more environmental friendly alternatives seem to be few.

Changing any of the three main components in a sandwich construction requires a new test to verify the strength of the new sandwich construction (see Appendix 1). Buying a different kind of core material or using another type of resin might change the properties of the sandwich structure and this change needs to be tested and later approved by the authorities. So even though switching costs appears low it can be complicated to switch to a new or partial unknown supplier that has no certifications or references.

There will not be a detailed explanation of the power relations of aluminium suppliers, since the focus of this study primarily is on composite materials. Even though aluminium represents the second largest metals market in the world and it is mainly extracted from bauxite areas in Brazil, South West Africa, and Australia (55). Since the suppliers are numerous and aluminium is a common material the supplier power is assumed to be low.

In relation to the plastic helpers Tuco is currently using a Danish company called Bodotex Composites located in Vejle in Denmark. Plastic helpers such as plastic sheets, adhesive tape and tubes are produced by a wide range of producers and there is no cost connected for Tuco to switch supplier since there exist limited differentiation between the suppliers. On the other hand the suppliers of these materials do not solely deliver to the shipbuilding industry, but to a wide range of industries. Hence there is an equal distribution of power between the shipbuilding industry and the suppliers in this case. During the project it was found difficult to get other data than the functional properties of the plastic helpers and even after being in contact with Bodotex Composites the chemical content could not be obtained. Under such circumstance if a company like Tuco considers changing to more environmental friendly plastic helpers it would be hard for them to make an enlightened choice. The suppliers have power in an environmental aspect by not informing about the content of their products. However, the LCA results showed that the plastic helpers only have minor environmental impact in the construction phase, which diminish this power.

It is relatively easy to switch supplier of energy, since the market for energy supply is heavily regulated by the Danish government which attempts to ensure equal terms for all energy suppliers (78). Around 17% of the environmental impact in the construction stage origins from the use of natural gas for heating and around 7% from power consumption (see Figure 29). Tuco can limit their use of energy and heat by making their location and buildings more energy efficient. However, a heavy investment in e.g. insulation of buildings could limit the possibilities to change location in the future. The payback time should be reached within a few years since the natural gas expenditures during the winter can be 50,000 DKK per month (Appendix 1).

6.1.3. Industry Rivalry

The industry investigated is the composite shipbuilding industry in Northern Europe, with the main focus being Denmark. The focus is the Danish maritime industry, but since Tuco collaborates with companies from other North European countries the definition of the industry has to include these countries in a limited extent as well. According to Tuco their market segment is every market for ships or ferries where weight, fuel consumption and speed are keywords, since weight and speed determines the fuel consumption (Appendix 2).

Competitors capable of building commercial ferries in CFRP are few. One of the big actors in Scandinavia is the Norwegian shipyard Brødrene AA with 91 employees (79). Brødrene AA has been building commercial composite ferries since the mid 1970s and can be regarded as the market leader in Scandinavia. Another big actor is Kockums shipyard in Sweden, which have delivered 45 different composite projects during the last 50 years with their primary buyer being the Navy (80). In Denmark companies like Danish Yacht in Skagen, Faaborg Værft, and Mathis Værft in Aalborg are the main competitors. Danish Yacht has around 100 employees while Faaborg Værft and Mathis Værft have 49 and 9 employees respectively (see Table 25). A range of minor yards for which composites are a side business also exist (Appendix 20).

Another picture is found when looking at direct competitors who do exactly the same as Tuco which is manufacturing CFRP hulls for later assembly at another shipyard. The above mentioned competitors in Denmark and Scandinavia are all building complete ships. They can as well as being a competitor also being a co-operator to Tuco. Tuco can supply a finished hull to these shipyards that will then assemble the engine, propeller, fuel tank, and so on. If Tuco had a permanent agreement with a shipyard then this cooperation could become a competitor for the other shipyards building complete ships in CFRP (Appendix 6).

The market for CFRP ships is sensitive and unfortunate episodes like Sollifjell being damaged on her maiden voyage can harm the industry and make buyers choose other materials than carbon fibre. The sensitivity aspect can also be found in the industry rivalry where Brødrene AA attacked Tuco and Båtservice Mandal for destroying the market for CFRP boats. According to Brødrene AA they were responsible for the episode with Sollifjell, since they did not have the right competencies and experiences for building CFRP hulls and ferries (81). Another reason for this attack can be that Brødrene AA wants to remain being market leader and do not want new actors in the industry. Either way this example shows that there is rivalry within the industry of CFRP ships.

During the interviews with Kai Nielsen and Jonas Pedersen from Tuco the competitive parameters which defines industry rivalry among the shipyards was discussed. According to Kai one of their core competences is:

"Our core knowledge is really how to install the feeder line to resin and vacuum and how they are situated and how you do this with a high degree of certainty that it is going to be a success."

Tuco's ability to be specialised in the vacuum manufacturing technique is an advantage. Another competitive advantage is that they are quick and flexible. It only takes Tuco 3-4 weeks to construct a male mould before the production of a hull can begin which for other shipyards using a female mould would take around 9-12 weeks according to Kai Nielsen. Delivery time is in many cases decisive and the shipyard who can deliver fast and on time will have a competitive advantage. Tuco has no stock of materials at their location and the 3-4 mould construction weeks are used to collect offers and get materials from suppliers.

The flexibility parameter is related to Tuco's use of foreign subcontractors hired on project based contracts and work 10-14 hours a day when in Denmark. According to Jonas price is a competitive parameter and their ability to be a quick and effective organisation makes them more effective with regard to price. By decreasing the waste percentage from 25% to 10% Tuco could become even more effective in relation to price, but also environmentally. Tuco's competitive advantage of being quick and deliver at time, but at the same time having no stock is quite similar to just-in-time manufacturing and LeChatlier's principle (23). This way of doing business removes costs associated with a storeroom and decreases the change of materials or products becoming obsolete on the shelf.

According to Porter (20) price competition is most likely to occur if products are nearly identical and switching costs are low for the buyer. This is the case in the shipbuilding industry since the products whether it is a ship or ferry are built according to the requirements set by the Danish maritime authority and classification societies. Quality differentiation between competitors is not crucial, since quality is defined beforehand and listed in the specification (Appendix 2).

Reputation is another competitive advantage hold by the shipyards which has proven over time that they can do a satisfactory job. At the interview with the naval architect the reputation factor was outlined as essential when deciding which shipyard should be given an order. In the high value market it was often more important for a ship owner to be sure to get a high value ship as specified and at time, than saving money. A quote from the CEO at Tuco Jonas Pedersen underpins this:

"When you compare shipyards then I think it is more relevant to look at references than to look at quality. The quality is that everyone promises to comply with the demands set by DNV. It is more important what references they each have that can document they can do it."

A proven ability to build to classification standards is another way for a yard to differentiate itself from competitors. A yard can have experience building to a given classification society's rules, which will increase the trust that the yard can build in accordance to the rules again (Appendix 7). Such previous co-operations and experiences can minimize the risk of extra costs and time used in a project.

A consideration was done on other competitive parameters. Even though Tuco and other shipyards with knowledge about composite are able to repair and offer after sale support services this was not found to be a competitive advantage at the present moment. If the market for composite ships experience growth then a new business opportunity could evolve for after sale services related to repair and maintenance.

When looking at exit barriers they are mainly high for shipyards having a dock which they either rent or own. If forced out of business a possibility to change to other types of materials like steel or aluminium do exist in case the shipyard possess the competencies to build in these materials. Another exit barrier would be if a large stock of composite and related materials were gathered which had to be sold before going out of the business. In relation to this it has to be mentioned that a floating dry dock is not needed when building small lightweight ships. A potential investment in better insulation of the production hall could increase the exit barriers at least the first years after the investment. Hence the exit barrier for Tuco is low, because they are a small company which do not have a dock or stock of materials. For other companies in the industry the exit barriers might though be higher.

Industry growth is slow at the moment because the opportunity to use composite materials in shipbuilding is still quite new. Ship owners are sceptical whether composite is a real alternative to steel or aluminium and whether it guarantees the required stability, strength and fragility (Appendix 5 and 6). The demand for lightweight ships built in composite materials is primarily coming from the offshore industry supplying the wind, oil and gas sector, since regulation related to service ships is different and less strict than for passenger ferries (see section 0). The offshore sector have seen the advantages of using lighter boats or service ships which are increasing their availability i.e. how often and for how long they can operate at sea. A mix of stakeholders including shipyards, knowledge institutions and the Danish government are cooperating to create a future marked in Denmark for small commercial ferries built in composite materials and this can in the future increase industry growth (Appendix 16 and Appendix 18).

In summary the industry rivalry is relative benign, because Tuco is specialized and delivers a differentiated product compared to the rest of the industry. The forces increasing the rivalry are related to little differentiation between final products and slow industry growth. Industry rivalry is also a bit complex since the same company can be both a competitor and a co-operator when looking at the competitive market for Tuco. Some of the decisive competitive parameters is found to be price, time and references.

6.1.4. Buyer Power

An introductory citation from the interview with Danish Yacht explains the main barrier related to buyers:

"Composite and lightweight constructions is a new thing in the commercial world and there is a lot of traditions associated with known materials. Therefore it demands a long haul to convince all actors that this is the right."

Often there is not one single buyer which has the whole responsibility for buying a new ship. In the case of ferries a buyer can be the municipality, the national state in form of a public ferry operator or a commercial ferry operator. The main environmental impacts for a ship occur in the operation phase due to the fuel consumption. In order to assess the environmental possibilities for a ship or a ferry it is interesting to look at buyer interest and position. The focus of a buyer is to get a ferry that performs a given service (49), but sometimes the buyer can lack knowledge of the physical and legal constraint of a ferry. To attain this knowledge and to support in the design process the ferry owners will contact a naval architect. The naval architects would then represent the ship owner and due to their central position in the decision process their motives become relevant when analysing buyer power.

The following is based on an interview with a Danish naval architect who had experiences in consulting ferry companies in Denmark. The naval architect and the ship owner together have to figure out the specifications and design of a new ship. Often the owner has a clear idea about what he wants and the naval architect then tells him what is technological possible and what is not. The naval architect interviewed in this study had professional expertise with composite materials which originated ones a shipyard suggested fitting part of a vessel in composite. The idea was to make the bow in composite, but in the end it could not be done because there was no proven method to assemble the composite bow to the rest of the vessel made in aluminium. Here the naval architect had a negotiation power in the decision phase of whether to use a new material or not based on technological restrictions.

Another aspect that affects the negotiation power of a buyer represented by a naval architect is their level of knowledge and experiences with composite materials. If a consultant has no previous experience with ships built in composite materials, he either needs to attain the competencies externally or he will be more likely to avoid projects involving the use of composite materials. The naval architects knowledge, competencies and familiarity have an indirect effect on the negotiations.

The relationship between a shipyard, a naval architect and a ship owner is based on trust and reliability (Appendix 6). If there has been a successful cooperation before and good relations has been established this increase the possibility for future projects and agreements. The importance of trust is underpinned by a citation from the interview with Danish Yacht:

"A relationship between a shipyard, a naval architect and a shipping company is a matter of trust. It might be that you can demonstrate a certain quality in a design by means of fluid dynamic calculations, but to get there you need to use some money. So before you go into cooperation you need to trust that each actor individually can perform the task and deliver the right result"

Such good relations can have a positive effect for the shipyard since a higher price can then be demanded. Good relations and successful project also tend to spread in the industry which will improve the reputation of the shipyard. Buyer power is related to the history and references of the shipyard and the portfolio of orders delivered in the past. A close cooperation between e.g. a shipyard and a naval architect can have a downside. If each co-operator becomes more and more dependent on the other, it might increase the price simultaneously. So you need good relations, but everyone is business people and therefore you need to keep such cooperation on a short leash economically (Appendix 6).

Tuco can threaten to integrate downstream by hiring or cooperating with a naval architect able to make calculations on composite structures. Combined with the extended knowledge about the manufacturing process this downstream integration will enable Tuco to better communicate the material properties to the buyer and hence increase the chance of an order. As mentioned in the theory section about 80% of the environmental impact is fixed in the conceptual part of the product design phase. If Tuco is able to influence the design of the hulls they build, it can be beneficial for the environmental performance of their products. Currently this is only a consideration made by Tuco, but it might be realized one day.

Price sensitivity is generally high inside the maritime sector because it is an industry which is cost driven and ship owners often have tight budgets. This could be affected if the shipyards building in CFRP material could document and convince the ship owners that the extra investment needed for a CFRP ship compared to an aluminium ship would be offset by future cost savings on fuel and maintenance. In case a comparison of the total life cycle costs would be in favour of the CFRP ship this would fit well with an industry so focused on costs. As Porter (20) argues, if a product or service can pay for itself many times over by improving performance or reducing material or other costs, buyers are usually more interested in quality than in price.

The industry's product has some effect on the buyer's other costs and high effect on the total environmental impact. The costs related to operation of a ferry are fuel consumption, maintenance and salary to crew members. The environmental impact is mainly related to the fuel consumption. Fuel consumption and maintenance costs are dependent on the type of ferry bought. The cost for salary and number of crew members is partly determined by regulation and whether the ferry is built in accordance with the HSC code or not. Hence the buyers' other costs and environmental impact are related to the type of ship they order and the operated route.

A vessel built in composite is standardized due to the requirements set by the classification companies. There might be some differences in design and structure, but in general the materials used and the quality of a final product built by two different shipyards are the same. This none-differentiation between the final products increases buyer power, but as mentioned earlier other factors like delivery time, reputation and price are also influencing buyer power and when considering these factors the shipyards has a certain degree of bargaining power as well.

In general the buyer power is high, since it is the buyer who can freely change shipbuilder, but it is also the buyers who have all the risk of the final product. Some of these risks are related to the cost of fuel, salary and to problems that might arise if the ship cannot sail. It is a buyer’s use of a ferry that gives the largest environmental impact by burning of fuel. It must mainly be the buyer who needs to shows an interest in more environmental friendly ferries. Trust and a good reputation of the shipyard can decrease buyer power, since no buyers are willing to take unnecessary risks.

6.1.4.1. Buyers Experiences

Experiences with composite materials for use in shipbuilding are few and the track record for commercial ships build in composite is short. One of the few Danish buyers who have experience with composite ships is the Danish navy. A telephone interview with Commander Michael Bruhn Rasmussen from the Danish navy revealed some of the experiences gained in the 1900ies and 2000ies when the navy had a series of ships called standard flex.

Figure 39: The STANDARD FLEX ship MSFI used by the Danish Navy (82)

These hulls were constructed using a sandwich structure consisting of glass fibre, polyester resin and core material. Overall the navy was satisfied with these ships which had lower maintenance costs than a similar steel ship. Another advantage was if one of the standard flex ships was in contact with the docks. This could cause a hole in the hull, but there would be no damages to frames or the like, which could be the case for a less elastic steel ship if it hit the dock to hard. Some of the problems experienced were gas pockets and delamination between the glass fibre and core material. According to Danish Yacht this is a known problem for older boats build in glass fibre and polyester resin that delamination can occur.

Since the standard flex ships were built more than 15 years ago similar types of problems are rare today mainly due to technological improvement of the materials (Appendix 6). Furthermore the use of polyester as resin material is not a good idea according to Danish Yacht, and better and stronger resins like epoxy has been introduced which decreases the chance of delamination and gas pockets. The construction method has also been improved since the 1990ies with the introduction of vacuum infusion (see section 4.6) and degasifying of core material all guaranteeing a better attachment between fibre and core.

6.1.4.2. Secondary Buyer

An analysis and discussion will be made linking the end-of-life stage of the life cycle methodology with a secondary buyer in Porter's model (see Figure 10). So far no market for reused CFRP exists partly due to the fact that no large amounts of CFRP scrap have been accumulated yet. As can be seen from Figure 31 the environmental benefits can be significant if CFRP were recyclable. However, a recycled CFRP-product will only have relevance and be environmental beneficial if someone is willing to buy the recycled product instead of the virgin material. In order words the recycled product needs to have some kind of commercial value.

Today the disposal options of CFRP are either landfill or incineration. Both options result in harmful environmental impacts and do not take advantage of the energy or usability still present in the carbon fibre structures. Future research in this field can make the industry more profitable and environmentally friendly and make the disposal phase a source of income instead of a cost. Some successful attempts have been done to use glass fibre scrap from wind mills in building materials as fibre reinforcement or in asphalt as filling (Appendix 4). During the spring of 2013 Turban Composites ApS began production of glass-fibre mats made from pure glass fibre production waste and cut-offs (83).

Figure 40 Example of product from Turban Composites ApS (83)

When interviewing the production manager at Tuco he mentioned that they already used a products called chop, made of recycled glass fibre where orientation of the fibres is random. The benefit with chop is that it can contain more resin and is therefore very usable in joints. The possibilities of recycled composite materials are still limited and future research could increase the number of possibilities for reuse (Appendix 4).

At present most research is related to recycling of glass fibre since the majority of composite scrap from the windmill industry is of this type (Appendix 12). One example is the project Genvind which is looking at recycling of plastic composites with a special focus on the windmill industry (84). The project was initiated in December 2012 and is supported by 18 industry partners, together with a number of research institutions and networks. Experiences and knowledge gained in such projects can be used when considering the disposal options of a CFRP ferry.

A future market for recycled carbon fibre material will depend on the amount of carbon fibre waste or scrap. This can be seen in the glass fibre market where the amount of scrap is now reaching levels where it is profitable to consider recycling or reuse in large scale. Information about the exact contents of the specific scrap or waste, like use of additives, hazardous chemicals or fire resistant coating need to be obtained before methods of waste handling can be decided. Here cooperation between designers, suppliers and dismantlers is essential since a lot can be done during the design phase by e.g. attaching relevant information about recycling or dismantling to the product itself. Legislation can likewise accelerate the need for other disposal options than incineration or landfill. This is already happening in countries like Austria, Germany, Sweden and Holland where landfill of biodegradable wastes or recyclable materials has been banned (85).

Principle 11 from (23) relates to design for performance in commercial after-life. This principle is stating that if one component is obsolete a design does not have to be replaced or retired. Instead by allowing for a product or process to be upgraded through component substitution, the useful life can be extended and future performance standards can be met. The environmental impact is minimized to the single component rather than the whole product. This can be translated to the shipbuilding industry by considering retrofit or component substitution in the design phase making it possible to replace or substitute parts of the ship after years of operation instead of retiring the whole ship.

At present there are no recycling options for resin-filled CFRP, and in that respect aluminium have a clear advantage. Whether or not a market for recycled CFRP will arise depends on the research done in the field and if the recycled product has a quality acceptable for a potential secondary buyer. The power a secondary buyer will have on Tuco depends on future legislation and research.

6.1.5. Threat of Substitutes

The most direct substitute in case of the three CFRP catamaran ferries is a catamaran ferry build in aluminium since they are both lightweight vessels competing for the same market. This is further proved by the fact that the two previous ferries Fjordkongen and Fjorddronningen both made in aluminium took over operation of the route when there were start-up problems with the three CFRP ferries in the beginning of 2011 (see section 4.8). Furthermore both types of ferries can transport passengers at high speeds over a body of water. When changing the perspective to ferries in Denmark the threat of substitutes include steel ferries and bridges as well, since both can transport people and cars over a body of water. However, the following will mainly focus on substitution between ferries made in different kind of materials.

Once it is decided which type of material to use for a ferry, whether it be composite, aluminium, or steel the later cost of switching material becomes high for the buyer. There are services and infrastructure related to the different kind of products like design and location of the port facilities and gangway needed to load and unload passengers. Before deciding on a type of product the switching cost for the buyer is low, and the cost at that point is primarily dependent on a potential agreement with a naval architect.

In a performance perspective steel and aluminium ferries have the advantage of being reliable since the properties of both metals are well known and documented. CFRP is a relative new material and not all properties and limits of the material are fully documented and tested (Appendix 4). The price of a metal ferry is lower compared to a CFRP ferry. However, the maintenance costs for CFRP is often lower than for steel and aluminium (53) (see section 5.6). When it comes to durability and lifetime of the ferries steel have the advantage of being non-combustible, but steel corrode and its strength diminish over time (Appendix 7). Aluminium is fire resistant and corrosion free, but can after many years of operation experience metal fatigue and lose strength (86). Furthermore if a fire erupts aluminium will rapidly loose structural integrity. Composite materials do not corrode and the expected lifetime is around 30-40 years according to Tuco. If handled properly and by avoiding contact with docks or other hard objects the composite material should maintain structural integrity and strength during the whole lifetime (Appendix 4). Another advantage of using a lightweight material like composite instead of steel or aluminium is the ability to operate and maintain stability in high sea which is especially useful in the offshore industry where harsh weather is often present (Appendix 6). At the moment the main disadvantage is that composites are highly flammable and additional fire resistant material or insulation is needed.

Whether retrofit of existing ferries is a threat or an opportunity can be debated. Retrofits are a threat in the respect that the possibility of a retrofit decreases the buyer's willingness to buy a completely new ferry. On the other hand retrofit is an opportunity for the CFRP technology to be implemented on a wider range of maritime products, and can help increase a buyer's practical knowledge and experience with composite materials.

6.1.6. Threat of Entry

In case of shipyards building in lightweight materials for the commercial market the threat is primary related to newcomers being able to build to classification standard.

Trust and reliability becomes a competitive advantage due to the buyer's focus on low cost and delivery time. Newcomers might be able to build to classification rules, but they will have a hard time proving that they are able to deliver the right product on time if they have no previous references (Appendix 2). Therefore the current shipyards have a benefit of demand side scale, because they have a network and a good brand, which is important in a conservative and cost driven market like the maritime. When the established shipyards have such a network among the buyers it gives an unequal access to distribution channels for newcomers, but this probably goes for many other industries as well.

On the supply-side the assembly shipyards need to have access to a dock either directly by owning a dock or by cooperating with someone in possession of a dock. In the case of composite ships and ferries the low weight of the hull decreases the need to be located right next to a dock in the production phase. An example is Tuco which is located around two kilometres from the nearest dock which is Faaborg harbour. This gives limitations to the size and dimensions since the roads and paths used when transporting the hull on a truck allow for a certain width of the hull. Hence there is limited capital requirement in starting a new composite shipbuilding company. If not located close to a dock the size of the hull and ship can though be limited by the transportation route to the dock.

Using information from two Danish trade associations 45 shipyards were found in Denmark by April 2013. By looking at homepages of these shipyards their buyer segment and type of product were identified and the number of employees was found using the CVR-register. In Table 25 the shipyards in

Denmark which has new shipbuilding as part of their product portfolio can be found. Shipyards with four or less employees have been omitted from the list.

Table 25: Showing the largest shipyards in Denmark which are making new ships or boats. Danske Maritime =DM, "Skib- og Bådbyggeriernes Arbejdsgiverforening"="SB", experience in CFRP = yes, experience in glass fibre = (yes), product type "both"=service and newbuild, Buyer both= leisure and commercial

Number of employees	Shipyard	Trade association	CFRP production (glass fibre)	Type of product	Buyer segment
200	Karstensens Skibsværft A/S - 1917	DM	no	both	commercial
100	Danish Yacht - 2000	DM	yes	newbuild	both
99	A/S Hvide Sande Skibs- & Baadebyggeri - 1950	DM	(yes)	both	both
50	Assens Skibsværft A/S - 1865	DM	no	both	commercial
49	Faaborg værft - 1970	SB	yes / (yes)	both	commercial
49	Quorning Boats ApS	SB	yes	newbuild	leisure
12	Tuco Marine Group	SB	yes	both	both
9	Mathis værft A/S - 1876	SB	yes	both	both
9	Hellers Yachtværft ApS	SB	no	newbuild	leisure
9	Faurby Yacht A/S	SB	(yes)	newbuild	leisure
9	Bredgaard Bådeværft ApS - 1965	SB	(yes)	both	both

In the leisure segment there are a couple of medium sized shipyards which have experience in CFRP or other composite materials. The threat of entry from the shipyards having commercial buyers, but no experience in composite is present if they can attain material knowledge of composites. From the leisure segment the treat of entry would raise if these shipyards began to build according to classification standards. The biggest threat of entry, seen from the perspective of Tuco, would be if a commercial shipyard began to partner up with a leisure shipyard having knowledge about composite materials. Much like the way Tuco came into the commercial segment by partnering up with Båtservice Mandal AS.

Another threat of entry is the foreign subcontractor workers used in different project. These workers have the possibility to accumulate knowledge and references from project to project. If they wanted they could start up their own shipbuilding company in their home country which in this case would be either Poland or Lithuania where costs and salary is lower than in Denmark.

6.1.7. Summary

When considering the five competitive forces that shape an industry different forces stand out. The ship owners have a relative high buyer power with their ablity to swich from one shipyard to another. The easy swifting arise due to the certification process all the yards have to oblige to. The buyers also have large power over who enters the industry, since relations and reputation related to the buyers are primary barriers of entry. Another important force for a shipyard building ships in CFRP is the threat of substitues. Since the industry is conservative and not willing to take many risks with a new and yet unproven technology the likelihood of them sticking to more familiar materials like steel and aluminium is present. However, a continues use of metals is not only a threat for the composite industry, since the possibilty for making retrofit where a combination of e.g. steel and CFRP could be made. The prospect of using composite material for shipbuilding in an industry very focused on costs is clear. The industry could have a strong interest in using these new and lighter materials since the total cost of ownership of a CFRP ferry can be lower compared to a metal ferry because of better fuel efficiency and less maintenance work. Tuco are considering to use downstream integration and become a sparring partner in the design process, which could increase their competitive advantage by having a better and more optimized product to sell.

6.2.PEST

A PEST analysis will be made to specify which factors are affecting the industry of lightweight ferries in Denmark. This will be done to see how Tuco influence the Danish maritime sector and whether trends in the macro environment hinder or support a sustainable development of the industry.

6.2.1. Political

Tuco is located in Denmark, a country with political stability, close to none corruption, and one of the wealthiest countries in the world (87, 88). In Denmark when a ferry route is put out to tender the decisive parameter is price (89, 90). In Norway environmental considerations and expected emissions of carbon dioxide and NO_x are included in the decision process as long as the price difference between two offers is less than 20% (49) (see section 4.8). Here the investment price and operation cost is a parameter together with expected emissions. The difference in procurement rules for Denmark and Norway means that ferries with low fuel consumption and high purchase prise like a CFRP ferry have more difficulties getting into the Danish market than the Norwegian market (Appendix 2).

Regulation

One of the main barriers for building ferries in composite materials is fire safety. A material like CFRP is combustible and this creates some challenges in relation to national and international regulation. The most used regulation is the SOLAS (safety of life at sea) convention which is an international maritime safety treaty. It is administrated by IMO (international maritime organization) and the first version was adopted in 1914 shortly after Titanic' wreck. The main objective of the convention is to specify minimum standards for the construction, equipment and operation of ferry, compatible with their safety. In Denmark the Danish Maritime Authority (DMA) is responsible for national regulation which is closely related to the SOLAS convention. For many years the convention stated that only ships built in steel or equivalent was allowed, setting an obstacle for the use of composite materials. This was changed with the introduction of regulation 17 based on SOLAS chapter II-2 (part F). This regulation states that fire safety design and arrangements may deviate from the prescriptive requirements provided that the design and arrangements meet the fire safety objectives and functional requirements of the regulations. To do so an engineering analysis shall be carried out based on guidelines using a deterministic performance based approach to verify that the fire safety of the design is at least equivalent to that specified in the regulation (91). However, such an analysis can be a relative costly process (Appendix 6) and quite time demanding (Appendix 5).

The three Norwegian catamaran ferries all comply with the high speed craft code (see section 4.3) which makes it easier to build passenger ferries in alternative materials. A ship built in accordance to the HSC code must have exactly one passenger deck, not be more than 4 hours from refuge and be easy to evacuate. All these conditions result in less strict fire safety regulations.

Ferries have to meet the standards of the different flag states like DMA in Denmark. In order to get insurance a ferry needs to follow classifications rules specified by a classification society. In Denmark the classification societies have a close cooperation with DMA when inspecting new or existing ships (Appendix 7). In relation to classification rules new materials such as composites have a challenge. Classification standards are made on the basis on existing ships, and one cannot built in a new material if no standard related to this material exists. However, the standards cannot be made before a ship has been built, so this possesses a dilemma for the industry.

Political Intentions

The strong focus on fire safety requirements is partly related to history. The fire accident on Scandinavian Star in 1990 resulting in 159 dead (92) brought focus to fire safety on ferries. Even today the memories of this event mean DMA is precautious when approving a new ferry. DMA is though interested in helping the Danish shipyards and would like to find a solution which makes it possible to build ferries in composite materials in the future (Appendix 3).

The role of DMA cannot be underestimated since they are responsible for approving new ferries and enable the possibility of building CFRP passenger ferries for Danish routes. At the present time DMA are hindering a market for composite ferries, but from their side of the table they are the ones being criticised if something goes wrong. If DMA in the future gave a permission to certain Danish shipyards to build CFRP passenger ferries this could act as a barrier of entry for foreign competitors willing to enter the Danish market.

In recent years there has been an increased focus on environment and sustainability issues in Denmark. In the blue growth plan from December 2012 the politicians are focused on making the maritime sector more “green” (2), where “green” means environmentally friendly and sustainable. One of the objectives was to support shipbuilding in lightweight materials and promote alternative forms of fuel.

Not only the politicians and authorities affect the industry, but stakeholders from the industry can affect the political agenda through lobby work (93). In September 2012 a delegation from the maritime sector in Northern Denmark made a visit to the Danish minister of business and growth (93). Here they were presenting the idea of a lightweight ferry build in composite material. An effect of this can be seen in the blue growth plan where composite materials are mentioned.

The political and regulatory authorities affecting the shipbuilding industry are important for the existence of market segments and for the way ferries can be built and the ability for new markets to emerge. The regulatory authorities put high priority on safety, but are open for new ideas. The industry is not a passive partner in relation to the political agenda and acts actively to change the rules of regulation.

6.2.2. Economical

In Denmark there are public and private ferry operators. Institutions like “Dansk Skibskredit A/S” or “Kommuneleasing og kredit” can be of assistance when financing a new ferry. The majority of the routes in Denmark are small public routes driven by a municipality (see Figure 42), and some of these routes are eligible for financial assistance (94) (see Appendix 19).

The competition between ferry operators in Denmark is low since many of the routes are either owned by the municipality or a monopoly can be present after political agreements (90). The 2011 annual accounts for four different ferry routes in Northern Denmark can be found on the list below (95):

Egholm ferry:	- 5,284,200 DKK
Hvalpsund-Sundsøre ferry:	- 1,644,149 DKK
Thyborøn-Agger ferry:	- 2,200,000 DKK
Mors-Thy ferry:	- 5,086,075 DKK

On all four routes major deficits can be seen and based on these numbers the market for small ferries in Denmark is not economically sustainable. If the municipalities and operators want to make it a profitable business something needs to be done, because the income from passengers and vehicles do not match the expenses related to fuel, maintenance and salary. The municipalities have an incentive to be cost focused in order to balance their yearly budgets and they could probably be interested in a lightweight ferry with lower operation cost compared to many of their existing steel ferries. This could help strengthening the economy in the municipalities especially when additional expenditures associated with ferry transport in 2012 was 123 million DKK for all municipalities in Denmark (96).

In both the LCA and LCC analysis it was shown that fuel consumption during the operation phase was by far the most dominating parameter. Based on this a short analysis of fuel prices will be made. Globally the crude oil prices have increased dramatically within the last 10 years (see Figure 41).

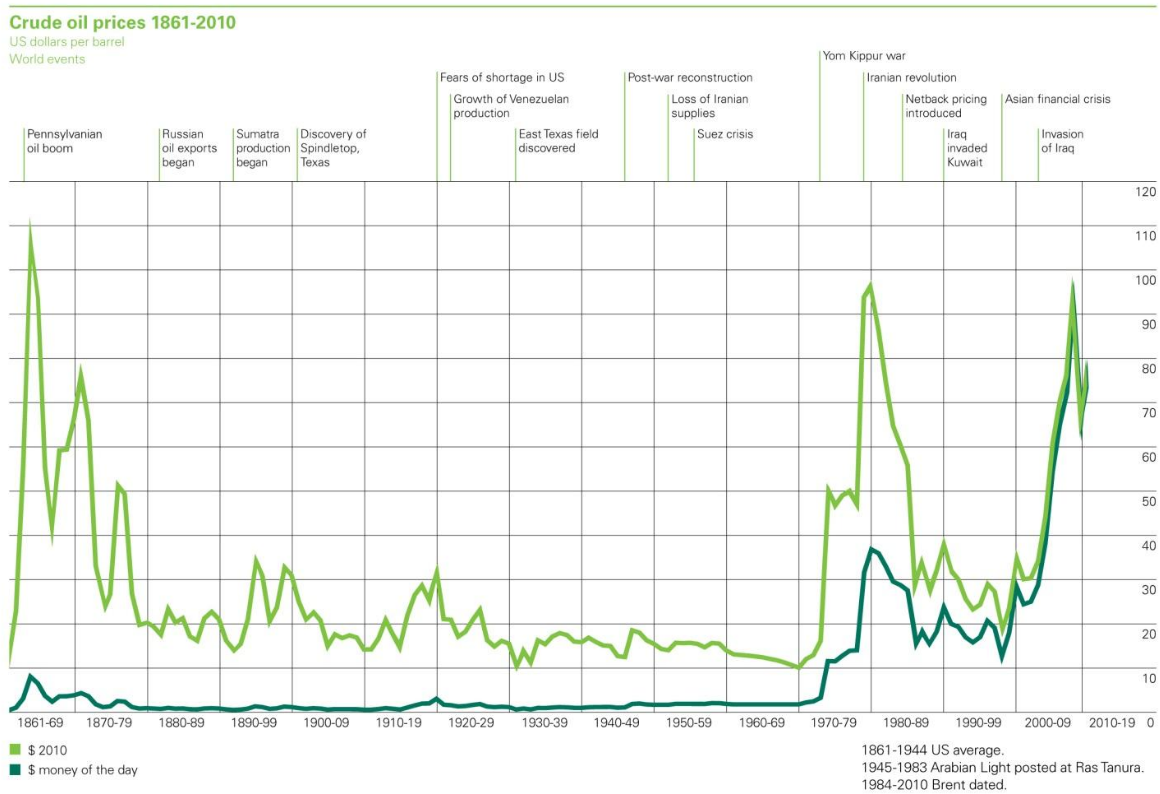


Figure 41: Crude fuel oil prices since 1860 (97)

The price for a barrel of crude oil has almost 10-doubled during the last 15 years. Even though this cannot be directly translated to the price of one liter marine diesel, because of various public taxes, this development has increased the cost of operation compared to 15 years ago. Since the fuel price is partly determined by national taxes specified by the politicians an increase in taxes could act as an incentive to reduce fuel consumption.

Within the last decade the focus of how ships are being built has changed. Ten years ago weight reductions were desirable in order to achieve higher speeds, where today it is desirable in order to reduce fuel consumption (Appendix 4). There is reason to believe that a change in focus from higher speed to fuel consumption is related to the increase in fuel price and the political agenda for the environment. In Denmark the government have introduced a carbon dioxide tax which is meant as an incentive to reduce CO_2 emissions. However, several types of companies including ferry operators do not have to pay this tax (98), and an alteration of this could be an extra incentive to reduce fuel consumption. In Norway a regulation states that all companies with an engine-power larger than 750KW must pay a fee to a fund called “NOX fond” (99). The objective of the fund is to reduce NOx emissions from businesses. Companies in Norway can apply for economic resources to reduce their emissions (100). By using the Norwegian way of controlling emission a company will have both an incentive not to emit NOx and CO_2 and for finding new ways of reducing emission. According to the CEO of Tuco it is better to reward with an order instead of using a fine. Whether it is a fine or a subsidy both instruments can be used to promote the implementation of CFRP ferries.

Other market segments than ferry operators exist, where the funds is less limited. In Northern Europe and Scandinavia there is a growing market potential in the offshore industry related to the wind, gas and oil sector (Appendix 18). The offshore industry is a high value market where quality and performance is essential because time out of operation means loss of big amount of money. Ship owners in these high value markets are more willing to pay extra for their products if they get a high quality product and this suit well with CFRP which offers good performance capabilities and availability rates compared to steel and aluminium (Appendix 6). Both Danish Yacht and Tuco are selling products to this market and Tuco has recently started a new project called TriWind directed at this market segment (101). A third market segment is the navy which has a lot of experience in using and maintaining composite ships especially glass fibre (see section 6.1.4.1). However, the composite ships in the Danish navy got phased out in 2011 after a political settlement.

So even though there might be regulation barriers and limited resources in the ferry industry the composite shipyards can find other market segments for selling their products, especially to the offshore industry which is already happening.

6.2.3. Social

The social factors will cover the geographical conditions and market segments in Denmark together with the experiences gained during a field trip to Tromsø in Norway. The section will be ended by a description of innovation and competencies in the maritime industry.

To assess the need for a new CFRP ferry in Denmark the geographical structure of the country and the population will shortly be described. There are 406 islands in Denmark of which 77 are inhabited (102). To support living on these islands and make a functioning infrastructure most of them are connected to the mainland or other islands either by a bridge or a ferry route. However, for 28 of the inhabited islands this is not the case probably since these islands per 1st of January 2012 had less than 1000 inhabitants all together (see Appendix 19). On Figure 42 and Table 26 the main domestic ferry routes in Denmark is presented including the route from Rønne to Ystad in Sweden, sine this route primarily serves Danes travelling between Bornholm and Copenhagen. Furthermore only routes with a yearly passenger transport of 10,000 passengers or more are listed (103).

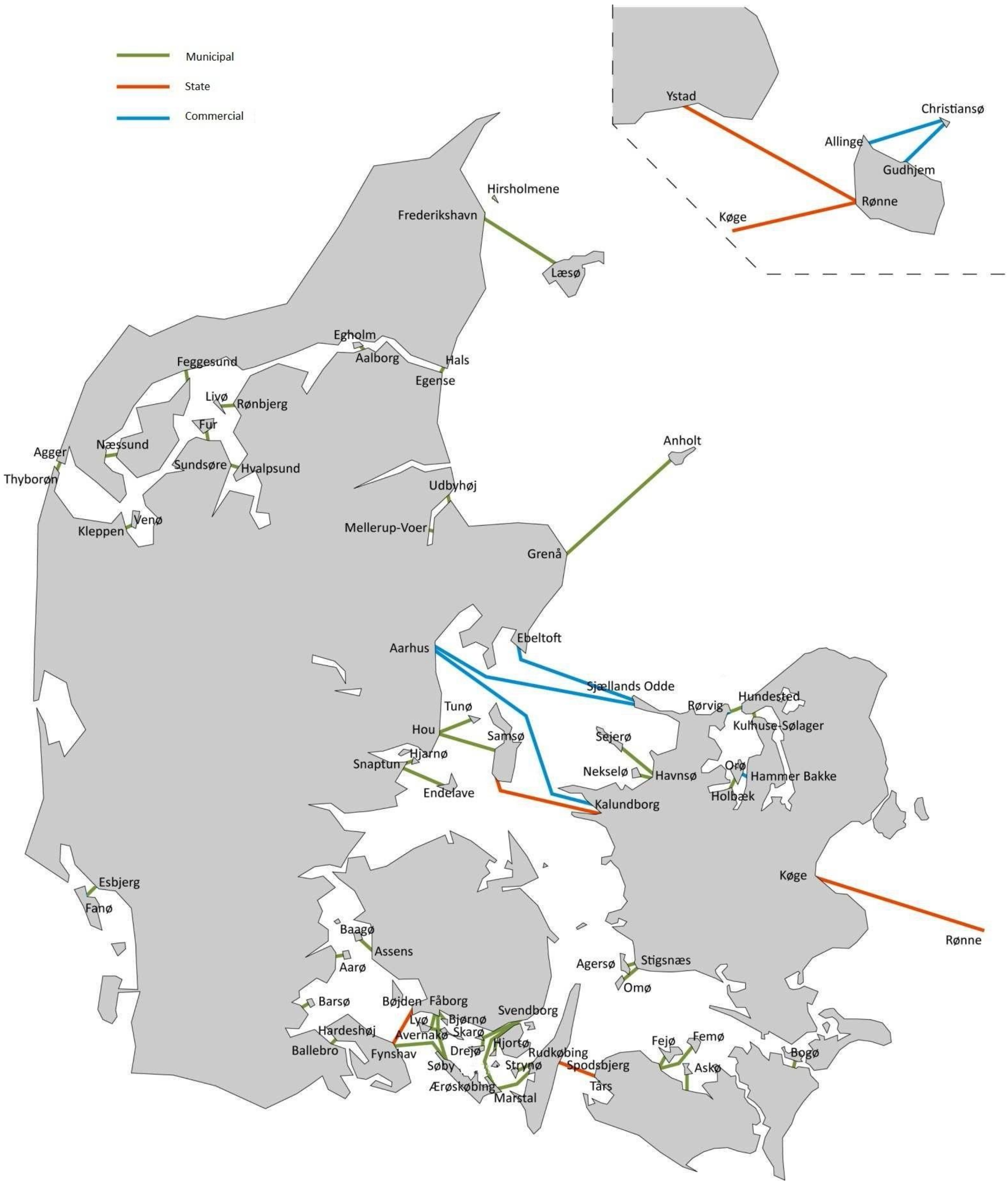


Figure 42: Domestic ferries in Denmark divided into three segments namely municipal, state and commercial routes (104). Post boat routes are not included on this map.

Table 26: Domestic ferry routes in Denmark which had at least 10,000 yearly passengers in 2011. Some of the routes are operated by more than one ferry and this is shown with a comma in the last column. Distances are found using Google Maps. The ownership is based on (104), green is municipal, red is state and blue is commercial routes. The building years are taken from (ferry-site.dk, faergen.dk, smaa-faergerne.dk) and the yearly passenger numbers for 2011 are taken from (103). The two routes to Christiansø are not included since no passenger numbers could be found for these.

From:	To:	Area/Island:	Yearly passengers:	Distance:	Ferry(s) built in:
Limfjorden			(x1000)	(km)	
Egense	Hals	Limfjorden	268	0,5	1961
Næssund Thy	Mors	Mors	83	1,0	1964
Agger	Thyborøn	Limfjorden	140	2,1	1975
Hvalpsund	Sundøre	Limfjorden	129	1,5	2006
Kleppen	Venø	Venø	237	0,3	2010
Branden	Fur	Fur	721	0,5	1996, 2011
Aarup Thy	Feggesund	Mors	138	0,7	2012
Kattegat					
Hou	Tunø	Tunø	48	13,5	1993
Endelave	Snaptun	Endelave	55	17	1998
Frederiskhavn	Læsø	Læsø	263	27,5	1995, 1997
Kalundborg	Aarhus	Sjælland	141	83	1996
Havnsø	Sejerø	Sejerø	81	19,5	1998
Kalundborg	Kolby Kås	Samsø	155	44	1998
Anholt	Grenaa	Anholt	28	50	2003
Sælvig	Hou	Samsø	385	20	2009
Ebeltoft	Odden	Sjælland	700	52	2009, 2013
Odden	Aarhus	Sjælland	1203	71	
Vadehavet					
Esbjerg	Nordby	Fanø	1690	2,6	1998, 1998
Lillebælt					
Assens	Baagø	Bågø	21	6,2	1976
Arø	Arøsund	Arø	139	1,2	1999
Ballerbro	Hadeshøj	Als	273	1,7	2001
Fynshav					
Rudkøbing	Strynø	Strynø	64	6,4	1966
Faaborg	Søby	Ærø	78	18,2	1979
Fynshav	Søby	Ærø	64	19,7	
Bøjden	Fynshav	Als	356	14,5	1982, 1984
Svendborg	Skarø/Drejø	Skarø/Drejø	41	17,8	1997
Svendborg	Ærøskøbing	Ærø	293	24,4	1999, 1999
Faaborg	Avernakø/Lyø	Avernakø/Lyø	77	10,8	2012

Smålandshavet					
Stubbekøbing	Bogø	Bogø	26	2,3	1959
Bandholm	Askø	Askø	39	5,7	1993
Kragenæs	Femø	Femø	45	13,2	1996
Kragenæs	Vesterby	Fejø	160	2,8	2002
Stignæs	Omø	Omø	50	8,0	2004
Stignæs	Agersø	Agersø	102	2,9	2012
Spodsbjerg	Tårs	Langeland	425	14	2012, 2012
Bornholm					
Rønne	Køge	Bornholm	57	170	2005, 2005
Rønne	Ystad	Bornholm	1364	67	2000, 2011
Ise- and Roskilde Fjord					
Hundested	Rørvig	Sjælland	323	5,7	1955, 1957
Holbæk	Orø	Orø	95	6,7	2003

From Table 26 it can be found that of the nearly 50 ferries listed around half of them are 15 years or older. The table is created based on literature and internet research where it was found that the above listed ferry routes in Denmark had between 10.000 and 1.400.000 passengers per year. From the webpage (105) it was found that additionally 20 routes existed in Denmark, but these had either low or unknown yearly passenger numbers.

Before making any conclusion of which routes could be suitable for a new CFRP ferry it has to be mentioned that the ability to carry vehicles either cars or trucks is needed on most of the routes in Table 26. The ferries operating a state or commercial route all have vehicle capacities and this requirement will most likely also be applicable to a new ferry on any of these routes. Furthermore most of the state and commercial routes have relative new ferries except for the route between Bøjden-Fynshav. The best market for a small lightweight CFRP ferry would be the municipal routes, since many of these ferries are 20 years or older and are going to be replaced in the near future. According to Krag and Trolle (104) the main difference between a commercial route and state or municipal routes is that the latter ones are publicly funded, since these routes are not profitable. This is also the reason that only routes which are commercial interesting are driven by private actors. The possibility to get a public grant and financial support is another argument to focus on the municipal routes.

A comparison between the municipal ferry routes in Denmark and the three catamaran ferries in Norway will be made. The distance of 150 km between Tromsø and Harstad is longer than any of the distances covered by the municipal routes. Out of the 32 municipal routes in Table 26 around 60% of the routes cover a distance shorter than 10 km and only 4 have a distance between ports of more than 20 km. A high speed ferry would therefore probably not be needed on most of the municipal routes and a traditional ferry with a lower speed would be sufficient. The results from the LCA analysis including the break-even point found in the LCC analysis would be quite different if comparing two traditional ferries, since the fuel consumption will decrease steeply with lower speeds meaning that other phases than operation would dominate.

During a two day visit to the Troms region in Norway some of the experiences gained by the operator and the local community were gathered. As already mentioned in this report the first months of operation contained a lot of criticism of the new CFRP fast ferries. A person living in Harstad having e.g. an appointment with a dentist or doctor in Tromsø could not be sure that the ferry would sail as planned and had to use other ways of transportation like bus or car to be certain to be there in time. The numerous cancellations and delays meant that passenger confidence decreased and the number of passengers was quite low for a period. The people of Tromsø even called the local newspaper with tips every time there was the least little thing wrong with the ferries and for a while there were paparazzi photographers waiting at the docks to get a picture in case something went wrong (Appendix 10 and Appendix 11). As Steinar from Boreal also pointed out the citizens loved the two old ferries and it was hard to follow two ferries with pride names like Fjordkongen (King of the fjord) and Fjorddronningen (Queen of the fjord).

Some of the lessons learned from the visit to Norway which had influence on the bad start of the CFRP ferries is related to the docks. It is important that the involved stakeholders in this case Boreal and Troms municipality remember to include everything in the planning at first. The location of the dock in Tromsø is not optimal for a light ferry due to the wind conditions. Often in Tromsø there is offshore wind causing drift of the ferry which makes it hard to berth. Additional auxiliary power on all three ferries had to be installed to counter the berth problem. To avoid damages to the hull additional stationary fenders can be placed on all docks, but due to disagreements between Boreal and the municipality this had yet to be done by May 2013. The temporary solutions were to mount mobile fenders on the existing stationary fenders (see Figure 43 left). In the meanwhile the ferries got damages when hitting the docks resulting in even more delays and cancellations.

Figure 43: The left picture shows the mobile fenders mounted on stationary fenders at the port in Tromsø. The right picture shows the new gangway in Finnsnes harbour.

The gangway (see Figure 43 right) needed adaptation, since the old gangways in both Tromsø Finnsnes, and Harstad were unsafe to use with the new CFRP ferries (Appendix 11). So communication and division of responsibilities between the municipality and the operator is important.

According to the captains on both Sollifjell and Fløyfjell it took a while for the crew to get used to the new ferries which were lighter than normally. As a result of the low weight, engine power and manoeuvre capabilities are crucial. According to the captains these CFRP catamaran ferries were different to sail than an aluminium catamaran ferry and it took a certain time of adaptation to become an expert. On the positive side both the two captains and Steinar agreed that it was some fantastic ferries with a good design, which decreased fuel consumption and made it easier to manoeuvre in bad weather. The design and low weight entailed less nose-down problems than for a comparable aluminium ferry.

A last social aspect investigated in Tromsø was passenger comfort. When the new ferries were taken into use the commuters complained about the accommodation conditions on the ferries. On the old ferries commuters had their own room with wireless internet and power sockets. The new ferries were arranged with one large passenger room and the seat arranged in rows like in a bus or an airplane. The seats were wide enough for comfort but it was observed that the backrest could not recline (see Figure 44). In addition it was not allowed for the passengers to go to the outside deck while the ferry was sailing.

Figure 44: passenger accommodation at Kistefjell

Boreal responded to the public complaints by installing additional power sockets and wireless internet (Appendix 11). In response to the missing accommodation conditions for commuters Steinar Mathisen explained, that it had not been specified in the tender documents that such accommodation were needed. The lack of specifications in the tender documents exemplify that a buyer not always know exactly what is wanted or needed. Sometimes a buyer might expect bidders to supply more than specified.

Innovation

The possibility to get new products to the market is dependent on innovation. Being innovative in the Danish maritime sector is not always beneficial which Maersk have experienced several times in the container freight industry (106). During the interviews with naval architect Henrik Dam, Kristoffer Jensen from Danish Yacht and the anonymous Danish Naval architect all mentioned the lack of appreciation for innovative and differentiated products in the Danish maritime industry. Despite this, regional initiatives have been made to create development cooperation between maritime companies in the same region. Danish Yacht is part of a North Jutland cluster called “MARCOD” founded in 2011 (107). Tuco is part of a Funen cluster called “Den Maritime Klynge på Fyn”(101) founded in 2012 with 41 members (108) and based on this cluster Tuco has become part of the TriWind project (101). Both clusters can be viewed as innovation catalysts as described by Gnyawali and Srivastava (109). So even though the maritime industry is bound by traditions, the collaboration networks in different regions generates new possibilities for companies.

Competences

A barrier identified in this study is the limited amount of people able to calculate on composites and make designs in CFRP. A design with the correct dimensions is essential for a well performing CFRP ship (Appendix 4). Furthermore one cannot just translate the thickness of an aluminium hull to a CFRP hull, because then the advantages of CFRP do not get exploited (Appendix 6). According to Kai Nielsen from

Tuco the well qualified naval architects with competencies about composite are located in England or Norway. Likewise the Danish naval architect interviewed in this study would also go abroad to look for the right competencies. So internally in Denmark there is limited expertise in CFRP ship design.

The art of making a ship design is tacit knowledge build over time and with explicit knowledge build partly on rules of thumb. A citation from the Danish naval architect underpins this.

"You have to apply common sense, you have to apply practical knowledge where you have combined theoretical approach with practice and gained good and bad experiences. This is where I see a future challenge because in Denmark we have a high level of theoretical knowledge of how we should do things, but in the future we will have less experience on the practical side. Those two areas have to be combined or otherwise you would not have a good solution."

The lack of tacit knowledge is a barrier when completely new materials have to be implemented and can make the stakeholders more reluctant to innovation (109). The right competencies might exist in Denmark, but in other industries like the leisure shipbuilding industry or the windmill sector.

6.2.4. Technological

According to Anastas and Zimmerman (23) it is difficult to envision a scenario where science and technology do not play a fundamental and essential role in moving towards sustainability. To start a consideration of technological development it is worth looking back in time. Some of the first composite ships built in Denmark during the 1990ies were the standard flex vessels used by the Danish navy (see section 6.1.4.1). They were produced using glass fibre, polyester resin and core material. Major improvements have happened since with the introduction of carbon fibre as composite laminate instead of glass fibre together with new and better resins like epoxy or vinyl ester instead of polyester. According to Danish yacht a lot of technological development has happened during the past ten years in the industry for composites and related products and this development will probably continue the next ten years. Similar upgrades have been done in relation to design and propulsion system which improve the quality and performance of a CFRP ferry.

One way of utilising technological advances and at the same time improving the green accounting could be to tailor the polymer properties. This can have positive environmental effect in cases where leaching of additives may be an issue and ease of recycling is important. In the automobile industry designers are reducing the number of plastics by developing different forms of polymers to have new material characteristics that improve ease of disassembly and recyclability (110). With the end-of-life phase in mind something similar could be used in shipbuilding when designing and choosing materials for a new ferry.

Another example showing the potential applications of carbon fibre can be found in the automotive industry. The German car manufacturer BMW have just launched their first ever carbon car called i3 which is made in modules of carbon fibre. The carbon chassis weights half as much as a steel counterpart and 30 percent less than aluminium (111). The car will cost around 40-50.000 dollar and is set to be sold from late 2013. The project has been underway for many years and the total cost for

BMW has been hundreds of millions of dollars for research and development. Such an example illustrates that other industries besides the maritime industry believe in carbon fibre as a material for the future. The more industries that are going for carbon fibre the more technological development is likely to occur and this can be beneficial for all companies selling products in carbon fibre.

One of the biggest challenges confronting shipbuilding in composites is fire safety. Technological innovations concerning fire resistant material or coatings are needed to be able to build a ferry in a composite material like CFRP. A possibility to cooperate with the windmill industry is present since a lot of know-how and testing of reinforced polymer is gathered in this industry. Research institutions and companies in both Denmark and Sweden like Danish fire technical institute, Force Technology, Technological Institute, DTU-Byg or DIAB have the facilities and resources to conduct tests and each of them use time in inventing new and better materials with regard to fire safety (Appendix 8).

The expected increase in demand for carbon fibre in the next decade will probably push the invention of new and stronger types of fibres, and decrease price and energy use as a result of increased supply. The expected increase in demand and supply of carbon fibre (see Figure 38) coming from the aerospace and wind energy industries will most likely accelerate the technological development.

Around 7-9 % of the environmental impact in the construction phase of a CFRP ferry origins from the use of PVC foam as core material (see Figure 29). PVC is not wanted in incinerations plants (112), since it can have significant environmental impacts because of released chlorine and hydrochloric acid under incineration. An alternative core material is balsa wood which has been used in different industries for quite a while. An example is the British mosquito planes during the Second World War which was made in a sandwich structure containing balsa wood. Balsa wood also has a long track record in boat building (Appendix 4). Balsa wood has better properties related to fire than PVC and furthermore it is a biodegradable material causing less impact when being disposed (113, 114). A disadvantage is that balsa wood tends to rot when being exposed to moisture.

Figure 45 : The left picture shows a fire test on a sandwich structure with three laminates and balsa wood made at SP (Appendix 4). The right picture shows the core material invented at Ecovative (115).

A completely new biodegradable core material is produced by Ecovative (see Figure 45 right). It is a foam material made from agricultural by-products mixed with mycelium that then grows into a desirable shape. The product has been used for packaging, but this technology can be adapted to sandwich composite structures. According to Ecovative (115) this material works with both natural and synthetic textiles. Materials like burlap, hemp, jute, wood veneers, fibre glass, and even carbon fibre can be adhered using mycelium instead of chemical resins. It was not possible to find literature about the fire properties of mycelium.

6.3.Strategic Results and Limitations

This chapter will answer the third sub-question in the problem formulation by discussing competitive parameters identified in the analyses and their influence on a sustainability development. An industry may support or hinder a sustainable development either directly or indirectly for example by improving social quality while polluting the environment. Competitive parameters can in the same way hinder, support or be neutral in relation to a sustainable development.

Trust between a buyer and a shipyard is crucial and bad episodes like the damages Sollifjell experienced on her maiden voyage may make a buyer choose better known materials than carbon fibre. Trust affects the social expectations which can be seen by the massive critique the three CFRP ferries experienced in the beginning. Two years later the public opinion has completely changed with most passengers coming back and very few delays or cancellations taking place. The lesson from Norway is that most changes take time and demand adaptation, which is important to remember if a CFRP ferry is put into service in Denmark one day. Trust has not directly been found in literature to describe a competitive advantage. However, Porter (20) mentions brand value as a way a company can differentiate itself from competitors. Brand value is related to trust in the sense a brand give presumption that the product possesses some unchangeable basis requirements. In that way brand value is related to trust and in the maritime industry trust is a key parameter for all actors and not just between a buyer and a shipyard. This is also one reason why references are so important, since large amounts of money are at stake when investing in a new ship or ferry and very few are able to build in carbon fibre.

In the case of CFRP shipbuilding in Denmark the high focus of the industry on trust implies that there is little willingness to take risks. The trust aspect and need for good references hinders a quick development because the buyers want to be sure of the quality and functionality of the product, and prefer to see examples before deciding to buy themselves. New technologies are always emerging which can influence possibility of more sustainable alternatives. The conservativeness of the industry might hinder sustainable development, but it also ensures that the finished ferries can fulfil their function in a safe and trustworthy way.

Lack of knowledge and experiences can be a barrier for a sustainable development. A ship owner might be more liable to invest in a well-known material like aluminium or steel, than a new composite material that is connected with unanswered questions. Some of the questions are the uncertainty or prejudices about future disposal options, fire safety regulation, durability, possibility to repair CFRP and deciding the optimal design. Experiences from the Norwegian CFRP ferries can help to answer some of these questions and identify potential strengths and weaknesses of a CFRP ferry. So lack of knowledge and the presence of prejudices can hinder develop of the CFRP ship market.

In the offshore industry there is a high focus on availability meaning the time a ship can operate depending on the weather and wave height. Here light vessels build in CFRP have proven useful as they increase the availability rate (Appendix 6). The possibility to build to the offshore industry means that the shipyards can accumulate experience and knowledge in CFRP shipbuilding which eventually can be applied in ferry projects. By obtaining experiences and knowledge the design and implementation time may be shortened and hence make it more reliable to venture into a CFRP ferry project.

Cost is one of the most important competitive parameter and the extra investment cost of a CFRP hull compared to an aluminium hull might abstain potential ship owners from buying. In relation to life cycle thinking an LCC analysis is a powerful tool to convince potential buyers, because it makes it possible to understand the economic benefits of using CFRP, if the fuel savings and maintenance costs in the operation phase offset the extra investment. LCC is relative easy to calculate since one often knows the fuel consumption, investment price and maintenance costs during the lifetime of the ferry or at least can obtain a good estimate. In this study only the investment price and fuel costs were obtained, but maintenance costs could have been obtained through a service repair site of the two reference ferries.

Comparing the two life cycle analyses LCA and LCC (see Chapter 5) show that the payback time, or break-even point to use an economic term, is less than 3 months environmentally and 4 years economically. The difference illustrate that the environment is more sensitive than the economy suggesting that if something is economical profitable, by using less resources or energy in the operation phase, it is most likely also beneficial for the environment. A focus on cost can hinder a sustainable development if the economical breakeven point is longer than the contract of operation, since the operator cannot be sure what will happen to the ferry after the contract has expired. In Norway the contract specifications often demand a new ferry when a route is put out to tender (Appendix 10).

Continuing in the economic perspective a lack of development makes the ferries sensitive to fluctuations in fuel price. As found in the life cycle analysis fuel cost accounts for a significant part of the total life cycle cost and fuel prices have been increasing the last 10 years. One way for the regulatory bodies to even the score between the environmental and economic break-even points can be to introduce fuel taxes on ferry transport like they do in Norway, which would shorten the period before reaching economic break-even.

Scandelius and Cohen (31) suggest that communication with potential buyers should focus on the added value of the more sustainable product. For a CFRP ferry the added value for a buyer lies in the operation phase through better fuel economy, improved manoeuvre capabilities and passenger comfort. Port and docks equipment will have to be adapted and if a buyer does not want to modify the current equipment it will be a barrier for investing in a new CFRP ferry.

Tuco's competitive advantage of being flexible and quick stems from their ability to change production capacity. The regular workforce only counts 10 hourly paid employees, but in case a large order is received additional workforce can be hired from abroad. In a sustainability perspective eco-efficiency (Figure 2) can be obtained through lean production by decreasing the amount of waste and reducing expenses for heating. In addition a lean production will ensure a competitive cost advantage.

A single focus on hull production ensures Tuco a high level of competences and specialized knowledge, and put them in a strong position to cooperate instead of compete with other shipyards. The highly specialized competences could be used to improve the design phase by utilising the material properties of CFRP and hence save fuel in the use-phase. Tuco's specialised knowledge can support an eco-efficient sustainable development by affecting the design phase of a ship project.

Geography can be considered a competitive parameter. The difference between islands in Denmark and fjords in Norway limits the need for high speed ferries in Denmark. Whether geography benefits or hinders a sustainable development is depending on the functionality of the ferry. For now a high speed ferry is easier to get approved and the largest fuel saving is achieved for higher speeds. Tuco's current location on Fyn means that they can easily collaborate with other maritime companies or institutions like the newly started project TriWind. However, benefits of a specific location are dependent on the competencies in the local area. Collaboration and social interaction will increase awareness and possibility for innovation networks (109).

This insight of how competitive parameters influence a sustainable development can be used if changes in the sustainability of an industry are wanted. For a company such a Tuco the insight can contribute to a strategically consideration on how to promote and market their own products best possible. Trust is a competitive parameter and the established composite shipyards will have a competitive advantage since they have proven that they can do the job. Tuco is one of the established composite shipyards and a LCA analysis can provide them with documentation of the things they are doing, assess their environmental performance and act as a barrier for new entrants. Such documentation can be used to outline areas for optimisation. The gain of the environmental performance assessment will depend on whether a cost focused buyer actually requests more environmental friendly ships.

Rules and regulations are a main barrier affecting all the other competitive parameters, because they define if it is legally possible to build CFRP ferries. The rules are made to ensure safety on ferries, and hence link to the social pillar of sustainability. In order to influence rules and regulations lobby work can be an effective tool to communicate the material properties and limits of CFRP.

Whether a project regarding a new CFRP ferry supports a sustainable development of the economic and social pillars related to jobs in Denmark is unknown. There still exist a number of shipyards in Denmark like “Karstensens Skibsværft” or “Faaborg værft” which build ships in aluminium and steel. If a new small island ferry was built in CFRP in Denmark it could take away a potential order from these shipyards. So whether more workplaces will be created is unknown, but if a foreign order for a new CFRP ferry or ship is obtained which would normally go to a foreign shipyard then it contributes to a growth of the Danish shipbuilding industry.

A main limitation of the identified competitive parameter is based on how the strategically analysis have been performed. Through interviews with different stakeholders from the industry the competitive parameters of trust, cost and time have been identified. Additional interviews with e.g. an aluminium shipyard or a ship owner operating mainly aluminium ferries could identify other competitive parameters relevant to incorporate when having this discussion. An attempt was made to get in contact with a larger Danish ferry owner operating aluminium catamaran ferries, but without any luck. An interview with a supplier could have increased the validity of the analyses as well by getting their view on supplier power and threat of substitutes. The study is limited to the Danish maritime sector and cannot directly be applied to industries where other competitive parameters are important or where the operation phase has less impact, since this would change the results in both the LCA analysis and the strategic analyse.

Chapter 7 Perspectives

Sub-question 4 will be answered in this chapter by looking at the possibilities for composite ships in the Danish maritime market. Perspectives for the high speed ferry market, the offshore market and the possibilities for retrofit will be evaluated. The risk of foreign shipyards entering the composite market will shortly be mentioned. A section about fire safety and a section about scenarios for a high speed ferry in Denmark will end this chapter.

When considering future perspectives of a CFRP ferries in Denmark an issue arises. Ferry transport does not require the same functions in Denmark as in Norway. In Norway the three CFRP ferries delivers an alternative to drive a car. The geography of Norway is made up by many fjords, and people can either get from one side of a fjord by driving in car around the fjord or take a passenger ferry. The geography of Denmark is quite different consisting of more than 400 islands, where 77 of these are inhabited. A person can get to and from an island by either taking a ferry or a bridge, if such exist. A bridge is a permanent construction enabling the citizens a high level of mobility, but a bridge can be pretty expensive to build. If there is no bridge, the only alternative to get to and from an island is by ferry or private boat. If a ferry is the only way of transporting people from islands the users often requires additional services like the ability to transport cargo and vehicles. In this case study no demand for vehicle capacity was present, since cars or trucks can get from Harstad to Tromsø by road. However, for many islands in Denmark the need to get your car or truck with the ferry is present.

An identical design of the Norwegian CFRP ferries cannot be applied directly to Danish conditions. In the LCA analysis it was found that fuel consumption was the most environmental damaging process for a high speed ferry. The same conclusion was made in the Eco-island ferry project (5) for a traditional ferry with lower speed and lower fuel consumption. If the design of a CFRP high speed passenger ferry should be applied to Danish conditions and be used to transport people to and from islands a solution could be a two ferry concept. One ferry should transport people only and another ferry should then transport cargo and vehicles. However, most of the distances between islands in Denmark are shorter than 10 km (see Table 26) and the accelerating and decelerating of a high speed ferry would be unnecessary fuel consuming. For most municipal routes in Denmark a ferry with lower speed would therefore be optimal. Even though the routes are different in Denmark compared to Norway three suggestions for high speed routes can be found in section 7.2.

When looking at other market segments than ferries an industry which is already using composite is the offshore industry (Appendix 6). The geographical location of Denmark is ideal for shipbuilding to the offshore market since extraction of oil and gas takes place in the North Sea and offshore wind turbines is installed many places in the Danish waters. Light composite service vessels are a good solution when technicians need to be transported to and from an oilrig or wind turbine, and good properties related to stability, comfort, and speed have made these vessels popular (Appendix 6). A possibility to get experience and gain knowledge is present in the offshore industry. However, it should be noted that less strict regulation is valid for these service vessels than for passenger ferries. Mainly because the number of passengers on a service vessel is often below twelve and they are expected to be professionals used to sail and therefore know what to do in case of an emergency (Appendix 7).

During the interviews a number of concerns were found related to the building of ships in composite materials. Some were curious about the amount of maintenance work and the durability of the composite materials which they saw as fragile. Others were interested in knowing the lifetime of a composite ship, what would happen in the end-of-life phase, and whether recycling was a possibility. Additional concerns like composites being inflammable and too expensive were also mentioned. Some of these concerns are more prejudices and could be a result of lack of experiences with composite materials. It show that a number of hurdles needs to be managed before all the stakeholders in the industry are prepared to order, design and build ships in composites.

Composite ships are a niche market representing a small fraction of the total maritime market. Whether composite ships one day will compete for the big orders on container ships or bulk carrier only time can show, but optimism prospers in the industry. This can be seen by a citation from Danish Yacht.

"I believe there is huge potential in composite and it will take over more and more of the steel constructions, since fuel economy will become increasingly important. I don't think there is any doubt that one day we will see a container ship built in composite, because that is the way we are going with composites. It is only a question about when the Chinese and Koreans in earnest set about this kind of production, because they are the ones with the capacity to do it. It is unrealistic to believe we can continue to be the only actors."

This possesses a dilemma for the Danish shipyards, because if composite materials one day become the standard material to use for shipbuilding the big shipyards in Asia could obtain the competencies and techniques and outmatch Danish shipyards at least for orders on big ships. A market consisting of smaller ships like island ferries and service vessels for the offshore industry would probably be less attractive for a big shipyard in Asia.

Lastly retrofit of existing vessels could be a potential market. This would maybe decrease the demand for complete new composite ships, but on the other hand a retrofit project could also include making certain parts in composite materials, so it is a complex situation. Another possibility which could open up a whole new market is to make a cruise-, tank- or container ship lighter and less fuel consuming by making the superstructure in composite and then assemble it with a hull made in steel. A Swedish project called "LASS" looking at this idea has already been done (53).

The perspective of the strategic analyses has been focused on Tuco and then the market for lightweight ships. In the analysis of threat of entry it was found to increase competition if other shipyards began to corporate in order to get into the commercial market for CFRP ships. Seen from a societal perspective this could be a positive development, because it will imply that more companies deliver an environmental friendly product and thereby limit the overall use of harmful materials. If more shipyards began to manufacture hulls in CFRP it could increase the employment rate in Denmark, if followed by a simultaneous growth in the market for composite ships. This is though on prerequisite that a growing market for composite ships does not lead to closures of Danish shipyards making aluminium or steel ships. During one of the last interviews with Tuco in June 2013 it was revealed that the workforce had been increased with two extra full time employees, which indicates a certain growth in the market.

7.1.Fire Safety

Even though it was not one of the initial subjects in the problem statement fire safety was in several of the interviews identified as the major barrier for building ferries in composite materials. Therefore it was decided to add a separate chapter concerning this subject to look at the perspectives related to fire safety.

Fire safety is at present the major barrier to be able to build ferries in composite. A fire on a passenger ferry can potentially injure and kill a lot of people and hence create headlines that will harm the social and economic parts of a sustainable development. During the fire approval process of ferries the risks of losing human lives should of course be prevented by any means. For ferries built in steel and aluminium the materials have been in use for decades and a great deal of knowledge has been obtained about the fire properties of these materials. The knowledge has led to the description of generic fire safety procedures for ferries built in steel or equivalent materials like the SOLAS convention. For new composite materials such as CFRP there is limited experience and similar generic fire safety procedures can be hard to describe before more knowledge have been generated through for example pioneering or demonstration projects. Until then the maritime stakeholders and authorities must accept a longer process and project time, if they want CFRP ferries in Denmark.

A discussion about the risk of losing a life as a result of fire versus the unit for the damage endpoint human health will be made. The human health indicator is measured in DALY which is a measurement of years lost and years lived with disability (see section 5.4). It could be interesting in a further study to investigate which ferry solution would result in most years of lives lost based on a comparison between fire risks and human health impact category. A citation from Grunde Jomaas from DTU relates to this:

"The problem with fire is that no one wants to put a price on it, on a life. Insurance companies do it, because for them it is pounds and pennies. If you did it, one could compare some straight up analysis on value hedges and human security, and yes what a human life is worth there."

In the LCA analysis it was found that for an operation time of 30 years the difference in human health between the aluminium model and the CFRP model was 4100 DALY (Appendix 31). This is a very sensitive subject and DMA would probably never use that kind of arguments or analyses, but in a life cycle perspective the discussion is quite relevant. If composite materials are not approved by the authorities for ferry production the environmental impact caused by the extra fuel consumed by another ferry will have an effect on human health. The question is whether this impact is higher or lower than the possibility for fire and related loss of human life. The procedure for fire safety is another area for discussion. As Grunde Jomaas points out, that without a procedure for how to do things one will fall back on a simple comparative fire analysis between composite and steel, and here steel will always win.

Different ways of thinking and doing fire safety analysis is probably needed, because composite materials will have a hard time to pass exactly the same fire tests as steel or aluminium. One solution could be to make a more function based approach that relates to the performance demands of the specific product. According to Grunde Jomaas some test does not have relevance on human safety. An example could be if a certain regulation specified that a material was not allowed to lose structural integrity during the first 60 minutes of fire. If a ferry could be evacuated in 15 minutes, then such a test would be less relevant. So the function of the ferry and the surrounding conditions must be considered when making a fire safety analysis. This is also one of the reasons why a ferry built for the HSC code is easier to get approved, since all passengers must be on one deck which decreases the evacuation time.

During an interview with DMA it seemed like they wanted to make it possible to build ships and ferries in composite materials (Appendix 3). They were open for other approaches than they were used to in order to develop a new code of practice. This is underpinned by the following citation from Torsten Arnt Olsen.

"It should not be that we have some bureaucratic rules which hinder development here."

The approval of a CFRP ferry will demands a formal safety analysis or risk analysis which is a new and complicated task also for the authorities which needs to determine whether such an analysis is good or bad. Before making any conclusions it is important to look at it from both sides of the table and understand that it might take time to develop a new set of rules and it will demand a lot of cooperation between the authorities and the industry. A reason for optimism is that both parties have an interest in finding a solution because they see it as beneficial for the Danish society and want to support this potential progress. Furthermore adaptive fire regulation procedures might be able to reduce the amount of toxic materials used in the production of a ferry and hence decrease the environmental impacts.

Lastly a link can be drawn to the article about twelve principles of green engineering (23). Principle 8 states that design for unnecessary capacity or capability should be considered a design flaw including "one size fits all" solutions. An example of a design flaw could be if a generic set of fire safety rules valid for all areas and countries were made. This could imply that too much insulation was applied and the thickness of the sandwich structure was oversized in some cases. These examples could be regarded as design flaws since a waste of materials would take place and at the same time the ferry would be unnecessary heavy resulting in higher fuel consumption. So from a sustainability point of view a set of generic rules is maybe not always the best solution. However, in Anastas and Zimmerman (23) it is mentioned that when safety is an issue then design flaw can at least be rationalized.

7.2. Market Scenarios in Denmark

To transfer the idea of a high speed CFRP ferry from Norway to Denmark three scenarios of high speed ferry routes in Denmark were created. For all three scenarios the CFRP ferry is assumed to have passenger capacity only to be most comparable to the Norwegian catamaran ferries.

- **Scenario 1 - Bornholm**

  The first scenario is a ferry transporting people from Rønne on Bornholm to a harbour south of Copenhagen. This should be supplemented with another ferry transporting vehicles and cargo from Rønne to either Køge in Denmark or Ystad in Sweden. The sailing distance from Rønne to Copenhagen is roughly 170 km (91.8 NM) and with a speed of 33 knots it would give a travel time of a little less than 3 hours. The harbour in Copenhagen should be close to public transport to ensure easy transportation into the Copenhagen region.

  Presently two high speed catamaran ferries capable of transporting cargo, vehicles and people are in operation on the route from Rønne to Ystad in Sweden (see Figure 42). From Ystad passengers have to take train or bus to get to the centre of Copenhagen. The overall travel time using the ferry and train from Rønne to Copenhagen is 3 hours. The two ferries are both relative new (see Table 26), so new ferries are probably not needed in the near future. However, the distance from Copenhagen to Bornholm is relative long which could justify a high speed ferry.

- **Scenario 2 - Fynshav**

  In the waters south of Fyn, called Fynshav, several small and medium sized islands are located. Today most of the islands are serviced by an individual ferry taking the inhabitants to larger towns like Faaborg or Svendborg.

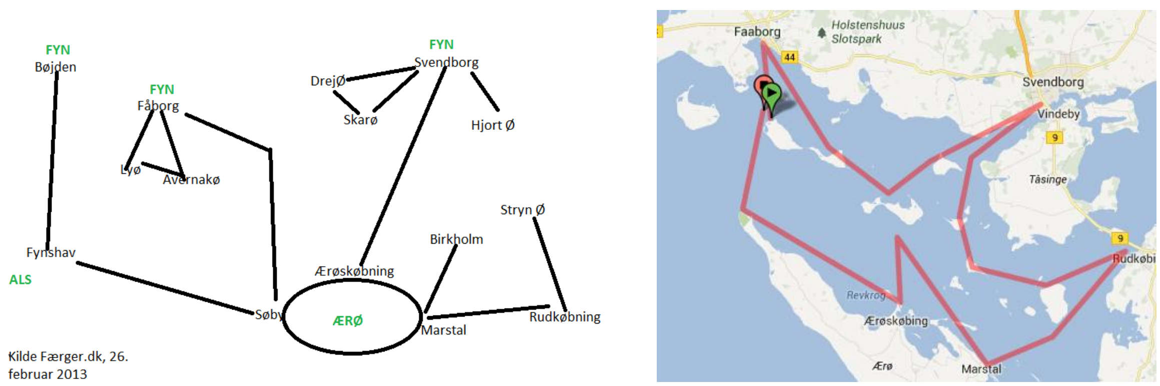


Figure 46: Left picture showing a schematic representation of ferries in Fynshav. The right picture shows the suggested route for a shuttle ferry in Fynshav made using Google Maps.

Two CFRP-ferries could act as a shuttle ferry between the islands, transporting inhabitants from island to island and making it possible to reach an appointment in one of the larger towns. The right picture on Figure 46 illustrates a suggestion for a route in Fynshav with approximately 13 stops along the route. This route would only cover the municipal routes and therefore the routes to Bøjden and Fynshav is not included. One ferry would go clockwise along the route and the other ferry would go counter clockwise.

The route is approximately 130 km long, and with a speed of 30 knots the whole trip would take around 140 minutes. This is significant faster than the existing ferry routes, for example an 18 km trip from Søby to Faaborg takes 1 hour and the 24 km trip from Ærøskøbing to Svendborg takes 75 minutes. The average speed of the high speed ferry would probably be lower than 30 knots, because of the many stops and short distances between some of the islands in Fynshav. Furthermore the shuttle ferry service could be supplemented with shared car arrangements or busses, once the passengers arrive at the ports.

- **Scenario 3 - Aalborg**

One of the longest distances in Denmark by sea is between Copenhagen and Aalborg, which by car or public transport takes around 4 hours. The present alternative is airplane which takes 45 minutes and public transportation from airport to city centre of approximately 30 min giving a total transport time of 75 min. In May 2013 there were a little over 82,000 domestic travellers in Aalborg Airport (116), with most of them going to Copenhagen. This means that on a daily basis around 2500 passengers are properly interested in fast transportation between Copenhagen and Aalborg.

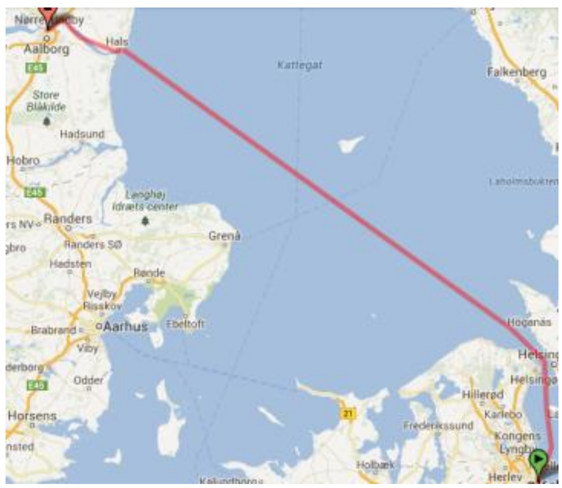


Figure 47: Idea for a ferry route between Aalborg and Copenhagen (from Google Maps).

In Figure 47 the route for a waterway between Copenhagen and Aalborg is suggested. The route is approximately 250 km long and with a speed of 33 knots the travel time would be 4 hours. A high speed ferry would not be able to compete on travel time with an airplane. The travel time is identical to taking a train, but train is a more environmental friendly way of travelling than ferry (117).

Out of the three scenarios presented the second concerning Fynshav seems to be the best. The benefits for a route in Fynshav are that it could provide a more environmentally friendly way of transportation and eventually improve the infrastructure depending on the specific route pattern of the two ferries.

Chapter 8 Discussion

The first sub question in the problem statement will be discussed in this chapter. It will be discussed what it has meant for the depth and width of the analysis that an interdisciplinary approach combining theories and concepts from strategy and life cycle thinking has been used. Whether it was useful or not to combine the academic approaches will be discussed in the following.

The interdisciplinary approach used in this study has made it possible to combine strategic analyses with life cycle thinking such as LCA. On Figure 10 the combination of the different phases in the LCA analysis and Porter's five forces can be found. On the figure it can be seen that a link was found between the three competitive forces supplier power, buyer power and industry rivalry with the steps material processing, manufacture, and use. Another link was found between threat of substitutes and reference flow in which the former was used to specify aluminium as the optimal reference flow instead of steel when looking at lightweight ferries. A direct link between threat of entry and the LCA model could not be found, but the LCA in itself can act as a differentiation force by being a reference, because a barrier to entry for new shipyards looking to build ships in composite materials is the lack of references. A LCA analysis used to assess and optimize the environmental performance of a company can be used as a competitive advantage. Examples in this study is the identification of a higher waste percentage than expected and the need to have better insulation of the production hall to decrease heating costs.

The LCA supplemented the strategic analysis in the way that it illuminated the consequences of the buyer, since it is the buyer who performs the majority of the environmental impact in the operation stage. The LCA for the supply side of the product chain illustrated minimal changes in environmental impact by switching from one resin supplier to another e.g. from epoxy to polyester. The environmental impacts found in the LCA analysis can therefore be used to locate hotspots in the product chain and specify which actors are responsible for or related to a given hotspot. It can also assess whether alternative materials or suppliers will actually mean a decrease in environmental impact. If a company wants to pursue a sustainable strategy a LCA can be used as documentation for specifying which processes in the product chain need to be changed.

The two phases, extraction and end-of-life in the LCA, belonging to the ecosphere are not mentioned explicit in Porter's model. When trying to combine the two academic approaches a suggestion was therefore made which can incorporate the wider life cycle perspective in Porter's model. A possible link between the extraction stage and supplier power was found. It is often the supplier which buys the raw materials and there exist a power relation between the supplier and a raw material extraction company. Tuco can decide to improve their environmental performance by putting stricter requirements on the products or materials they receive from a supplier. This can affect the requirements this supplier put on an extraction company or force the supplier to switch to another company. Looking at the other end of the life cycle namely the end-of-life phase not much is mentioned in Porter's model either, but again a possible link can be argued. If a technology for recycling carbon fibre did exist a potential profitable market for reused carbon fibre could develop. A company entering this market could be seen as a second buyer and could have a power relation to not only the shipyards, but also to the suppliers of the carbon fibre, since the company must be certain of the quality and content of the recycled fibres. If the recycled fibres had a high enough quality the shipyard itself could be a second buyer and reuse the material in a new hull. This is already the case with glass fibre production waste which is chopped, rolled up and used by Tuco when manufacturing a composite hull. If something similar was possible for carbon fibre there could be a potential market, because as found in the LCA analysis, around 25% of the carbon fibre material used ends up as production waste. As shown in the sensitivity analysis (see Figure 31) the environmental gain of recycling just 50% of the carbon fibre instead of sending it to landfill or incineration is significant. Furthermore carbon fibres have high energy content (113) (Appendix 8) so if dismantled and handled correctly the energy recovered from e.g. incineration could be sold and used for other purposes. So when looking at the life cycle perspective and especially the end-of-life treatment a focus can be put on easier dismantling of the ferry, less toxic materials and easier way to recycle the different raw materials. It can be discussed with current suppliers and affect supplier power. It can also mean that for the ship owner the disposal of a CFRP ferry becomes a source of income instead of a cost. Before it is possible a lot of effort has to be made on developing new technologies or methods for separating the fibres, resin, and core material and for recycling the fibres. Project Genvind (84) has this as one of its main objectives.

On Figure 10 a green circle illustrates the technosphere and the industry environment while a blue circle illustrates the ecosphere and the macro environment. The macro environment was analysed using a PEST outlining the political, economic, social and technological factors influencing the industry. The direct link between PEST and life cycle thinking is firstly the LCC analysis which relates to economic factors and secondly a social LCA which relates to social factors. However, this does not mean that the political or technological factors have no relevance for life cycle analysis. As Porter suggest factors from the macro environment like political institutions as governments or authorities and technology innovation can influence any of the five competitive forces and it can be argued that they can influence the different stages of a LCA analysis as well. A government policy prohibiting the use of certain chemicals or the emission of toxic substances might influence raw material extraction, material processing and manufacturing. This would affect the processes in the product chain and change the results in the LCA analysis. On the other hand LCA can be used as a political tool to determine which industry or technology is most environmental friendly and aid in the decision process when making new laws, tax regulation or granting subsidies. Likewise technological invention can influence for example end-of-life treatment by making it possible to extract and recycle the fibres from the sandwich structure, which would also affect the results found in a LCA analysis. So even though an attributional LCA analysis assess present environmental impacts related to a product or service a change in any of the PEST factors can change the product chain and thereby the LCA analysis as well. An LCA can highlight and quantify patterns of sustainability but it cannot supplement the strategic analyses in finding new market segments or telling which market to target. In the search for new markets the social part of the PEST analysis is useful in viewing under which conditions a CFRP ferry can be sold.

If a company decides to use the LCA as a tool to support its sustainable strategy development a number of uncertainties need to be considered. As mentioned earlier any changes arising from the macro environment can affect both the competitive forces and the outcome of a LCA analysis. Since macro environmental factors like government policies or market economy is often out of range for a company it has to adapt to these changes. If for example the current way of handling carbon fibre scrap or waste namely landfill was found to be very polluting for the ecosystems this would change the environmental impacts found in the LCA analysis. A government could then raise the taxes associated with landfill and make it less profitable to buy a CFRP ferry. Changes in the macro environment can also be a good thing for the carbon fibre shipbuilding industry. If the oil prices suddenly increased steeply this would favour the CFRP ferry in the LCC calculations and make it more profitable to invest in a lighter and less fuel consuming ferry.

A difference found between a LCA analysis and strategic analysis like Porter's five forces or PEST is the scope. Where a LCA focus on one single product or product chain the strategic analysis often focus on an entire industry or a company in a given industry. Porter's five forces have been used to show possibilities and limitations in interaction and competition between companies, while the LCA have been used to track the material entities and show the consequences of a product by means of environmental damage endpoints. Each damage endpoint in a LCA can be seen as a way to compromise the consequences for many actors into numbers. The actors are both humans getting sick and animal species getting exterminated due to the production of a product. In this study it was found to be a strength that the two approaches had different scopes, since factors not directly included in the strategic analysis like end-of-life treatment or raw material extraction supplier power could be discussed. Whether a company can use it for strategy formulation or not depends if the company itself or its customers wants to go for a more sustainable product chain or improve the sustainability profile of the company.

In Porter's five forces not much is mentioned about cooperation and knowledge sharing between companies and stakeholders even though cooperation and knowledge sharing is often mentioned as means to achieve a sustainable development. This can be seen as a weakness in Porter's five forces because he mostly considers the competition aspect of an industry. It can though be argued that cooperation between actors in an industry can be viewed as a possible competition strategy. As a mean to decrease industry rivalry two competing companies could cooperate and in this way obtain a competitive advantage. An example of this is the competition between Tuco and Danish Yacht for offshore ship orders on one side, and the cooperation on the other side exemplified by Tuco supplying the hulls for a ship later to be assembled at Danish Yacht.

During the data collection phase of the LCA analysis it was found that a great deal of knowledge sharing between the shipyard and suppliers is needed to obtain data for all the different materials used in the product system. A problem with the comparative LCA approach was that similar data was needed from a competing shipyard delivering the reference product, and this could be difficult to get. It also demands a certain degree of trust before a shipyard and its suppliers would inform all details about the amount of inputs materials and production methods used. In this study the strategic analysis was easier to obtain information to. During interviews with various stakeholders in the industry a lot of information was obtained related to industry rivalry, competitive parameters, barriers to entry, and buyer power. Based on this study it seems like an environmental analysis like LCA will demand more cooperation and knowledge sharing than a strategic analysis. Of course it depends on how comprehensive the strategic analysis needs to be and what one is focusing on in the given case.

A comment will be made to LCA which has been criticised for being time consuming and costly (118). In this study the data collection has been quite time consuming due to many small details should be obtained through different channels than Tuco. Some information was not possible to obtain even though several attempts was made. If more companies should use methods like LCA to assess their environmental performance ease of data collection and information could be a way. For a company to choose more environmental products from a supplier the need for better product description is present.

The interdisciplinary approach has made it possible to see aspect otherwise concealed. A pure strategic analysis would have revealed the main competitive factors as being trust and cost. It would probably not have ended up suggesting Tuco to contribute to the design process by downstream integration. This was found from the LCA results and the amount of production waste which suggested that a possibility to optimize the design process was present. A pure LCA analysis might find it beneficial for Tuco to insulate their production halls, but it would not have mentioned the risk of Tuco becoming less mobile. If Tuco wanted to switch locations the investment made in improving the insulation of the production hall would be less prudent.

The interdisciplinary approach can target eco-efficiency (see Figure 2 left) by focusing on less use of environmental damaging materials while at the same time being economic profitable. The approach can discuss the liveability by combing social aspect and environmental aspect, and this can be seen in the human health category of the LCA and in the discussion of depopulation of Danish islands. To a limited extend the approach has been used to discuss the equity combination of the economic and social pillar in the evaluation of job creation in Denmark related to a potential market growth of composite ships. However, social aspect such as workers right and minimum wages has been outside the scope of this report. To further discuss the social aspect of sustainability a SLCA analysis could be made.

Whether it is recommendable to use this interdisciplinary approach in a future study will be discussed. If a company wants to implement a more sustainable business strategy then this approach can be useful. The LCA can be used as documentation to outline different areas where changes need to be made in order to become more sustainable. The LCA does not say whether these areas are possible or economic reasonable to change and that is where the strategic analysis can supplement. For example it might be found in the LCA analysis that the use a certain supplier product result in high environmental impact. The strategic analysis might however show that this specific supplier product is both cheap and of high quality compared to other products and that from a strategic point of view it would be a bad idea to switch. Another example is the possibility to decrease natural gas consumption related to heating by investing in better insulation of the production hall, but as shown in the strategic analyses this might decrease the mobility of Tuco’s location. A model like Porter’s five forces can help to specify the possibilities and consequences of changing e.g. suppliers or whether a change will actually improve the competitiveness of the company. The LCA can be used by a company to prioritize which improvements will give the highest return environmentally and the strategic analysis can then say if it is practically possible and will increase competitive advantage. Concurrent to a LCA analysis one can calculate the life cycle cost of a product by doing a LCC analysis. This can be used by a company as a selling point to show a potential buyer the cost of a product through its entire lifetime. In this case study the break-even point occurred after 4 years of operation and that it a good selling point to a ferry operator having a 10 year contract with a municipality. An LCC analysis can affect industry rivalry and threat of substitutes by being able to document potential cost saving.

As mentioned in the section about design for sustainability (see section 2.9) a parallel can be drawn between the interdisciplinary approach used in this study and Eppinger's model of biological and industrial life cycles (see Figure 11). According to Eppinger the sustainability of a product is often decided in the product design process. Tuco is already having a production strategy in compliance with LeChatlier's principle, which states that system components should be output pulled rather than input pushed through the use of energy and materials. Since Tuco is not ordering new input materials before an order is received this does not only decrease warehousing costs and make them less vulnerable to changed customer demands, but it also supports a sustainable development by eliminating the risks of materials becoming obsolete. Tuco's wish to be able to consult with the naval architects in the design process might decrease the chance of over-sizing and make it possible to utilise the material properties of composites to a higher degree. This is an example of a strategy that can support a sustainable development by decreasing the amount of materials and energy used for production resulting in a lighter hull which means lower fuel consumption in the operation phase. Increased collaboration between Tuco and a naval architect could also decrease the high waste percentage found in the LCA analysis. Another proposal made in this study is related to principle 11 and product upgrading through component substitution. If Tuco and the naval architect made a design which allowed for component substitution in the future like a more efficient engine or screw, this would increase the lifetime of the ship and support a sustainable development.

The results found in this study underpin the change of focus taking place in LCM. According to Grimes-Casey (25) research in LCM is shifting the focus of attention from the impacts of production to the impacts of consumption. In the LCA analysis the largest impacts was found to occur in the operation phase caused by the fuel consumption. An analysis of the industrial lifecycle must include the rules and values of an industry together with existing relations between producers, buyers and suppliers. In this report the industrial lifecycle has been analysed through Porter's five forces and PEST coupled with the results from the LCA analysis. This has made it possible to include lifecycle thinking in a strategic context and investigate the interrelation between the biological lifecycle and the industrial lifecycle. A focus on the biological lifecycle alone cannot guarantee a sustainable development, since especially the economic and social pillar is strongly connected to the industrial lifecycle.

To conclude the two interdisciplinary approaches have supplemented each other meaning that the analyses become more comprehensive and it highlighted connections that would not have been found if the approaches had been done separately. The authors of this study think that combining life cycle thinking with strategic analyses can be useful as the two approaches supplement each other with new aspects and extensions to achieve sustainability.

Chapter 9 Recommendations

During the analysis and discussions strategic and environmental aspects of high speed CFRP ferries have been evaluated in respect to sustainability. Based on the evaluation recommendations for both Tuco and other stakeholders will be made.

To increase eco-effectiveness, just-in-time and lean principles can be used in the production phase and twelve principles (23) can be used in the design phase. Reducing the amount of waste and over production can reduce the environmental impact that Tuco's own production have on the environment. A reduction of waste from 25% to 10% can reduce the impact from the construction phase with more than 9%. If overproduction, exemplified by excess use of natural gas, can be reduced with 65% the damage from the construction phase done to human health will be reduced with 9%. A reduction of overproduction and waste will also decrease the cost of construction and could make Tuco more competitive.

Design is the key for Tuco to a continue making environmental friendly products. The main environmental impacts occur during the operation phase by burning of fossil fuels. Having an optimal design and ensuring that any ferry or ship has a minimum of fuel consumption will reduce environmental impact. When Tuco only is manufacturing the hull they limit their possibility to significant impact the environmental effect, because 80% of it is decided in the concept phase of a design project (34).

Cooperation or partnership with other companies such as naval architect and assembly shipyards can contribute to strengthen Tuco's position as CFRP specialist and make the product more recognizable for buyers by downstream integration. Cooperation or partnership with a naval architect can help Tuco get into the design phase of ship projects.

Trust has been identified as an important competitive parameter. To maintain trust Tuco should built their brand on always delivering good products, on time and to agreed price. A good working atmosphere between buyer, naval architect, Classification Company and Tuco should always be a top priority. By delivering good product and by having a good working atmosphere Tuco can obtain references and built brand value.

After sales service could be a selling point for Tuco. In the research it was shown that the knowledge of how to maintain a CFRP ferry was limited and the lack of knowledge could make potential buyers more cautious. With introduction of after sale service the fear of hull damages could be handled. After sales service could also be expanded to composite ships which Tuco have not built, and thereby get in contact with new potential buyers and expand their good reputation.

To support a sustainable development Tuco could buy as environmental benign products as possible. Few environmental benign alternatives exist for the material categories Tuco uses, but by being aware of new materials and being willing to test them, Tuco can reduce the environmental impact from suppliers. Alternative materials could be biodegradable materials for the core material in the sandwich structure, other fibre structures, alternative resins and plastic helpers. However, the maritime industry does not appreciate innovation and new product would not necessarily give Tuco a competitive advantage.

In the project description of a new ferry it is important for potential buyers to remember all the supplementary elements like the gangway, wind and sea conditions, port equipment and seating arrangement. The gangway have to fit to the new ferry, the ferry must have enough engine power to manoeuvre in even strong wind and sea conditions, and the port equipment must not damage the ferry. If the duration of a journey is long it should be possible for commuters to work on board.

Patience is a virtue also for potential buyer. The lesson learned in Norway is that it can take time to implement a new product with different characteristic than an old product. In the project phase a new product might require more time, to eliminate all the hiccups. To counter the prolonged project phase the public political factors could decide to venture into prototype project. In such a project new competences could be built and future projects could become more effective. An example is the CRFP ferry which will sail between Thy and Mors in northern Jutland (119).

Design competences of how to use composite materials in shipbuilding are in short supply in Denmark. If the full potential of the CFRP technology should be reached then naval architect should be educated in composite ship design or designers from e.g. the windmill industry should be educated in ship design. Education of naval architects should include mandatory courses focusing on composite calculations and designs.

Disposal options of CFRP are presently limited to landfill and incineration, where landfills are currently the most environmental benign disposal option. It would be environmental beneficial if CFRP could be recycled and become a source of income for operators. Further research in recycling of CFRP is needed to make marketable products from recycled CFRP. A recycled product of pure fibre could be used in other products of lower quality. For potential buyers a known disposal option would help them know what to do with a CFRP hull after use and reduce the risk of old CFRP hulls being disposed in harmful ways.

Cluster networks are a way to increase knowledge sharing, awareness of the benefits of using composites and co-operation between leisure and commercial shipyards. This can eventually support a sustainable development. This is a benefit for the society, but if the cluster networks took place without Tuco, it can be seen as a threat for Tuco.

Higher fuel taxes or similar strong economic incentives on ferry transport can be a way for the politicians to accelerate demand for more fuel effective ferries. The politician could take heed of the Norwegian legislation were they have a reward and punishment system like the “NOX fond”.

Rules and regulations especially related to fire safety could be adapted to embrace new technologies by having function based requirements instead of prescriptive norms. If function based rules cannot be made a close collaboration between industry and authorities have to be an alternative.

Chapter 10 Conclusion

The interdisciplinary approach applied in this study has been used to analyse the industry and market for composite ships in Denmark. The combination of life cycle thinking with strategic methods like Porter five forces and PEST analysis have identified factors and connections which would not have been found if the analyses was done separately. A LCA analysis was done firstly and was used to supplement the later strategic analysis. In Porter five forces not much was mentioned about disposal and waste treatment, but by combining it with a life cycle perspective and the end-of-life phase of a LCA analysis a secondary buyer link was created. The strategic analysis supplemented the LCA analysis by identifying aluminium as the reference flow based on threat of substitutes. Initially the three CFRP ferries in Norway was intended to be compared with the two old aluminium ferries servicing the route, but doing an interview with the operator it was made clear that a better comparative LCA would be made if the smaller aluminium ferry “Renøy” was used as reference.

A purpose of this study was to decide the degree of and potential for sustainable development in the maritime industry for CFRP shipbuilding. In this context all the three pillars of sustainability were intended to be analysed namely environmental, economical, and social. To do so the interdisciplinary method was applied to analyse the industry both in relation to sustainable development, competitive parameters and market potential. The method was used on a case study consisting of a Danish shipyard Tuco Marine Group and three Norwegian catamaran fast ferries build in 2009-10. It was shown that the interdisciplinary approach could be used to develop a more sustainable strategy for a company in the industry. The LCA model has supplemented Porter’s model by illustrating the environmental consequences of actions and how to best circumnavigate these.

The analysis also revealed that a strong focus on cost and traditions together with lack of competencies and experiences with carbon fibre is an obstacle for achieving the sustainable benefits of using this new and lighter material. However, it is seen that environmental progress can emerge even though the industry is cost driven, since the cost savings related to lower fuel consumption also mean less emissions and environmental impacts. It was though found that there is no reason why the expectation of costs in the maritime industry cannot be united with sustainability, since a more sustainable product using less fuel and input materials often leads to lower life cycle costs. So even though the industry may not directly strive for sustainability it can happen unintended. The majority of the environmental impacts and costs occur in the operation phase due to the extensive fuel consumption. The economic break-even point is four years, but in general it is not possible to say whether a CFRP ferry is more profitable than a similar aluminium ferry. Profitability depends on various parameters like distance of the route, number of daily departures, the fuel consumption of the ferry, and the maintenance costs. All these needs to be compared to the investment price of buying, designing and approving the two reference ferries.

During the interviews and subsequent analysis it was found that trust between shipyards, suppliers, buyers, naval architects, and Classification Companies was found to be of major importance. If a shipyard, naval architect or buyer did not trust that they would get a good product or piece of work they would not continue the cooperation. In relation to this it was found that good references were crucial to obtain a competitive advantage for a shipyard. Another finding was that the industry in general and especially the ship owners were not willing to take any risks by testing more sustainable products or services unless it provided clear economic profit. One of the segments which did order vessels build in composite materials was the offshore industry, and this was identified as a good market to obtain knowledge and experiences which later could be used in for example the ferry sector.

When looking at the specific case of the three Norwegian CFRP ferries and comparing it to the Danish conditions a number of differences were specified. Major differences in geography was found since the Norwegian CFRP ferries was used to transport only people over longer distances, while a Danish ferry operating between the mainland and an island needs to carry vehicles and cargo over a comparable shorter distance. A high speed ferry would probably not be needed on most routes in Denmark and the few commercial routes where high speeds are needed the ferries are relatively new. For a traditional ferry with lower speed and fuel consumption operating on a shorter route the results of a LCA and LCC analysis would be different than in this study. Another lesson learned from the history of three CFRP ferries in Norway was that most changes take time and demand adaptation and both the public and municipality needs to be aware of that. This is important to remember if a composite ferry is put into service in Denmark one day.

To summarize the competitive parameters, a CFRP ferry is lighter than a similar aluminium ferry and therefore has lower fuel consumption per sailed nautical mile. On the contradictory side the present design time is long compared to a steel or aluminium ferry, and the fire safety question is a major obstacle. There exist relatively few shipyards in Denmark capable of building ships in carbon fibre and the picture is not much different when expanding to Scandinavia and Northern Europe. The market for carbon fibre ships is still a niche market mainly for the offshore industry. In Denmark there is a lack of competencies to design and make calculations on composite materials and it was found that most of the shipyards and naval architect companies would go abroad to look for these competencies. Tuco has expressed a wish to be able to advice in the design phase in the future in order to optimize the design and avoid to oversize. In relation to technological development of the materials especially carbon fibre a certain technological development can be expected in the next 10-20 years since the aviation and windmill industry are expected to increase their demand for carbon fibre considerably. As the demand for carbon fibre increases so does the amount of production waste and scrap. This could accelerate the possibility to recycle the carbon fibre, which even for a small recycle percentage was found to be beneficial for the environment in the sensitivity analysis of the LCA.

The analysis has showed a pattern of actions influencing sustainability. If other should want to make a similar analysis it would be time wise beneficial to be inside the industry and thereby have an understanding of the key competitive parameters beforehand. The method can be used to tune company strategies for life-cycle-thinking and explain how to use sustainability as a competitive advantage. The method is based on existing well established strategic models and analyses, which can make it more acceptable for business strategists who consider becoming more environmental sustainable.

This thesis has through the interdisciplinary approach tried to find ways for making sustainability part of a realised strategy. Through the LCA analysis quantitative measures of sustainability have been found. The quantitative results have acted as a filter in the strategic analyses where the maritime industry has been combed for emergent patterns of sustainability. The patterns found in the strategic analyses have been used to suggest plans and ploys in the chapters concerning perspective and recommendations. To summarise the interdisciplinary approach has found ways to make sustainability a deliberate strategy even though the current perspective of the maritime industry do not value sustainability.

Chapter 11 Future Studies

A lot of topics have been scanned, but in some areas there was a lack of information which could be investigated further. In the following suggestions for future studies will be presented.

In the analysis and descriptions of the present ferries and routes in Denmark the amount of people travelling a route did not always corresponds to the subsidies given to the routes. This was noted by the Danish Interior Ministry; “after the two objective criteria, population and distance covered, it seems substantial fluctuations in relation to the current level of subsidy exist” (96). Two studies could be made to see on the need for ferry transport in Denmark, one in relation to depopulation and infrastructure of the islands, and another study could see at the possibilities to have economic sound ferry transport. If the society wants people living on the small islands there is a need to have sufficient infrastructure to prevent depopulation.

A couple of the interviewees and the contact person Ingrid Marie Vincent Andersen raised questions about the durability of CFRP (Appendix 3 and 5). Limited literature could be found on this subject and most was related to glass fibre. The sector in Denmark with most experience about the durability of composites at sea was found to be the navy. A short telephone interview was conducted with commander Michael Rasmussen from the Danish navy based on his experiences with glass fibre ships in the 1990’ies and 2000’ies. Even though Michael mainly had positive experiences with glass fibre ships this subject could be investigated further. A quantitative study of the maintenance need on composite ships could be made based on experiences from the offshore industry and other navies. The results could be compared to maintenance of steel and aluminium ships. Such a study should include considerations like the operation time at sea, the types and amount of damages and their causes, the navigational condition and the cost of repair and service.

The present study has focused on CFRP-ferries and their market potential. Another market that briefly has been mentioned is the offshore markets need for lighter ships. A market analysis could be made looking at supply and service ships for the offshore market.

LCA have in this thesis been used to think strategically about sustainability. Different articles have been found on how researchers have used LCA on different cases. A meta-analysis could be made of all the different LCA applications to determine how LCA in general have been used in decision making contexts.

As mentioned in the introduction, many of the large Danish shipyards have closed down over the last decade, but the Danish ship owners still manage a significant percentage of the global merchant fleet. This study has looked at a niche market for ferries, but not on the global patterns of competition for new shipbuilding. It raises the question whether Denmark has the potential to become a new major shipbuilding nation again.

The captains on the CFRP-ferries in Troms all claimed the superior manoeuvrability in bad weather of the CFRP ferries compared to other ship designs. This could be decided by an investigation of the seaworthiness of composite ships compared to aluminium ships.

The only real disposal options for composite materials today has been found to be landfill and in some cases incineration. Investigation into the disposal and recycling options in relation to future technological development could be made.

A weighting method that enables future researchers to use the industry stakeholders own values in the impact assessment method could be developed (see section 5.5.4).

It could be interesting in a further study to investigate which ferry solution would result in most years of lives lost based on a comparison between fire risks and human health impact category.

Social aspects like worker rights, discrimination, and working conditions have not been discussed in this study. To further discuss the social aspect of sustainability in depth a SLCA could be made in combination with a strategic analysis to evaluate the sustainability of the development.

An approach could be developed which assessed fire safety risks and years lost in relation to human health in LCA methodology (see section 7.1).

Make an empirical study of cluster networks in Denmark and investigate their influence for innovation and sustainability in the Danish maritime industry.

References

1. Værfter blev sejlet i sænk af storrederne | arbejderen [Internet].; 2011; cited 7/18/2013]. Available from: http://arbejderen.dk/artikel/2011-12-22/v-rfter-blev-sejlet-i-s-nk-af-storrederne.

2. Danmark i Arbejde Vækstplan for Det Blå Danmark, , (2012).

3. Carbon fiber market expected to reach $2.4billion in 2014 [Internet].; 2009; cited 7/27/2013]. Available from: http://www.carbonfibergear.com/carbon-fiber-market-expected-to-reach-24-billion-in-2014/.

4. Hjørnet N. Prsentation skibsteknisk selskab, 11 marts. 2013.

5. Eco island ferry - comparative LCA of island ferry with carbon fibre composite based and steel based structures [Internet].; 2013; cited 6/10/2013]. Available from: http://www.eco-island.dk/pdf/Eco_E_Ferry_LCA_20130418(JS).pdf.

6. Project targets [Internet].; 2013; cited 7/27/2013]. Available from: http://www.eco-island.dk/project.html.

7. Bruntland G. Our common future: The world commission on environment and development. . 1987.

8. Daly HE. Beyond growth: The economics of sustainable development. Beacon Press; 1997.

9. Lozano R. Towards better embedding sustainability into companies' systems: An analysis of voluntary corporate initiatives. J Clean Prod. 2012 APR 2012;25:14-26.

10. Jones SA, Rose K, Tull K. A strategic approach to improve environmental policy-making for end-of-cycle product management. J Environ Assess Policy Manage. 2011 DEC 2011;13(4):651-72.

11. UNEP. Life cycle management a business guide to sustainability. 2007.

12. The three pillars of sustainability [Internet].; cited 7/24/2013]. Available from: http://www.thwink.org/sustain/glossary/ThreePillarsOfSustainability.htm.

13. UNEP. Green economy report. UNEP; 2011.

14. Scherer AG, Palazzo G, Seidl D. Managing legitimacy in complex and heterogeneous environments: Sustainable development in a globalized world. Journal of Management Studies. 2013 MAR 2013;50(2):259-84.

15. Berns M, Townend A, Khayat Z, Balagopal B, Reeves M, Hopkins MS, et al. The business of sustainability: What it means to managers now. MIT Sloan Management Review. 2009;51(1):20-6.

16. Mintzberg H. The strategy concept 1: Five p's for strategy. U. of California; 1987.

17. Porter M. What is strategy? Harv Bus Rev. 1996 NOV-DEC;74(6):61.

18. Grant RM. Contemporary strategy analysis. 7th ed. Wiley; 2010.

19. PRAHALAD C, HAMEL G. The core competence of the corporation. Harv Bus Rev. 1990 MAY-JUN;68(3):79-91.

20. Porter ME. The five competitive forces that shape strategy. Harv Bus Rev. 2008 JAN 2008;86(1):78.

21. Henry A. Part two strategic analysis, the general Environment**
**. In: Understanding Strategic Management. 2008th ed. Oxford University Press.

22. European Commission. International reference life cycle data system (ILCD) handbook—general guide for life cycle assessment—detailed guidance. 2010. EUR 24708 EN. european commission, joint research centre. Institute for Environment and Sustainability, Luxembourg.Publications Office of the European Union. 2010.

23. Anastas P, Zimmerman J. The twelve principles of green engineering as a foundation for sustainability. Sustainability Science and Engineering. 2006;1:11-32.

24. Ny H, MacDonald JP, Broman G, Yamamoto R, Robért K. Sustainability constraints as system boundaries: An approach to making life-cycle management strategic. J Ind Ecol. 2006;10(1-2):61-77.

25. Grimes-Casey HG, Seager TP, Theis TL, Powers SE. A game theory framework for cooperative management of refillable and disposable bottle lifecycles. J Clean Prod. 2007;15(17):1618-27.

26. Life cycle cost analysis - eco-island ferry [Internet].; 2012; cited 6/20/2013]. Available from: http://eco-island.dk/pdf/BRd6035-01_LCC_report_rev_1.pdf.

27. Dreyer LC, Hauschild MZ, Schierbeck J. Characterisation of social impacts in LCA. The International Journal of Life Cycle Assessment. 2010;15(3):247-59.

28. Jørgensen A, Wangel A, Petrova K. Social life cycle assessment - an introduction. DTU; 2012.

29. International labour organization [Internet].; 2013; cited 7/27/2013]. Available from: http://www.ilo.org/global/lang--en/index.htm.

30. Finkbeiner M. Towards life cycle sustainability management. Springer Science Business Media; 2011.

31. Scandelius C, Gohen G. A life cycle stakeholder management framework for enhanced collaboration between stakeholders with competing interests. In: Finkbeiner M, editor. Toward life cycle sustainability management. Springer; 2011.

32. Rasmussen LB. Supervisor meeting in april. 2013.

33. Hopkins M, Eppinger S. How sustainability fuels design innovation. MIT Sloan Management Review. 2010.

34. McAloone T, Bey N. Environmental improvement through product development. DTU Technical University of Denmark, Copenhagen. 2009.

35. Maritim omstillingspulje [Internet].; 2013; cited 8/2/2013]. Available from: http://www.soefartsstyrelsen.dk/tema/MaritimOmstillingspulje/Sider/Default.aspx.

36. High speed craft [Internet].; 2013; cited 7/27/2013]. Available from: http://www.imo.org/OurWork/Safety/Regulations/Pages/HSC.aspx.

37. Carbon fibre [Internet].; 2013; cited 7/20/2013]. Available from: http://compositesdirect.com/media/catalog/product/cache/1/image/9df78eab33525d08d6e5fb8d27136e95/c/a/carbon-fiber-2x2-twill_3.jpg.

38. Carbon fiber market: Gathering momentum [Internet].; 2012; cited 7/23/2013]. Available from: http://www.compositesworld.com/articles/carbon-fiber-market-gathering-momentum.

39. Guide to composites [Internet].; 2013; cited 7/27/2013]. Available from: http://www.gurit.com/guide-to-composites.aspx.

40. Tensile property testing of plastics [Internet].; 2013; cited 7/29/2013]. Available from: http://www.matweb.com/reference/tensilestrength.aspx.

41. Carbon fabrics: Core composites, inc. [Internet].; cited 7/20/2013]. Available from: http://www.corecomposites.com/composites/reinforcements/carbon-fabrics/.

42. Composite core materials [Internet].; 2013; cited 7/27/2013]. Available from: http://composite.about.com/od/distcores/a/Composite-Core-Material.htm.

43. Coman A. A comparison of composite superstructures on ro-ro vessels versus conventional steel superstructures [dissertation]. ; 2011.

44. Bolick DR. Composite fabrication via the VARMT process. Triangle Polymer Technologies.

45. Complete guide to composites, part 6 [Internet].; 2013; cited 8/4/2013]. Available from: http://www.autospeed.com.au/cms/A_108698/article.html.

46. Gu Y, Li M, Wang S, Li Y, Zhang Z. Manufacturing carbon nanotubes toughend glass fiber/epoxy resin laminates using double vacuum assisted resin infusion molding. 18th International Conference on Composite Materials. 2010.

47. Hansen HL, Hedegaard E, Kühl M, Mortensøn O, Nielsen AR, Wagner A, et al. Folk og glasfiberfartøjer fra det sydfynske øhav. Østergaard MK and Hermansen K, editors. Marstal Søfartsmuseum; 2012.

48. DI's InitiativPris 2005 til tuco yacht værft aps [Internet].; 2006; cited 7/27/2013]. Available from: http://www.teknikogviden.dk/artikelarkiv/2006/2/di%27s-initiativpris-2005-til-tuco-yacht-vaerft-aps.aspx.

49. Kontrakt - Avtale Om Kjøp Av Hurtigbåtruter i Troms, , , 2009).

50. Olsen SI, Hauschild MZ, Rosenbaum RK. Chapter 11: Scope definition - note 06 chapter 11 scope (definition final draft for 42372.pdf). In: ; 2012.

51. Fartøyliste - hurtigbåter - boreal [Internet].; cited 6/11/2013]. Available from: http://www.boreal.no/fartoeyliste-hurtigbaater/category592.html.

52. Marine traffic [Internet].; cited 6/12/2013]. Available from: http://www.marinetraffic.com/.

53. Cost and energy assessment of a high speed ship [Internet].; 2002; cited 6/13/2013]. Available from: http://www.s-lass.com/en/Documents/LÄSS rapporter/Cost and energy assessment of a high speed ship.pdf.

54. Renøy [Internet].; cited 6/12/2013]. Available from: http://hsc-norway.stormkast.net/renoy1.htm.

55. Aluminium industry [Internet].; 2007; cited 5/22/2013]. Available from: http://www.aluminiumleader.com/en/serious/industry/.

56. Boat_Longevity [Internet].; cited 6/11/2013]. Available from: http://www.ericgreeneassociates.com/images/Boat_Longevity.pdf.

57. Kwon K, Frangopol DM. Fatigue life assessment and lifetime management of aluminum ships using life-cycle optimization. J Ship Res. 2012;56(2):91-105.

58. Krydsfiner - fysiske egenskaber [Internet].; 2003; cited 7/29/2013]. Available from: http://vot.teknologisk.dk/8765,3.

59. PVC and industry waste [Internet].; 2011; cited 6/20/2013]. Available from: http://www2.mst.dk/common/Udgivramme/Frame.asp?http://www2.mst.dk/udgiv/publikationer/1998/87-7909-034-6/html/bilag1.14.htm.

60. Aluminium in shipbuilding [Internet].; 2007; cited 7/23/2013]. Available from: http://www.aluminiumleader.com/en/around/transport/ship.

61. Media releases - austal unveils its largest ever catamaran [Internet].; 2010; cited 6/20/2013]. Available from: http://www.austal.com/en/media/media-releases/10-12-10/Austal-Unveils-Its-Largest-Ever-Catamaran.aspx.

62. How is it produced? [Internet].; cited 7/23/2013]. Available from: http://www.aluminiumleader.com/en/facts/extraction/.

63. 35m-cat-norway [Internet].; cited 7/23/2013]. Available from: http://www.tuco.dk/index.php/en/cases/35m-cat-norway.

64. Aluminium recycling prices [Internet].; cited 6/17/2013]. Available from: http://www.benefits-of-recycling.com/aluminumrecyclingprices/.

65. Iron recycling [Internet].; cited 7/23/2013]. Available from: http://www.recyclingmanagement.com/Iron-Recycling.

66. Diesel engines 12V/16V 2000 M72 [Internet].; 2013; cited 6/20/2013]. Available from: http://www.mtu-online-shop.de/fileadmin/dam/product_images/print_images/DB_12V16V2000M72_3232231.pdf.

67. Diesel engines 12V/16V 2000 M70 [Internet].; 2013; cited 7/25/2013]. Available from: http://www.mtu-online-shop.de/fileadmin/dam/download_media/print_media/DB_12V16V2000M70_3231461_090810.pdf.

68. 4045DFM50 diesel engine [Internet].; 2013; cited 7/25/2013]. Available from: http://www.deere.com/en_US/docs/engines_and_drivetrain/specsheet/MAR/4045DFM50_A.pdf.

69. Goedkoop M, Heijungs R, Huijbregts M, De Schryver A, Struijs J, Van Zelm R. ReCiPe 2008. A life. 2009.

70. Goedkoop M, Heijungs R, Huijbregts M, De Schryver A, Struijs J, van Zelm R. ReCiPe 2008; A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. 2013.

71. Olsen SI. 2013.

72. Chapter 3: Landfill gas safety and health issues [Internet].; 2001; cited 6/21/2013]. Available from: http://www.atsdr.cdc.gov/hac/landfill/html/ch3.html.

73. Friis AM, Andersen P, Jensen JJ. Ship design part 1. DTU; 2002.

74. ReCiPe [Internet].; 2013. Available from: http://www.pre-sustainability.com/recipe.

75. Bekendtgørelse af lov om afgift af affald og råstoffer [Internet].; 2011; cited 7/26/2013]. Available from: https://www.retsinformation.dk/Forms/r0710.aspx?id=133844.

76. Resin types [Internet].; 2013; cited 7/29/2013]. Available from: http://www.netcomposites.com/guide/resin-types/7.

77. Biddle R, Packer J, Thomson A. X polymers A industrial resins. In press 2008.

78. Danskerne betaler overpris for energi [Internet].; 2005; cited 7/30/2013]. Available from: http://www.dors.dk/sw2909.asp.

79. Brødrene aa AS [Internet].; cited 7/25/2013]. Available from: http://1890.no/id/Brødrene-Aa-AS.

80. Kockums kompositkunnande - kockums [Internet].; cited 7/1/2013]. Available from: http://www.kockums.se/produkter-tjanster/civila-produkter/kompositteknologi/.

81. Kongene av karbonbåter - tu.no/industri [Internet].; cited 7/1/2013]. Available from: http://www.tu.no/industri/2011/05/23/kongene-av-karbonbater.

82. Skibene i 2. eskadre - missil og minerydningsfartøjer - MSF'ere [Internet].; cited 7/25/2013]. Available from: http://forsvaret.dk/2ESK/Enheder/SF300/MSF/Pages/default.aspx.

83. Nye produkter på basis af genanvendt glasfiberaffald [Internet].; cited 7/1/2013]. Available from: http://markedsmodningsfonden.dk/projekt/0/34/490.

84. Projekt genvind [Internet].; 2012; cited 7/27/2013]. Available from: http://www.dakofa.dk/Aktiviteter/konferencer_seminarer/121211/Materiale/1450,%20Per%20Bo%20Ludwigsen.pdf.

85. Waste: Should landfill be banned [Internet].; 2012; cited 6/7/2013]. Available from: http://eep.org/EEP2009/News/Customer-release/Waste--Should-landfill-be-banned--.aspx.

86. What is metal fatigue [Internet].; 2013; cited 7/29/2013]. Available from: http://www.burgoynes.com/content/what-metal-fatigue.

87. 2012 corruption perceptions index -- results [Internet].; cited 6/28/2013]. Available from: http://cpi.transparency.org/cpi2012/results/.

88. DEPweb: GNP per capita, all regions [Internet].; cited 6/28/2013]. Available from: http://www.worldbank.org/depweb/english/modules/economic/gnp/datanot.html.

89. Tilbudsloven - bekendtgørelse af lov om indhentning af tilbud på visse offentlige og offentligt støttede kontrakter - retsinformation.dk [Internet].; cited 6/28/2013]. Available from: https://www.retsinformation.dk/Forms/R0710.aspx?id=113858.

90. Bekendtgørelse af lov om færgefart - retsinformation.dk [Internet].; cited 6/28/2013]. Available from: https://www.retsinformation.dk/Forms/r0710.aspx?id=121290.

91. Bekendtgørelse om meddelelser fra søfartsstyrelsen D, teknisk forskrift for skibes bygning og udstyr m.v., passagerskibe i national fart [Internet].; 2011; cited 7/29/2013]. Available from: https://www.retsinformation.dk/Forms/R0710.aspx?id=137066.

92. Brandchef: Besætning bag brand på scandinavian star [Internet].; 2010; cited 6/7/2013]. Available from: http://www.dr.dk/Nyheder/Indland/2010/04/11/064315.htm.

93. Industri » ole sohn ser på maritime perspektiver [Internet].; cited 6/28/2013]. Available from: http://www.maritimedanmark.dk/?id=15738.

94. Lånebekendtgørelsen - bekendtgørelse om kommunernes låntagning og meddelelse af garantier m.v. - retsinformation.dk [Internet].; cited 6/30/2013]. Available from: https://www.retsinformation.dk/Forms/R0710.aspx?id=145202#Bil1.

95. Færger giver røde tal [Internet].; 2012; cited 8/3/2013]. Available from: http://www.nordjyske.dk/nyheder/faerger-giver-roede-tal/2d0c4a97-e66e-4079-aa84-3a4e88e8c311/4/1513.

96. Indenrigsministeriet. Tilskudsordningen vedr. kommuner med mindre øer. 2013. Report No.: 2013.

97. Crude oil prices 1861-2010 [Internet].; 2011; cited 6/30/2013]. Available from: http://oilintheus.com/2011/06/crude-oil-prices-1861-2010/.

98. CO2-afgiftsloven - bekendtgørelse af lov om kuldioxidafgift af visse energiprodukter - retsinformation.dk [Internet].; cited 6/28/2013]. Available from: https://www.retsinformation.dk/forms/r0710.aspx?id=133858.

99. Regelverk - næringslivets hovedorganisasjon [Internet].; cited 6/30/2013]. Available from: http://www.nho.no/regelverk/category463.html.

100. Støtte fra fondet - næringslivets hovedorganisasjon [Internet].; cited 6/30/2013]. Available from: http://www.nho.no/stoette-fra-fondet/category464.html.

101. Udvikling fyn | sammen om vækst - jan fra ærø og tuco fra faaborg på vej mod maritimt eventyr [Internet].; cited 6/30/2013]. Available from: http://www.udviklingfyn.dk/nyheder/jan-fra-ærø-og-tuco-fra-faaborg-på-vej-mod-maritimt-eventyr.

102. BEF4: Folketal 1. januar efter øer [Internet].; 2013; cited 7/24/2013]. Available from: http://www.statistikbanken.dk/statbank5a/default.asp?w=1680.

103. Skib33: Indenrigs færgetransport efter færgerute og enhed [Internet].; 2013; cited 7/24/2013]. Available from: http://www.statistikbanken.dk/statbank5a/default.asp?w=1680.

104. Krag A, Trolle JG. Danmarks småfærger - en fælles standard. 2012.

105. Vejen til din færgerejse [Internet].; 2013; cited 2/27/2013]. Available from: http://www.faerge.dk/.

106. Alphaliner: Maersk betaler dyrt for at være first mover [Internet].; cited 7/4/2013]. Available from: http://shippingwatch.dk/Rederier/article5468989.ece.

107. MARCOD booster væksten i dansk maritim klynge [Internet].; cited 7/4/2013]. Available from: http://www.kanalfrederikshavn.dk/index.php?id=7&tx_ttnews[tt_news]=32509&cHash=c1cc757f2076dd07139f604b790354b2.

108. Udvikling fyn | sammen om vækst - fremdrift i den maritime klynge [Internet].; cited 7/4/2013]. Available from: http://www.udviklingfyn.dk/nyheder/fremdrift-i-den-maritime-klynge.

109. Gnyawali DR, Srivastava MK. Complementary effects of clusters and networks on firm innovation: A conceptual model. J Eng Technol Manage. 2013 JAN-MAR 2013;30(1):1-20.

110. Automotive technology: Greener products , changing skills. Center for Automotive Research; 2011.

111. Ulrich L. Carbon car. SPECTRUM.IEEE.ORG. 2013 January;North American:30-1.

112. Erhvervsaffald og udvalgte affaldsstrømme 1.14 PVC [Internet].; cited 7/4/2013]. Available from: http://www2.mst.dk/common/Udgivramme/Frame.asp?http://www2.mst.dk/udgiv/publikationer/1998/87-7909-034-6/html/bilag1.14.htm.

113. Marquis DM, Pavageau M, Guillaume E. Multi-scale simulations of fire growth on a sandwich composite structure. J Fire Sci. 2013 JAN;31(1):3-34.

114. Marquis DM, Pavageau M, Guillaume, E. and Chivas-Joly C. Modelling decomposition and fire behaviour of small samples of a glass-fibre-reinforced polyester/balsa-cored sandwich material. Fire and Materials. 2012.

115. Structural composites | ecovative design [Internet].; cited 7/4/2013]. Available from: http://www.ecovativedesign.com/applications/structural-panels/.

116. Passagertal | aalborg lufthavn [Internet].; cited 7/3/2013]. Available from: http://www.aal.dk/om-aalborg-lufthavn/passagertal/.

117. Ecopassenger [Internet].; 2013; cited 7/30/2013]. Available from: http://www.ecopassenger.org/.

118. Eco-concept modeling [Internet].; 2013; cited 7/27/2013]. Available from: http://www.sustainableminds.com/software/eco-concept-lca-software.

119. Søfartsstyrelsen skyder millioner i udvikling af færge af kulfiberkomposit - ingeniøren [Internet].; cited 7/17/2013]. Available from: http://ing.dk/artikel/soefartsstyrelsen-skyder-millioner-i-udvikling-af-faerge-af-kulfiberkomposit-159916.

120. The online royalty free public domain clip art [Internet].; 2013; cited 7/29/2013]. Available from: http://www.clker.com/.