Master's degree thesis

LOG950 Logistics

A comparative Life Cycle Assessment between conventional and electronic books

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Molde University College
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Preface

The master's degree thesis is the last assignment in the study program 'Master of Science in Logistics' at Molde University College, specialized university in logistics. The thesis is written in the spring semester 2014 and gives a credit of 30 ECTS.

Writing a master's degree thesis has been a learning process from the beginning to the end. It has included interesting brainstorming, ideas and discussions. By researching parts of the supply chain for conventional and electronic books I have learned more than I ever thought I would know about the book industry, and especially about electronic reading. It gave me an insight into the foundation of conventional books and eBook readers. From production of both products, and all to the end when a consumer have a book to read in their hands.

Acknowledge

I would like to give my gratitude to my supervisor Svein Bråthen for giving me professional guidance through the writing process of the master's degree thesis. He has been giving me feedback when I needed it, and valuable tips and instructions on how to proceed with the thesis.

I would like to thank all the companies I have been reaching out to for their friendliness and eager to help me with the thesis. I would especially like to thank Bring Logistics department Molde for meeting me and guide me through their distribution pattern for conventional books.

In the end I would like to thank my family and friends for giving me support and strength the months while writing the master's degree thesis.

Monika Kolvik
Molde, May 27th 2014

Abbreviations

CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents
CSR	Corporate Social Responsibility
EBook	Electronic book
EBook reader	Dedicated reading device for electronic books
EPA	United States Environmental Protection Agency
GL	Green Logistics
GHG	Greenhouse gases
GSC	Green Supply Chain
GWP	Global warming potential
HAP	Hazard air pollutants
HGV	Heavy goods vehicle
ILUC	Indirect land-use change
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LCI	Lice cycle inventory
MH_4	Methane
NO_X	Nitrous oxides
NTM	The Network for Transport and Environment
PNEAC	Printers’ National Environmental Assistance Center
RE	Renewable Energy
SC	Supply chain
VOC	Volatile organic compounds

Table of Contents

List of Figures

List of Tables

1. Abstract

The case description is clarified first in the thesis, before the research questions are introduced. It is then looked closer into the theory of green logistics and the different dimensions around this topic. Energy consumption in parts of the supply chain of both two book options will be given a deeper knowledge to. The research model, method and data will be described, before the analysis is performed. Findings from the analysis will be listed and from these findings there will be a discussion and answering the research questions. In the end a conclusion based on the findings from the performed LCA is constructed.

The thesis had a higher focus on energy consumption, emission factors and energy efficiency through the supply chain, except raw material and 'end-of-life' phase, for both conventional and electronic books. The deeper input into these segments strengthens the potential for a greener and environmental friendly supply chain.

A life cycle assessment (LCA) has been performed to be able to compare the two book options in an environmental manner. The 'end-of-life' stage in the LCA was presented for both options, but due to time restrictions this part was not conducted in the thesis. An interesting finding in the analysis where the difference in total CO_2e in the distribution phase, for both products, between the emission values from the Network for Transport and Environment (NTM) professional calculator and the equations calculated in the thesis.

In the conclusion it is highlighted that there is a higher difference in total CO_2e between the two products. To be environmentally friendly a consumer needs to read one book every second month over a four year period to compensate for buying an eBook reader. The reason for this is the emission regarding the production of the two products, and the difference in distance and time in the distribution phase where the underlying reason is the number of transportation mode used in this phase and the longer route to travel for the eBook reader then for the conventional book.

2. Introduction

Environmental awareness among businesses has increased more and more over the later years. Still, businesses need to be even more aware of how their product, direct and indirect, affects the environment and what they can do to decrease the emission regarding their products life cycle. Consideration about the environment among businesses has gradually grown the last decades. In the year of 2014 many business value environmental friendly solutions, while they at the same time reach their profitability targets.

Books are one of the main product consumers buy online (Nielsen 2010). They can be accessed through bookshops, online shops, libraries, computers, mobile phones and eBook readers. Distribution of conventional books contains transport from production facility to warehouse and from the production facility transport to retailers, libraries or end-customers. EBooks are directly downloaded from the internet to an eBook reader, and goes straight to the end-customer without going through a physical retailer. To be able to read an eBook the consumer needs a reading device. This reading device could be a computer, tablet or smartphone that most people already own today, but the most convenient way to read an e-book is on a special designed reader called; eBook reader. Distribution of eBook readers comes into account while investigating the distribution of eBooks, since this is a necessary device to be able to read the eBook.

The topic of green logistics is a vital aspect for the environment and for future generations. It has an increasing interest to business over the world, and is almost an essential topic for a company to be able to compete with most business today. Corporate Social Responsibility (CSR) has emerged into many legal an ethical frameworks concerning how business function within the society (Emmet and Sood 2010). Consumers are paying more attention to the environmental issues connected to the products they are buying, and therefore are more concern about what they purchase and how the product is handled in a sustainable matter (Emmet and Sood 2010).

An important issue for this topic will be to compare the energy consumption and the emissions from the consumption between the two different book options. Looking closer into parts of the supply chain for the two products will give a result that favour one of the products in the answer for an environmental friendly solution. Renewable energy, as a source to be more environmentally friendly, will be introduced.

3. Case description

The thesis will have a theoretical interpretative approach that looks closer at some parts of the supply chain for conventional and electronic books in an environmental perspective. The foundation in this kind of study as Andersen (2013) describes it is that existing theory are being used to appraise, interpret and explain the case. Terminology and theoretical contexts will be used to summarize and structure empirical material and data.

The master's degree thesis will mostly have secondary sources, and therefore literature research will have a high impact for the outcome of the thesis. Data is still needed for the analysis to have a more realistic view of the content. Data will be collected from publishers, printing firms, producers of eBook readers, distribution firms and online shops where it is possible. The energy consumption from the different stages in the supply chain is investigated to find reasonable calculations for the analysis. Different parameters are set to measure the environmental impact of book distribution. To be able to answer the research questions from chapter 3.1 in the thesis an LCA for the two book options will be conducted.

3.1 Research Problem

The research problem is to investigate the supply chain, except raw material and 'end-of-life' phase, of conventional and electronic books in an environmental perspective. A comparison will be made with a main focus on emission factors and CO_2 equivalents. Improvements for a greener distribution of books will be discussed. Numerical measures will show the difference between the two products. The energy consumption and the estimated emission factors through the parts of the supply chain that are investigated will set the foundation for the conclusion in the end.

3.2 Conventional book

A conventional book is a printed book with glued, or sewn, pages on one edge and bound in covers. Books intentions are to communicate knowledge or entertainment through reading (Kang, Wang and Lin 2008).

3.2.1 Conventional book production

The printing stage is the start phase for a new conventional book in this research. The most common printing process used today is offset lithography, and this method will therefore be the printing process that will be analysed (Hignell book printing 2014).

Offset lithography is based on the principle that water and ink do not stick together (Hignell book printing 2014). Ink is placed on the printing plate where the text will show and will transfer the text onto the paper to print the book page (Printers' National Environmental Assistance Center [PNEAC] 2014).

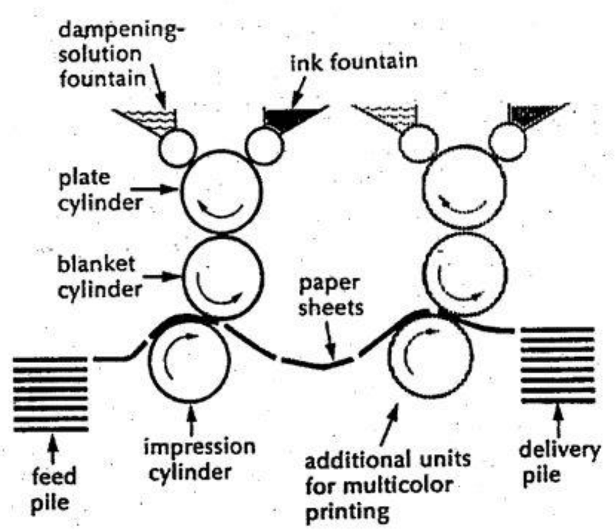

Figure 1: Offset lithography printing process. Source: PNEAC 2014.

Figure 1 illustrates the offset lithography printing process for a conventional book. The process starts on the left and printed pages with text are on the right side. The lithographic plate goes through a chemical treatment to render two different areas on the paper. The text area will show where the oil render, and the non-text areas will show where the water render. There are three printing cylinders in this process; the plate cylinder, the blanket cylinder and the impression cylinder. The paper sheets are rolling on line between the blanket cylinder and the impression cylinder. In the printing process the dampening solution fountain is first applied on the printing plate and render to the non-text areas of the plate. Second, the ink is applied on the printing plate and render to the text areas of the paper. The principal that water and oil do not mix prevents the two solutions to migrate into each other's areas on the paper.

3.2.2 Conventional book distribution

Conventional books are shipped to a warehouse after the printing stage. From the warehouse the books are shipped to a goods terminal before it ends up in a bookshop (Kozak 2003). The end-customer has to travel to a bookshop to buy the book.

3.2.3 Usage of conventional books

Conventional books can be read as long, and as often, as desired without any effect on the environment. When the consumer owns the book, no more emission is related to the conventional book.

3.2.4 'End-of-life' phase

The 'end-of-life' phase for a conventional book will begin if the consumer does not want to keep the book anymore. In this thesis it is assumed that the consumer keep the book for his whole life time. Books can be kept for more than 400 years (Zachary 2002).

3.3 Electronic book

An electronic book (eBook) is a digital copy of a conventional book with some extensions (Hua, Cheng and Wang 2010). An eBook reader is able to click on different words in the text and go directly to online resources as references, description or translation of a word (Kang, Wang and Lin 2008). The eBook reader gives the book automatic bookmark, possibilities to take notes and text-to-voice functions (Jiang and Katsamakas 2010). It is also possible to adjust the text size and font after the reader's preferences (Amazon 2014).

3.3.1 Electronic book reader production

The production stage for electronic reading devices will be focusing on dedicated reading devices. An eBook reader consists of microprocessor, operating system, memory, batteries, LCD technology, input device, input/output ports and desktop pc software (Kozak 2003).

Electronic ink is the technology that makes the text visible on the screen in an eBook reader. It is made out of millions of microcapsules. As the electronic ink firm E Ink Corporation (2012) describes it 'each microcapsule contains positively charged white particles and negatively charged black particles suspended in a clear fluid. When a positive or negative electric field is applied, corresponding particles move to the top of the microcapsule where they become visible to the reader. This makes the surface appear white or black at that spot'. This will then either show the text areas or the non-text areas.

EBook reader manufacturing consists of backlight guide, LCD glass, front glass color filter pattering, LCD panel and assembly of the module and eBook reader parts (Kozak 2003).

3.3.2 Electronic book reader distribution

Electronic reading devices are shipped to a warehouse after the printing phase. From the warehouse the eBook reader will be shipped to a cargo terminal before it ends up in a store that sells electronics (Kozak 2003). The end-customer has to travel to the shop to buy the eBook reader. Eboknorden and BokBasen gained the thesis with information on the distribution network for electronically books sent to consumers. Book files are saved online with the distributor and when a customer buys a book the online book file will automatically be sent to the consumers' eBook reader device.

3.3.3 Usage of electronic books

An eBook reader is a dedicated reading device for electronic books. Electronic ink makes the reading experience from an eBook reader similar as reading a conventional book (PricewaterhouseCoopers 2010). Electronic ink is more convenient to read on then on a normal LED-screen. A LED-screen makes the eyes more fatigue than the e-ink technology in eBook readers, the reason for this is the backlight in the screen. A dedicated reader for electronic books has no backlight and is easy to read on in direct sunlight. Therefore a fully charged eBook reader can last up to several weeks, depending on the frequent usage, before it has to be recharged (PricewaterhouseCoopers 2010). EBook readers have the possibility to read many books in parallel.

3.3.4 'End-of-life' phase

Electronic reading devices need to be replaced after some time. Socolof et al. (2001) describes the life of an eBook reader in two sections. The first four year of the eBook readers life the reader are effective in its full power. The last 2.5 year the eBook reader has a 45 % reduction of effectiveness. The consumer will need to buy a new reading device to keep reading the eBooks they have bought at the end of one of these periods.

4. Research questions

Creswell (2007) says that qualitative research questions are open-ended, evolving and non-directional. The research questions will restate the purpose of the study in a more specific term. Under the main research question there are two sub questions. Creswell (2007) describes sub questions as either issue questions or topical questions. An issue sub question as Creswell (2007) explains 'is that they take the phenomenon in the central research questions and break it down into subtopics for examination'. A topical sub question as Creswell (2007) explains 'cover the anticipated needs for information'. The research question in the thesis has two issue sub questions.

- Are there any decrease in emissions, energy use and environmental impacts when people choose to buy eBooks instead of conventional books?
    - What are the differences in the distribution pattern between conventional books and eBook readers?
    - What are the differences in the total CO_2e when buying either an eBook reader or a conventional book?

5. Theory

Theoretical background for the thesis is green supply chain, renewable energy and life cycle assessment. The theory part will give the reader a basic knowledge of the topics discussed in the thesis without knowing anything about the subjects from before.

5.1 Green Supply Chain

Emmet and Sood (2010) explain Green Supply Chain (GSC) as ‘considering the environmental effects of all processes of the supply chain from extraction of raw materials to the final disposal of goods’. Being ‘green’ is to consider the environmental effects the product, process or service has on the society while at the same time assuring maximized consumer satisfaction (Emmet and Sood 2010). Emmet and Sood (2010) describe GSC management as ‘fully integrate environmental considerations into traditional supply chain management’. McKinnon (2012) consider GSC as a responsibility for a firm which goes beyond its own boundaries. Business that takes environmentally consideration into their business core values wish to cooperate with other business with the same values. Some of the benefits to gain from greening the supply chain, if not for the obvious reason the environment, are decrease in costs and waste.

It is in the supply chain design where all the decisions are made that over 80 % of the carbon savings can be planned (Mangan, Lalwani and Butcher 2008). The decision on whether to use fossil fuel or renewable energy, or where to locate the warehouse and distribution centres all have a connection to the environmental impact the company will have on the environment. One example is the idea of making a delivery hub where all customers for the company can pick up their deliveries, instead of the company to distribute direct delivery for each end-customer (Mangan, Lalwani and Butcher 2008).

Green production as Emmet and Sood (2010) explains it is ‘an organisation strategy that focuses on profitability through using environmentally friendly processes’. The main task of greening the production is to make sure that the manufacturing processes reduces its emissions.

Traditional the selection of transport modes where based on two factors; cost and speed (Deutsche Post AG 2010). The increased awareness of CO_2 reduction makes sustainability a third important factor of the selection criteria. Environmental friendly packaging, transport and clean fuel are one of the main standards for green distribution (Rao 2008).

Environmental friendly packaging will be to use packaging that are biodegradable in nature and therefore will not harm the environment in any way. Rao (2008) have constructed a list that organisations have decided upon will make transportation environmental friendly:

- Use transportation vehicles that are using renewable energy as a fuel source when delivering products
- Make fewer trips for delivery by bunching the products
- Be sure to have enough energy for the trip
- Decrease the amount of emission
- Make sure the whole supply chain are using vehicles that have renewable energy as a fuel source

Minimization of carbon footprint from the supply chain is the main topic of consideration in the regulation of the environmental footprint of an organisation (Emmet and Sood 2010). This part will reduce the GHG emission in the supply chain. Energy efficiency and low energy supply play an important role in reducing the carbon footprint. Different supply chain strategies have different environmental effects, with different energy efficiency. The just-in-time (JIT) strategy for example gives frequent small loads and inefficient transport utilization, which are unsustainable from the environmental perspective (Mangan, Lalwani and Butcher 2008). Mangan, Lalwani and Butcher (2008) have made a list which improve the logistic efficiency and reduce the environmental effects:

- Decrease empty running and increase ‘backhaul’ loading
- Higher utilization of the vehicles capacity
- Optimise vehicle routing by using GPS systems
- Efficient loading of containers
- Increase awareness of optimizing vehicle driving style
- Improve operating efficiency of vehicles (fuel and wheel choice, etc.)

Greening of the supply chain has an impact on the effectiveness in the case that in reducing the waste the effectiveness will be increased at the same time (Emmet and Sood 2010). By reducing the waste the costs will also decrease. Compared to traditional supply chain going green can gain as much as 10 % increase in the firm’s profit (Emmet and Sood 2010). To be efficient a firm need all the information and data from the company to be measured, sufficient and available. Environmental data are challenging to fetch, and not always even measured in some companies. Specifications are description of the product a consumer needs. It gives standards to a specific industry and 80 % of the costs will be to follow these specifications. To be more efficient it is important to study the supply chain regular so that new updates can be taken into consideration and be able to investigate new more environmental friendly solutions. Activities and processes in the supply chain will be checked if it meets the firm's needs and specifications. By checking products and activities regularly it is easier and faster to change and improve certain processes.

5.2 Renewable energy

Renewable energy (RE) is an important source for greening of book distribution. Transportation modes can take in use renewable energy as a fuel and power source. Renewable energy is biodiesel, bioethanol, biogas, electricity, hybrid and hydrogen (Wee et al. 2012). The negative aspect of renewable energy is that it is not a constant source, because of the changing weather conditions. This is the most challenging part when it comes to distribution of RE. The reason why biodiesel and bioethanol has received great attention is that it is possible to use the fuel without modifications to the engine, or the refuelling equipment, which is in contrast to the other RE as hydrogen or electricity. Even though RE is not a new aspect it has been more popular in passenger cars then with freight vehicles (Leonardi, Browne and Allen 2012). RE has not been considered in most cases because of the missing public refuelling infrastructure. When the infrastructure is developed further the impression from experts is that the popularity of RE will increase.

The world's population are growing in a rapid speed and are forecasted to be 9 billion by 2050 and therefore the food demand will be increased by 60% (Popp et al. 2014). This has an influence with the growing expected living conditions and higher food quality for the 'less fortunate' people in the world today. The global energy supplies have increased by the doubled the last 35 years, but renewable energy as a fuel source has almost zero change and is only counting with 13 % in the total energy supply today (Popp et al. 2014).

The production of biofuel is causing negative aspects on the major land-use changes that have to be made for producing RE. It is causing damage on the biodiversity and other ecosystem resources in the world. When growing on marginal land the biodiversity are not changed. The more demand that arises for renewable energy, the bigger land is used for growing the fuel sources needed. When the demand of e.g. biofuel increases the prices will also increase. This has an impact on the prices of the whole agriculture production, which makes the prices for food increase as well. The increase in the food prices has a hard impact on the 'less fortunate' people in the world (McKinnon et al. 2010). Both industrial and developed countries have a food loss around 40 % in the supply chain. The difference between the countries are that in industrialised countries the food loss are happening in the retailer and consumer level, while the food loss in developing countries are happening after the harvesting and processing level (Popp et al. 2014). Increased production of biofuels can also mean a decrease in the availability of water, since the biofuel production is using water for production.

These indirect effects of biofuel production are generally called the indirect land-use change (ILUC) effect (Popp et al. 2014). It occurs when food crops are being used to produce additional demand on top of the existing use (Ernst & Young 2011). Indirect effects cannot be measured or observed, since the impact of one activity in one location cannot be isolated from other external effects which also can be driving the land use change (Ernst & Young 2011). In 2012 the European commission change one of the rules regarding ILUC which says that biofuels can only be produced on feedstock that do not compete with feedstock for food crops, this change is made to help decrease the negative effects of RE.

5.2.1 Biodiesel

Biodiesel is a renewable energy source which has none, or a lower, emission of CO_2 than traditional diesel. When looking closer into the whole supply chain of producing biodiesel it gives a 50 % lower emission of CO_2 than traditional diesel (Norwegian Public Roads Administration 2014a). Biodiesel is made out of biological raw materials as plant and animal oils (McKinnon, Brown and Whiteing 2012). The main source of material in biodiesel will vary from country to country since the local growing conditions changes according to location. In Europe the main material used in production of biodiesel is rapeseed (Opdal 2008).

5.2.2 Bioethanol

Bioethanol is produced by using plants that contains sugar, cellulose or starch (Norwegian Public Roads Administration 2014b). Often are bioethanol named E85 and E100 for the difference off the content of plants in the fuel compared to traditional gasoline in bioethanol. In the winter months the percentage of ethanol are lowered to around 75 % to be sure that the fuel are not freezing to ice.

5.2.3 Biogas

Biogas is made out of organic material as fertilizers, sewage and waste (ZERO 2014b). Conventional vehicle motors can be driven by using biogas in combination with traditional gasoline. Biogas is often planted locally since sewage is mostly used to produce biogas.

5.2.4 Electricity

Transportation modes which are using electricity as a fuel source only have emission from the production of the electricity (Norwegian Public Roads Administration 2014c). Electrical vehicles are using different kind of litium-ionbatteries, and make less noise than a traditional vehicle (ZERO 2014a).

5.2.5 Hybrid

Transportation that are using hybrid as a fuel source have two motors. One traditional motor for gasoline, or diesel, and one electrical motor (Norwegian Public Roads Administration 2014d). Together these two motors are the fuel source for the vehicle. The amount of electric and traditional gasoline that is being used together depends upon the usage of the vehicle (about.com 2014).

5.2.6 Hydrogen

Hydrogen is a gas when surrounded in normal temperature and pressure. This is why hydrogen is an energy carrier and not an energy source. The most common way to store hydrogen is to compress the gas to 200-700 bar and the second most common way is to cool the gas down until it gets liquid to a temperature of -253 degree Celsius (Norwegian Hydrogen Forum 2013). The negative aspect by these two production methods is that it is very energy intensive. Hydrogen can be produced from natural gas reforming, electrolysis, gasification, renewable liquid reforming or fermentation (Norwegian Hydrogen Forum. 2013). The most common method to produce hydrogen is with natural gas reforming. Natural gas reforming processes starts with using a catalyst for exposing natural gas and water steam for high temperatures from 700-1100 degree Celsius. From this process the outcome will be hydrogen and CO. The next step is to lower the temperature down to approximately 350 degree Celsius, and add more water. The outcome of the total process will be CO_2 and 4H2. The process has an efficiency of 75 % and the energy used in the process to create the heat is natural gas (Norwegian Hydrogen Forum 2014).

The main challenge when producing hydrogen is to decrease the costs for production technologies and fuel facilities in a way that hydrogen will be able to compete with the traditional fuel sources as fossil fuel. Vehicles that are using hydrogen as its fuel source do not contain any emission of CO_2, NO_X or particles (ZERO 2014c).

5.3 Life cycle assessment

A life cycle assessment (LCA) is as the United States Environmental Protection Agency (EPA) (2012) explains 'a technique to assess the environmental aspects and potential impacts associated with a product, process, or service'. This technique is performed by 'evaluating the potential environmental impacts associated with identified inputs and releases, while interpreting the results to help make more informed decisions'. Which means that in this research the decision is made upon whether the consumer buys a new hard-cover book every time he/she would like to read a novel, or buying an eBook reader one time and download books to the device every time the consumer would like to read a book. The decision is made up on the different environmental effects that arise between the two options, and the best choice will be the option which gives the least environmental impact. Benefits from performing an LCA will be that decision-makers have the right information on how to choose a product, or process, that will make the least impact on the environment. The information in the analysis can also be used in addition to cost and performance data to indicate the right selection of a product or process. The LCA can help stakeholders with information to gain their plan, so it will be accepted. Environmental areas of concern can be identified after the findings of the environmental impacts in an LCA.

The life cycle inventory (LCI) investigated in the analysis are greenhouse gases, which has it impact category on global warming potential (Curran 2012). LCI gives 'information about the inputs from the environment to the studied system and the outputs to the environment from the system' (Pihkola et al. 2010).

5.4 Summary

The main points from the theory section have been concluded in table 1. The base from each chapter in the theory which will be taken forward in the thesis has been listed behind the name of the theory topic.

Theory	*Base for the research*
Green Supply Chain	Being 'green' is to consider the environmental effects the distribution has on the society while at the same time assuring maximized consumer satisfaction. Benefits to gain from greening the supply chain, if not for the obvious reason the environment, are decrease in cost and waste.
Renewable energy	Transportation modes can take in use renewable energy as fuel and power sources as; biodiesel, bioethanol, biogas, electricity, hybrid and hydrogen. Some negative aspect of renewable energy is that it is not a constant source, because of the changing weather conditions, and it is causing negative damage to the biodiversity and other ecosystem resources in the world, because of the major land-use changes that have to be made for producing RE.
Life cycle assessment	An LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service. In this research the decision is made upon whether the consumer buys a new hard-cover book every time he/she would like to read a novel, or buying an eBook reader one time and download books to the device every time the consumer would like to read a book. The decision is made up on the different environmental effects that arise between the two options. The best choice is the option which gives the least environmental impact.

Table 1: Main points from the theory section. Source: Own illustration.

6. Literature review

This study has been focusing on finding similar and comparable studies of the research problem for the research. Literature has been searched and different articles, books and previous master thesis have been helpful for the outcome of the thesis. Especially the literatures mentioned below have been in great favor for the thesis.

McKinnon, Brown and Whiteing (2012) have been a great source for the outcome of the thesis. It has given a valuable insight into the different emissions from freight transport, and different calculation tools for the analysis of different transport modes. The analytical framework for green logistics in this book has closely been looked deeper into. The book shows strengths in greening of freight transport and especially for the environmental consequences regarding logistic operations. The book was helpful to understand and investigate the analytical framework for green logistics.

Kozak (2003) has been investigating the life cycle of printed and electronic scholarly book options. Valuable insight into how conventional and electronic book systems works have been described in this master's degree thesis. The thesis analyses real-life numbers and data for emission from both conventional book printing and eBook reader manufacturing.

Printers' National Environmental Assistance Center (PNEAC) is a collaboration between industries, government and technical universities in the United Stated, North America and the world. The partnership provides environmental and pollution information to printers, publishers and packagers. PNEAC (2014) have gained the thesis basic knowledge about the printing process for conventional books, especially for offset lithographic. The many fact sheets published by PNEAC have helped with information on calculation methods and theory for emissions from printing of conventional books.

EPA (2014) is the United States Environmental Protection Agency, which work to help the environment and the human health. Deeper knowledge into the different emissions and environmental issues has been investigated with help from information and reports from EPAs homepage on the internet.

The Network for Transport and Environment (NTM 2014) is a Swedish non-profit organisation which works to establish a common database and calculations for the environmental performance values for different transport modes. NTM has given the author of the thesis temporarily log in information to the professional travel and freight calculator established, to be able to find the emissions regarding the five different transport modes used in the distribution stage in the analysis. The report from this calculator has been used as a basis for the calculations in the distribution stage in the LCA performed in chapter 12.

The main points from the literature review have been concluded in table 2. The base from each literature which will be taken forward in the thesis has been listed behind the name of the literature.

Literature	*Base for the research*
McKinnon, Brown and Whiteing (2012)	Gives general emission outcome form different transport modes. Analytical framework is used as a base for this thesis.
Kozak (2003)	Previous study which this thesis will use the emission values from the production of eBook readers from.
Printers' National Environmental Assistance Center	Factsheets used in theory review and the analysis.
United States Environmental Protection Agency	Some of GWP values for different emissions in the analysis are taken from their internet page.
The Network for Transport and Environment	The professional freight calculator designed by NTM is used in the analysis for calculating the emission regarding distribution of both conventional books and eBook readers.

Table 2: Main points from the literature review. Source: Own illustration.

7. Customer Demand

In 2012, 19 million conventional books were sold in Norway. Over 5.3 million of these books where fiction books. Altogether, 207,379 eBooks where sold in 2013, where 715 where fiction eBooks (The Norwegian Publishers Association 2013a). These numbers indicates that the book market is still strong, but that the eBook market has still a way to go.

Factors that affect the demand of books are price, leisure time, seasonality, popularity of the book and availability. Easter and summer vacations are two popular seasons to read books because of time available and personal traditions. The popularity of one book, or an author, also increases the book sales in particular periods.

7.1 Future demand for electronic books

The European, and especially the Norwegian, e-book market are still in an initial stage. Consumers have still not recognised the major benefits of buying electronic books instead of conventional books (PricewaterhouseCoopers 2010). One of the advantages the consumers in the USA have, that Norwegian consumers do not have, is that they are offered eBooks with decreased prices compared to conventional books. PricewaterhouseCoopers (2010) has researched what experts anticipate about the future of eBooks. The report from the research show that all experts agree on the fact that eBooks and conventional books will co-exist together, but most experts tend to believe that eBooks will extinct the paperbacks in the future.

In 2012 there were 3,500 books in the Norwegian fiction eBook market, which is more than three times more than in 2011 (The Norwegian Publishers Association 2013a). A survey held by the Norwegian Booksellers Association (2013) shows that only 5 % bought an eBook the last time the person bought a book. EBook readers had a peak in 2011 with 23.3 million units sold in the global market. Predictions show that in 2016 the sale will be 66% less than its peak top in 2011, by 7.1 million units sold (IHS Technology 2012).

Borrowing eBooks from the public libraries can make the eBook more popular. The Norwegian publishers association published in early 2013 (b) that the Norwegian book market will have the opportunity to borrow eBooks from public libraries as soon as the technology are there. A trial period which goes to the end of 2015 will give the Norwegian citizens a chance to try the new concept. From June 2014 the citizens in Molde municipality will have the opportunity to start the trial period of borrowing eBooks through their local library (Møre og Romsdal Fylkesbibliotek 2014).

7.2 Forecast for electronic books until 2015

Forecasting is a method used to see further trends by using past experience (Chapman 2006). In this research it will be used a time series method for the forecast, since time series is a collection of observations made at a point in time (Nahmias 2009). By using this forecast method it is assumed that the past demand will follow the same pattern in the future (Chapman 2006). The demand data available for fiction eBooks contains trend, which means that the data available are having a tendency to make a pattern over time. In this research it is a curvilinear trend in the demand, which gives an exponential curve. Figure 2 is displaying the time series pattern for fiction eBooks from 2005-2012, which illustrates a nonlinear increasing trend.

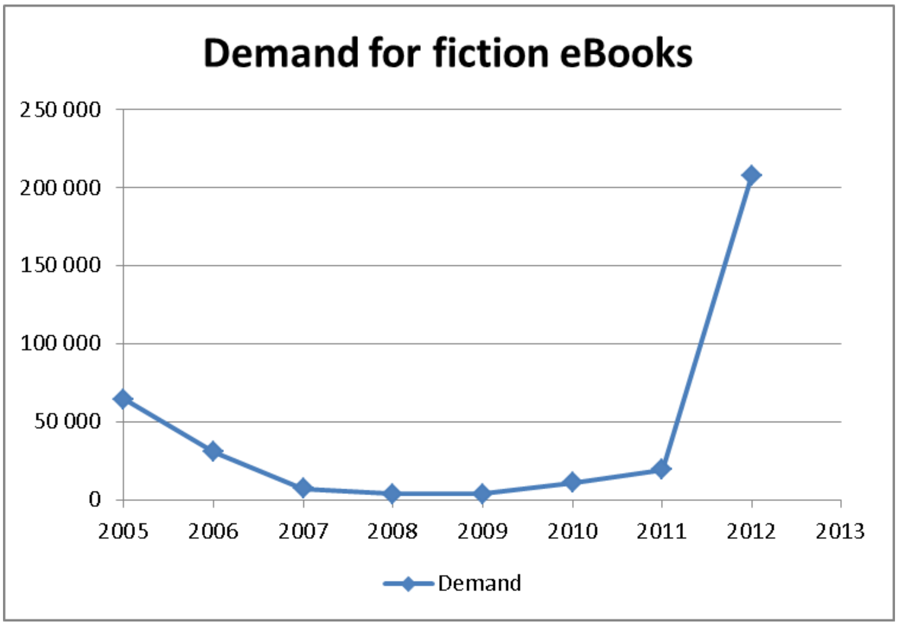

Figure 2: Time series pattern for eBooks from 2005-2012. Source: Own illustration based on the Norwegian Publishers Association 2012 & 2013a

The forecasting method used in this thesis will be regression analysis. Regression analysis is used when the demand pattern is non-linear and contains a trend (Nahmias 2009). It is assumed that a straight line can be represented by the equation (Nahmias 2009): $\hat{Y} = a + bX$. It is necessary to find the values of a and b to forecast the future demand. The values for a and b are found by using the two equations (Nahmias 2009): $b = \frac{S_{xy}}{S_{xx}}$ and $a = \bar{D} - b(n+1)/2$, where $S_{xy} = n\sum_{i=1}^{n} iD_i - \frac{n(n+1)}{2}\sum_{i=1}^{n} Di$,

$S_{xx} = \frac{n^2(n+1)(2n+1)}{6} - \frac{n^2(n+1)^2}{4}$, and $\overline{D}$is the arithmetic average of the observed demands during periods 1,2,…,n.

The excel sheet with the calculations for the forecast are added in appendix A.

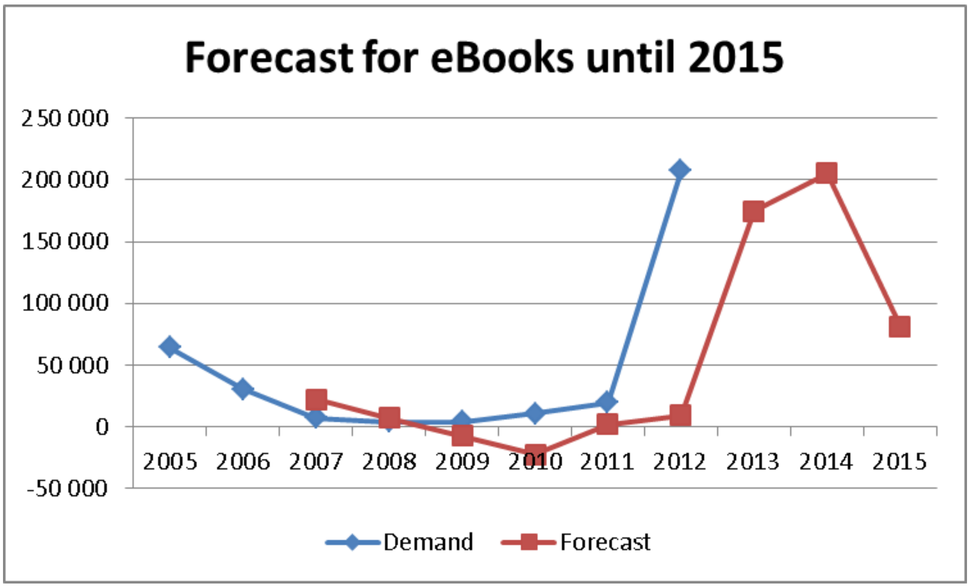

Figure 3: Forecast for fiction eBooks until 2015. Source: Own illustration based on The Norwegian Publishers Association 2012 & 2013a.

Figure 3 shows that the forecast will interpret a slightly increase in sold copies of eBooks this year, and in 2015 the eBook demand will decrease. The forecast for 2012 had an error of 198.043. The huge error indicates that the actual sales for the years to come could in real life be quite different then the forecast is predicting. Since the demand for 2013 are not yet available the forecast method used in this example do not contain the all the latest data. The forecast could be less accurate from year 2014 and on since real-life demand data are not available for the all years used in the calculation for the forecast method.

7.3 Product life cycle for electronic books

By researching the product electronic book it has been discovered which segment the electronic books are situated in the Norwegian eBook market. All products have different segments they go through during their life cycle. The products life cycle is divided into four segments; start-up, rapid growth, maturation and stabilization or decline (Nahmias 2009). The different segments stand for various stages in the life cycle for the product. The first segment is the start-up phase for a product. This is where the product is launched in the market and where the product is introduced for the consumers for the first time. The second segment is where the product is in a rapid growth period. This is where the consumers are getting familiar with the product and start to get familiar with it. The annual sales volumes are growing in a rapid speed over time. The third segment is the maturation phase. At this point the product is facing a period where it is important to keep the customers interested in the product. The fourth segment depends upon the previous segment. The two options that are facing the product is either stabilization or decline. If the product has managed to keep the consumers interest in the product it will be stabilized in the market. If the product lost the consumers interest this is the time where the product will have a decline in the market.

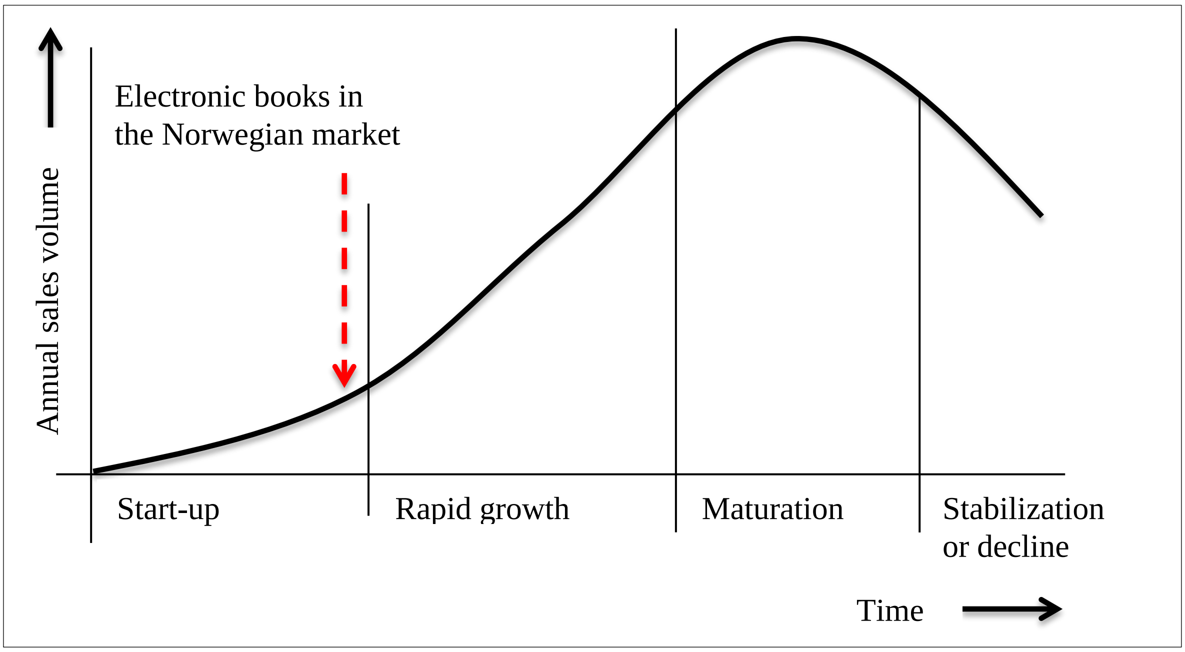

Figure 4: Product life cycle curve for electronic books. Source: Own illustration based on Nahmias 2006.

After researching the Norwegian eBook market for information about electronic books it can be seen that electronic books are in the late start-up phase in the market. By looking at the demand in chapter 7.2 it can be seen that the consumers bought 90.7 % more fiction eBooks in 2012 than in 2011. This indicates a growth from 2011 to 2012. If the annual sale of eBooks continues to increase with the same speed and popularity with the consumers the Norwegian eBook market for fiction books will soon be in the phase 'rapid growth'.

8. Energy consumption

The energy consumption from each activity in the supply chain of both book options will be stated in this chapter. In chapter 11 the data collected will be analysed.

8.1 Environmental effects from production

The production stage consists of different emissions regarding the two book options.

8.1.1 Emission from Offset Lithography printing process

Volatile organic compounds (VOC) and hazard air pollutants (HAP) are the main emission from offset lithography, which are the printing method used for hard cover books. VOC contains of chemicals that make ozone in the lower atmosphere (Jones 2004). HAP is a group of 188 toxic chemicals that have a high negative impact on the environment. The material in the printing process that emits VOC and HAP are fountain solution, cleaning solvents, ink oils, coatings and adhesives (Jones 2004).

8.1.2 Emission from production of eBook reader device

In this study it will be focusing only on the main device and therefore not the manufacturing of the battery or the cabling for the eBook reading device. Emission from the production of eBook readers consists of production of glass-, backlight- and panel component manufacturing, and the assembly of the parts.

8.2 Environmental effects from distribution

Emissions from the distribution phase consist of greenhouse gases (GHG). There exist 27 different GHGs and these are again divided into six different categories by the United Nations in 1997 (McKinnon, Brown and Whiteing 2012). The different categories are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_x), hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF_6). All the 27 different GHGs have different global warming potential (GWP). GHG emissions can be converted into CO_2e by multiplying their GWP value to the number GHG emitted (Pihkola et al. 2010).

The transport sector accounted for 13 % of all global GHG emissions in 2004, which mostly comes from the energy consumption of fossil fuels (EPA 2013).

8.2.1 Emission from train

The emissions from train depend upon the fuel used. Bring Logistics are using both electrical and diesel train to transport their goods from Oslo to Molde. Diesel engines are more energy efficient then petrol overall and therefore emits less CO_2 in the long run, but diesel emits more CO_2 per unit of energy then a petrol engine (McKinnon, Brown and Whiteing 2012). Table 3 displays the average emission factors for train within Europe. The amount of emission, from diesel and electrical train, is listed behind each emission factor in the first column.

Train	*Diesel*	*Electric*
Energy consumption (kJ/tkm)	530	456
CO_2 (g/tkm)	35	18
NO_X (mg/tkm)	549	32
SO_2 (mg/tkm)	44	64
CO_2e (g/tkm)	47	0,5

Table 3: Average emission factors for train. Source: McKinnon, Brown and Whiteing 2012.

8.2.2 Emission from HGV

The emission from HGV also depend upon the fuel used (McKinnon, Brown and Whiteing 2012). HGVs driven by Bring Logistics are using traditional diesel in their vehicles and are Euro 5 HGVs. Table 4 displays the average emission factors for HGV within Europe. The amount of emission, for Euro 1-5, is listed behind each emission factor in the first column.

HGV > 34-40-t	*Euro 1*	*Euro 2*	*Euro 3*	*Euro 4*	*Euro 5*
Energy consumption (kJ/tkm)	1,086	1,044	1,082	1,050	996
CO_2 (g/tkm)	72	69	72	70	66
NO_X (mg/tkm)	683	755	553	353	205
SO_2 (mg/tkm)	-	-	90	-	-

Table 4: Average emission factors for HGV. Source: McKinnon, Brown and Whiteing 2012.

8.2.3 Emission from LGV

The emission from LGV depends upon the fuel used. Table 5 displays the emission factors for LGV driven with diesel. The amount of emission, for LGV, is listed behind each emission factor in the first column and is taken from NTMs data. The report displaying NTMs data are listed in appendix B.

Emission	*LGV <3.5 ton (Euro 3)*
Energy consumption (kJ/tkm)	-
CO_2 (g/tkm)	59
NO_X (mg/tkm)	50
SO_2 (mg/tkm)	0

Table 5: Average emission factors for LGV. Source: The Network for Transport and Environment [NTM] 2014b.

8.2.4 Emission from aircraft

Table 6 displays the average emission factors for aircraft within Europe. The amount of emission, for aircraft, is listed behind each emission factor in the first column.

Emission	*Aircraft*
Energy consumption (kJ/tkm)	9,876
CO_2 (g/tkm)	656
NO_X (mg/tkm)	3.253
SO_2 (mg/tkm)	864

Table 6: Average emission factors for aircraft. Source: McKinnon, Brown and Whiteing 2012.

8.3 Environmental effects from the user phase

Reading an electronic book and reading a conventional book gives different environmental effects regarding emission factors. Conventional book reading in daylight give zero emission to the environment. Reading an electronic book gives emission regarding the electricity used.

8.3.1 Emission from reading electronic books

Electronic books are read on an eBook reader. The eBook reader use electricity every time it has to be recharged. The reader does not need to be charged more than once a month (Amazon 2014). The eBook reader use battery every time it turns the page, but do not use any battery when the consumer is reading the page.

8.3.2 Emission from reading conventional books

There is zero emission regarding reading of conventional books.

8.4 Environmental effects from 'end-of-life'

The 'end-of-life' phase is assumed in this research to have zero emission for both eBook reading devices and for conventional books. This is because of limitations regarding time and data availability.

8.4.1 Emission from 'end-of-life' for electronic book readers

As mentioned earlier the eBook reader will need to be replaced after four years to keep running 100 %, or at least after 6.5 years with the last two and a half years working in a 45 % reduction of effectiveness. Because of limitations to the studies the waste of the eBook reader will not be investigated, and it will be assumed that the eBook readers' life-cycle will start over again after approximately four years.

8.4.2 Emission from 'end-of-life' for conventional books

Conventional books will survive as long as the consumer wants to keep the book. As mentioned earlier a conventional book can last up to 400 years. Therefore it is zero emission regarding this phase.

9. Research Model

The research model illustrates the pattern for green supply chain in this research. The arrows in the model indicate the way the pattern follows. The dotted lines have indirect effects on green supply chain, while the linear lines have direct effect on the green supply chain. The boxes are factors in GSC.

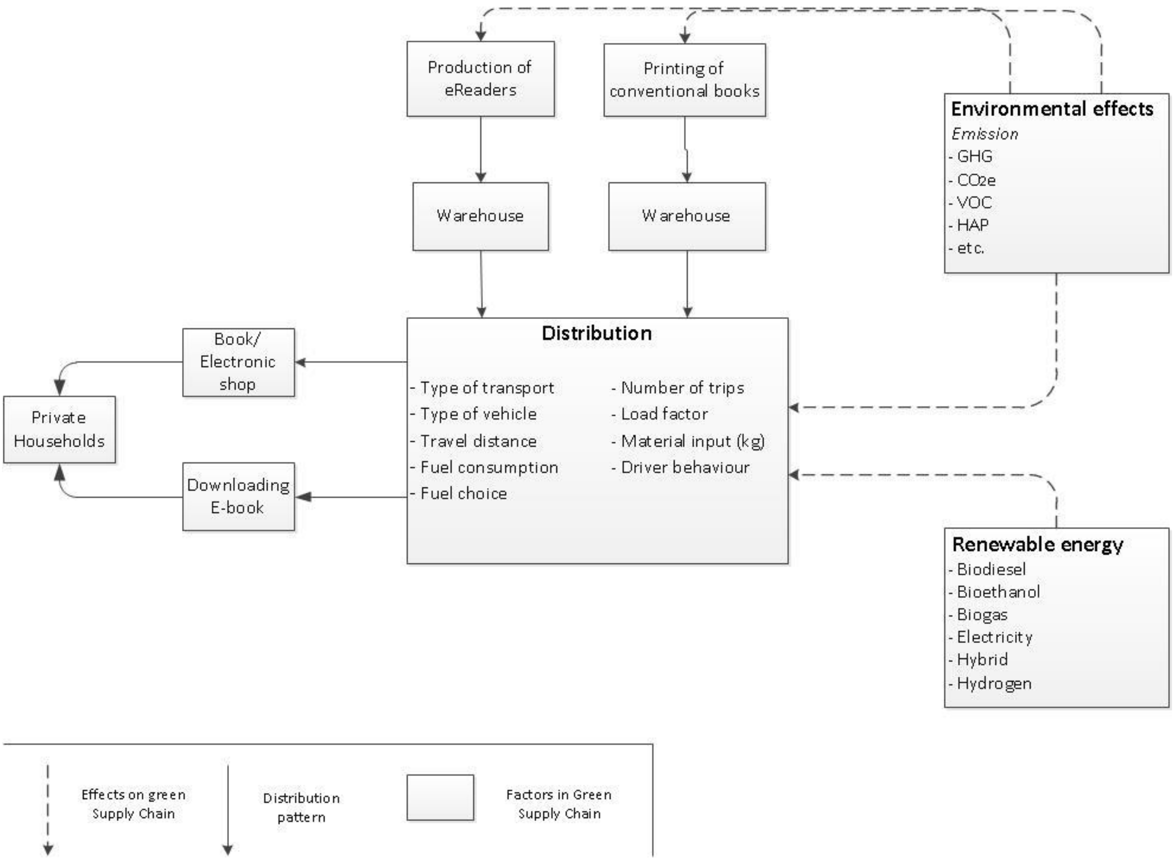

Figure 5: Research Model, Green SC. Source: Own illustration.

Production of eBook readers and printing of conventional books are the first aspect in the supply chain that will be investigated in this research. The next phase is transportation to the warehouse, before the products are distributed to book shops and electronic shops. In this model the consumer choose to buy the conventional book through a physical bookshop, and the eBook reader through a shop that sells electronics. An electronic book is bought online and is downloaded directly to the eBook reader device. The distribution contains of numerous of different parameters that can be measured. Reducing emissions from the distribution phase is the main contribution to decrease the negative environmental effects regarding GSC. Changing from fossil fuel to renewable energy will help decrease the emission from the distribution phase.

The research problem will be analysed through description of cases and literature.

Measurement parameters that effect the energy consumption of book distribution are listed below:

- Type of transport
- Type of vehicle
- Travel distance
- Fuel consumption
- Fuel choice
- Load factor
- Material inputs (kg)
- Driver behaviour

The choice between the types of transport to choose depends upon the products weight and distance to travel. The transport modes to choose from would be between road, sea, air and rail. Type of vehicle has an impact on the energy consumption since the choice between different types of vehicles is different. It could be, for example, to choose between light and heavy truck. These two trucks will influence the environmental impacts differently. Travelling long or short distances have an impact on lead time and which transport modes that are chosen. In fuel consumption lays the decision upon which fuel to choose for the transportation mode. The fuel choice stands between fossil fuel and renewable energy. Driver behaviour can change the indirect impact the transport has on the distribution of the products. It will be positive for the environment when the driver of the vehicle drives economic and environmental friendly. Load factor influence how many products that can be transported in one trip. Material input depends upon the weight of the products transported, and how many products that can be transported in one trip depending on the load factor for the transportation mode chosen.

10. Method

The study of conventional and electronic books started in different stages through the semester. The first step was to collect data needed for the analysis and the discussion in the thesis. Two different publishers, 20 printing offices and one research institute where contacted to collect data from the printing process for conventional books. After no success in getting the data needed from the companies contacted the data was collected from the literature.

One firm where contacted to collect information about the distribution of the two products. A meeting was arranged and data needed for the thesis was collected from Bring logistics department Molde. Since no firms in Norway manufactures eBook readers the main focus was to collect data from manufacturers of eBook readers from the most popular eBook readers as Amazons Kindle, Barnes & Noble's Nook and Sony's dedicated reading device. Both Amazon and Barnes & Noble would not release the information needed, since the information requested where proprietary. Sony representative for the European market sent many emails around in the system, and all the way to Tokyo where they manufacture their eBook reader, but in the end did not either end up with any data available for sharing.

To be able to research and write a thesis in five months, restrictions and limitations has to be set. The thesis is focusing on the purchase of fiction books in the Molde region, Norway. The stages researched in the LCA are production, distribution and usage. The 'end-of-life' stage are informed about, but not analysed because of time limitations. The same goes for the raw material stage before the production stage. An assumption is set that books are read in daylight, so no electricity from lamps will be taken into consideration. Theory and literature where searched for and written through the whole semester.

Harrison and Van Hoek (2011) has designed an cost-time profile (CTP) which uses cost information in conjunction with time information that will show if activities in an supply chain creates value or waste. This information is set into a graph to be able to visualize the profile of the information gathered. The lines in the graph visualize how cost and time work together in each activity. Long and horizontal lines means that the activity is using more time then costs in this particular activity. By focusing on these lines a reduction in time can be achieved. Steep and vertical lines means that the activity is using more cost then time in this particular activity. By focusing on these lines a reduction in costs can be achieved. A CTP can be used to prioritize which activities that need improvements in a supply chain.

By switching the cost information in a CTP with the energy use information collected for each activity the profile will be changed into this thesis preference as an energy use-time profile. By doing so the profile will show where the energy use occur in comparison to the time used in both supply chains for conventional and electronic books. In this way it can be observed where the energy use takes up more time then desired, and improvements to the supply chain can be suggested after performing the energy use-time profile on both book options.

11. Data description

The Norwegian publishing firms Gyldendal, Schibstedforlag and Aschehoug where contacted for collection of data for emission in the printing process for conventional books. None of the publishing firms could contribute with any data requested. The printing firm 07 Media that print the books for Aschehoug where contacted, but they did not measure the emission regarding their production. Altogether 19 more printing firms where contacted to try to collect data for the emission regarding the printing process. None of those firms where able to help out either. The research facility Østfoldforskning where contacted for the last chance to collect newer emission data. They did not answer, even with multiple e-mails both to the reception and the CEO. Because of limited data availability and no luck in contributions from businesses the emission data from the printing process where in the end taken from a previous study done by the state of Utah. The data in the study has been customized for this master’s degree thesis purpose.

For production of eBook readers Amazon for Kindle, Barnes & Noble for Nook, E Ink holdings and Sony where contacted to support the thesis with information about emissions and the manufacturing process of dedicated reading devices for electronic books. Amazon and Barnes & Noble will not release the information needed for the analysis since the information requested are proprietary. E Ink holdings never answered the request, with several follow-up email form the authors side. Sony sent the e-mail around in the system, but in the end didn’t have the data needed for the analysis in the thesis. Therefore data regarding the manufacturing of electronic reading devices are taken from a previous master’s degree thesis researched by Kozak (2003).

Different book distribution firms have been contacted for collection of data needed to compare the measurement parameters from section 8.1. The two biggest distribution firms for books in Norway are Forlagssentralen and Sentraldistribusjon. Research discovered that both firms are using the logistic company Bring to deliver their books to bookshops through Norway. Therefor Bring logistics department Molde will be the data source regarding conventional book distribution. NTMs (2014) professional freight calculator have been used to fetch the exact number of emission from distribution of both options, since Bring don’t measure these data themselves.

12. Analysis

McKinnon, Brown and Whiteing (2012) have designed an analytical framework for green logistics. The framework shows the complex relationship between the different parameters in green logistics and how they relate to each other. It gives an insight into the environmental effects that follows certain logistic activities.

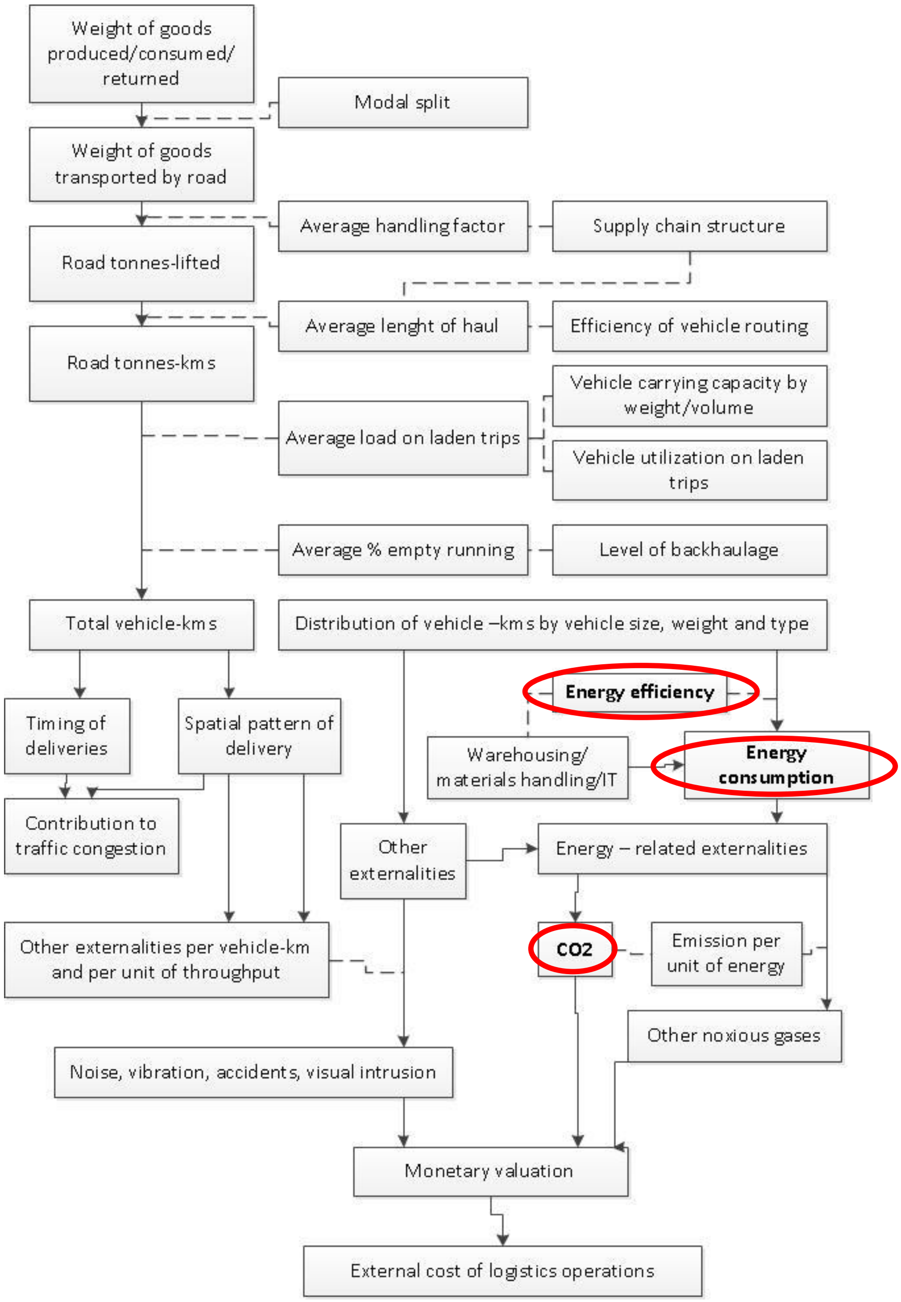

Figure 6: Analytical framework for Green Logistics. Source: McKinnon, Brown and Whiteing 2012.

The thesis is focusing on the key parameter 'energy efficiency' which aggregates the parameter 'energy consumption'. Energy efficiency are the ratio of distance travelled to energy consumed (McKinnon, Brown and Whiteing 2012). The parameter ‘CO_2’ are important for this thesis since the conclusion is based on the total CO_2e compared between the two book options.

The input data in the LCA include printing of conventional books, manufacturing of eBook readers, distribution and usage of both products. The output data includes emissions regarding these activities. The total CO_2e are calculated for one book and for one eBook reader to be able to compare the two book options.

Assumptions are made that one average book weights approximately 500 gram, has hard cover, is sewn and consist of 64,500 words (Moran 2012). Average reading time for a conventional book is 200-250 words per minute. This research will use 250 words per minute as the baseline. Previous research shows that reading from an eBook reader takes 30 % more time to read then reading from a conventional book (Kozak 2003). By taking 30 % of 250 words, this research assumes one person reading an eBook reads 175 words per minute. It is also assumed that an eBook reader weight approximately 0.176 kg. These assumptions will follow the LCA in the different phases.

12.1 Conventional book

The four stages that will be analysed in this research for the product life cycle for conventional books are set as figure 7.

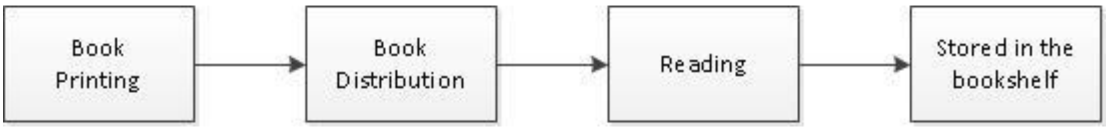

Figure 7: Product life cycle for conventional books. Source: Own illustration.

The first stage is the printing process of hard-cover books. It starts when all raw materials have entered the production facility and the facility is ready to produce the book. When the hard-cover book is finished produced the next stage, distribution of the book, will start. This activity is where the book is transported from the production facility to the company’s warehouse facility. Before it will be distributed to the cargo terminal in Molde, and again transported to the book shop that will sell the conventional book. The usage stage starts when a consumer has bought the book in the store and takes possession of it. The hard-cover book will normally be stored in a bookshelf until a new person wants to read the book.

12.1.1 Printing of conventional books

Offset lithography contains mainly of emission as VOCs and HAPs (NPi 1998). In table 7 and 8 the emission from the printing process are listed. In the second column the amount of emission from each emission factor are listed, and the GWP value for each emission factor are listed in column three. The last column displays the CO_2e for each emission factor. The following formula is used to convert all GHG emission to CO_2e (Jones, 2011) [1]: $CO2e = GHG \times GWP$.

VOC	*Amount (t/year)*	*GWP*	*CO_2e (kg)*
Ink emission	0.07	n/a[2]	n/a
Coating (HCFC-141b)	1.21	725	877.25
Fountain solutions	3.10	n/a	n/a
Wash solutions (HFE-347pcf2) Naphthalene	3.30	580	1,914
Total	-	-	**2,791.25**

Table 7: VOC emission from Offset Printing. Source: State of Utah 2002 and federal register online 2012.

HAP (Fountain solutions)	*Amount (t/year)*	*GWP*	*CO_2e*
Ethylene glycol ($C_2H_6O_2$)	0.24	0	0
Total	-	-	**0**

Table 8: HAP emission from Offset Printing. Source: State of Utah 2002 and Agency for Toxic Substances and Disease Registry 2013.

Since the emission factors from the table 7 and 8 are t/year the emissions needs to be divided by the number of days in one year, and then converted from ton to kilograms. One book is assumed to weight 0.5 kg. Offset printing has a printing speed of 20,000 pages an hour (RGB Design 2013), which means that the printer prints 40 books an hour. With a working day of 8 hours it will be printed 320 books each day.

$$VOC = \frac{7{,}015.73}{365} = 7.65\,\frac{t}{day} = 7{,}647.26\,\frac{kg}{day} = \frac{19{,}221.18}{320\ books} = 23.90$$

[1] This formula will follow for all calculations for the CO_2e.
[2] States n/a since no source has reported the GWP value for the given emission source. This will follow for all n/a.

$$HAP = \frac{0}{365} = 0\frac{t}{day} = 0\frac{kg}{day} = \frac{0}{320\ books} = 0$$

Total emissions from the printing stage of conventional books:

$$CO2e = VOC + HAP$$

$$CO2e = 23.90 + 0 = 23.90$$

Printing of one conventional book contains of 23.90 CO_2e, and contributes with 91.12 % to the total emission of the life cycle for conventional reading.

12.1.2 Distribution network for conventional book distribution

Bring logistics distribution network from Oslo to Molde consists of six nodes. Starting by picking up books from the production facility in Oslo, distributing the books to Brings cargo center at Alnabru, before the books are transported with electrical train to Dombås and from there shifted over to diesel train to Åndalsnes. HGV will transport the books to Brings cargo center at Årødalen where they will be distributed with LGV to bookshops in the Molde area.

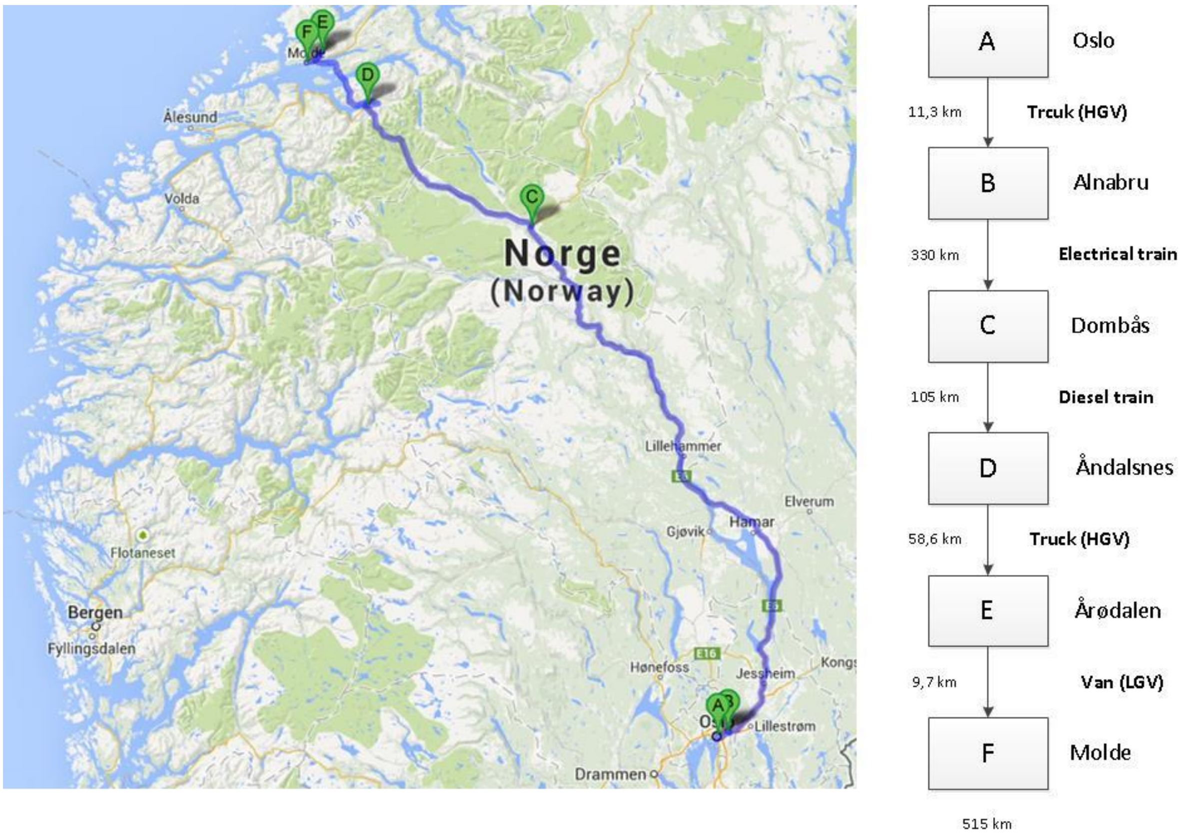

Figure 8: Distribution network; conventional books. Source: Own illustration based on Google 2014.

The analytical framework for conventional book distribution gives a systematic overview over the data collected. In table 9 the different data used in the research are presented in the second column.

Analytical framework	Conventional book distribution
Weight of goods transported	1 book = 0.5 kg
Modal split	HGV, train and LGV
Road tonnes-kms	515 km

Table 9: Conventional book distribution data. Source: Own illustration.

Table 10 displays the transportation and mode selection in the distribution stage for conventional books. The first column displays the origin of the transportation mode. The second column displays the destination of the transport mode displayed in third column. The fourth column displays the distance each transport mode travels during the distribution phase for conventional books.

Transport from	Transport to	Mode selection	Distance (km)
Printing	Warehouse	HGV	11.3
Warehouse	Cargo center	Electrical train	330
		Diesel train	105
		HGV	58.6
Cargo center	Book shop	LGV	9.7

Table 10: Transportation in distribution of conventional books. Source: Own illustration.

The values for emission in table 11, 12, 13, 14, 15, 20 and 21 are exported from the NTM professional freight calculator (2014). Both in the distribution phase for conventional books and for eBook readers there is a slightly difference between the total CO_2e from the calculator and the calculations made in the thesis. This difference could for example be that the calculator could be using other GWP values for the different emissions, or different equations when calculating the total emission. The report from NTMs professional calculator for conventional book distribution is attached at the end of the thesis in appendix C.

Emissions from HGV with trailer, 34-40 t, are listed in table 11. The first column displays the different emissions that are related to HGV transportation. In the second column the amount of emission from each emission factor are listed, and the GWP value for each emission factor are listed in column three. The last column displays the CO_2e for each emission factor, which is a result of the equation between the GWP value and the amount of emission from each factor[3].

HGV Emission	*Amount*	*GWP*	*CO_2e (kg)*
Carbon dioxide (CO_2) (kg)	72.11	1	72.11
Nitrous dioxide (N_2O) (g)	5.489	310	1.70
Nitrogen oxides (NO_x) (g)	202.7	0	0
Carbon monoxide (CO) (g)	130.8	1.9	0.25
Methane (CH_4) (g)	66.87	21	1.40
Particulate matter (PM) (g)	2.91	n/a	n/a
Sulfur dioxide (SO_2) (g)	36.06	n/a	n/a
Hydrocarbons (HC) (g)	74.16	n/a	n/a
Total	-	-	**75.46**

Table 11: Emission from HGV. Source: NTM 2014b, Intergovernmental Panel on Climate Change [IPCC] 2007a, IPCC 2007b, Harvey 1993. This reference is also valid for table 12, 13, 14, 15 and 21.

The NTM professional freight calculator reports 72.27 kg CO_2e from the HGV transportation, while the calculation shows 75.46 CO_2e. The error here is 3.19.

Emissions from electrical train distribution are listed in table 12 below.

Train (el) Emission	*Amount*	*GWP*	*CO_2e (kg)*
Carbon dioxide (CO_2) (kg)	3,319	1	3,319
Nitrous dioxide (N_2O) (g)	0	310	0
Nitrogen oxides (NO_x) (g)	6,223	0	0

[3] The same description for the table will follow for table 12, 13, 14, 15, 16, 17, 20 and 21.

Carbon monoxide (CO) (g)	1,320	1.9	2.51
Methane (CH_4) (g)	6,412	21	134.65
Particulate matter (PM) (g)	75.44	n/a	n/a
Sulfur dioxide (SO_2) (g)	19,110	n/a	n/a
Hydrocarbons (HC) (g)	23.26	n/a	n/a
Electricity (kWh)	6,286	-	-
Total	-	-	**3,456.16**

Table 12: Emission from electrical train.

The calculator reports 3,479 kg CO_2e from the electrical train transportation, while the calculation shows 3,456.16CO_2e. The error here is 22.84.

Emissions from diesel train distribution are listed in table 13 below.

Train (d) Emission	*Amount*	*GWP*	*CO_2e (kg)*
Carbon dioxide (CO_2) (kg)	1,090	1	1,090
Nitrous dioxide (N_2O) (g)	15.94	310	4.94
Nitrogen oxides (NO_x) (g)	20,140	0	0
Carbon monoxide (CO) (g)	5,789	1.9	10.99
Methane (CH_4) (g)	1,113	21	23.37
Particulate matter (PM) (g)	397.2	n/a	n/a
Sulfur dioxide (SO_2) (g)	615.5	n/a	n/a
Hydrocarbons (HC) (g)	2,702	n/a	n/a
Total	-	-	**1,129.3**

Table 13: Emission from diesel train.

The calculator reports 1,123 kg CO_2e from the diesel train transportation, while the calculation shows 1,129.3 CO_2e. The error here is 6.3.

Emissions from LGV (diesel) distribution (t/km) are listed in table 14 below.

LGV Emission	*Amount*	*GWP*	*CO_2e (kg)*
Carbon dioxide (CO_2) (kg)	2.38	1	2.38
Nitrous dioxide (N_2O) (g)	0.08	310	0.02
Nitrogen oxides (NO_x) (g)	8.66	0	0
Carbon monoxide (CO) (g)	0.41	1.9	0.00
Methane (CH_4) (g)	2.21	21	0,05
Particulate matter (PM) (g)	0.29	n/a	n/a
Sulfur dioxide (SO_2) (g)	1.19	n/a	n/a
Hydrocarbons (HC) (g)	2.46	n/a	n/a
Total		-	**2,45**

Table 14: Emission from LGV.

The calculator reports 2.36 kg CO_2e from the LGV transportation, while the calculation shows 2.45 CO_2e. The error here is 0.09.

Since the emission factors from the tables above are t/km the emission needs to be divided by the number of kg each book weights. One book is assumed to weight 0.5 kg.

$$1\ \frac{t}{km} = 1000\,\frac{kg}{km}$$

Total emissions from the distribution stage for conventional books:

$$CO2e = Truck + electrical\ train + diesel\ train + van =$$

$$CO2e = 75.46 + 3{,}456.16 + 1{,}129.3 + 2.45 = 4{,}663.37$$

$$\frac{4{,}663.37}{1000} = \frac{4.66}{2} = 2.33$$

Distribution of one conventional book has 2.33 CO_2e, and contributes with 8.88 % to the total emission of the life cycle for conventional reading.

12.1.3 Usage of conventional books

The usage of conventional books has zero emission related to the reading. This section is therefore cleared from the analysis.

12.1.4 'End-of-life' for conventional books

The 'end-of-life' phase for conventional books has zero emission since the book is stored in a bookshelf when it is reading of the book is completed. This section is therefore cleared from the analysis.

12.2 Electronic books

The four stages that will be analysed in this thesis for the product life cycle for electronic books are set as figure 9 below.

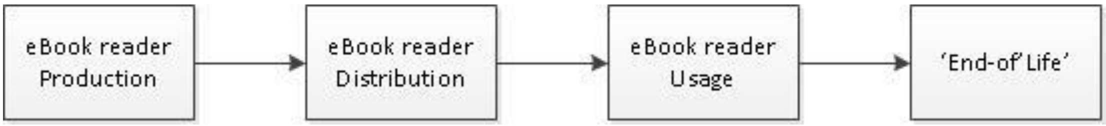

Figure 9: Product life cycle for electronic book. Source: Own illustration.

The first stage is the production of eBook readers, and starts when all raw materials has entered the production facility and are ready to manufacture the eBook reader. When the eBook reader is finished produced the next stage, distribution of the eBook reader, will start. This is where the product are transported to the company's warehouse facility before it is transported to the cargo terminal in Molde, and from there transported to the shop that will sell the eBook reader. The usage stage starts when a consumer has bought the eBook reader in the store and takes possession of it. The 'end-of-life' stage starts when the consumer decides that the eBook reader is no longer efficient and is no longer in use at home, which normally will be after a four years period.

12.2.1 Production of electronic book readers

Data information for the production of electronic reading devices is taken from the literature, since no firms were willing to give information to the thesis. Only the manufacturing of the eBook reader itself is considered in the analysis because of time limitations. Manufacturing of the lithium-ion battery and cabling are therefore left out of the research.

The production of dedicated reading devices for electronic books consists of emissions as listed in table 15, 16, 17, 18 and 19.

Glass Emission	*Amount*	*GWP*	*CO_2e (kg)*
Carbon dioxide (CO_2)	1.30e-01	1	0.13
Nitrogen oxides (NO_x)	9.54e-02	0	0
Total	-	-	**0.13**

Table 15: Emission from glass manufacturing for eBook readers. Source: Kozak 2003.

Backlight Emission	*Amount*	*GWP*	*CO_2e (kg)*
Dimethylether (CH_3OCH_3)	9.26e-05	1	0.00
Nitrogen oxides (NO_x)	2.95e-02	0	0
Ethanol	4.63e-05	670	0.31
Total	-	-	**0.31**

Table 16: Emission from backlight manufacturing for eBook readers. Source: Kozak 2003, and Murrels 2007.

Panel Component Emission	*Amount*	*GWP*	*CO_2e (kg)*
Carbon dioxide (CO_2)	4.82e-03	1	0.00
Nitrogen oxides (NO_x)	4.11e-04	0	0
Particulate matter (PM)	2.74e-05	n/a	n/a
HCFC-225ca (Dichloropentafluoropropane)	1.40e-04	120	0.02
HCFC-225cb (Dichloropentafluoropropane)	1.40e-04	586	0.08
Heptane	7.77e-05	n/a	n/a
Hydrochloric acid	7.32e-06	4,400	0.32
Methyl ethyl ketone (C_4H_8O)	1.35e-04	n/a	n/a
Nomethan hydrocarbons	7.77e-05	n/a	n/a
Toluene (C_7H_8)	5.44e-05	2.7	0.00
Total	-	-	**0.42**

Table 17: Emission from panel component manufacturing for eBook readers. Source: Kozak 2003, and Murrels 2007.

Assembly Emission	*Amount*	*GWP*	*CO_2e (kg)*
Carbon dioxide (CO_2)	2.16e-03	1	0.00
Nitrogen oxides (NO_x)	5.48e-01	0	0
Acetic acid	1.36e-03	n/a	n/a
Sulfur dioxide SO_2	1.12e-03	n/a	n/a
Acetone (CsH_6O)	1.86e-04	0.5	0,00
Al-etchant	1.37e-02	n/a	n/a
Ammonia (NH_3)	6.23e-02	0	0
Argon (Ar)	5.80e-03	n/a	n/a
Cr-etchant	4.12e-02	n/a	n/a
Diethylen glycol	9.69e-05	n/a	n/a
Hydrochloric acid	6.06e-02	4,400	266.64
Hydrofluoric acid	5.21e-02	1,410	73.46
Hydrogen	1.33e-04	0.3	0.00
Isopropyl alcohol	1.78e-02	0	0
ITO etchant	6.86e-03	n/a	n/a
Monosilane (SiH_4)	1.54e-03	n/a	n/a
N-bromoacetamide	9.18e-03	n/a	n/a
Nitric acid (HNO_3)	2.69e-04	0	0
Nitrogen fluoride	2.45e-01	n/a	n/a
Phospine	6.26e-02	n/a	n/a
Polyimide	1.40e-04	n/a	n/a
Sulfur hexafluoride (SF_6)	7.30e-03	22,800	166.44
Tetramethyl ammonim hydroxide	6.43e-01	n/a	n/a
Total	-	-	**506.54**

Table 18: Emission from assembly of the parts in an eBook reader. Source: Kozak 2003, IPCC 2007a, eurammon 2011, Fuglestvedt, Isaksen and Wang 1994, 3M 2010, Institute for Reference Materials and Measurements 2007, Ramfjord 2012

Total emissions from the production stage of one eBook reader:

$$CO2e = glass + backlight + panel\ component + assembly =$$

$$CO2e = 0.13 + 0.31 + 0.42 + 506.54 = 507.4$$

Production of eBook reader has 76.59% contribution to the total emission of the life cycle for electronic reading, and consists of 507.4 CO_2e.

12.2.2 Distribution network for electronic book readers

The distribution phase for dedicated reading devices for electronic books will be restricted to consumers in the Molde region. Therefore the assumptions are set that the eBook readers will be distributed by the same distribution firm Bring as for conventional books when they arrive in Oslo. The second most known eBook reader from the USA, Barnes & Noble's Nook, are manufactured by the technology company Inventec in Taiwan (goodereader 2013). No contact was established with Barnes and Nobles, but the assumptions are still set as the eBook readers are manufactured in Taiwan. The eBook reader will be transported with freight airplane from Taiwan Taoyuan international airport (TPE), to Oslo airport, Gardermoen (OSL). When the eBook reader has arrived in Norway, Oslo, they will be transported with HGV to Brings cargo center at Alnabru, and from there be transported with the same transport modes as for conventional books.

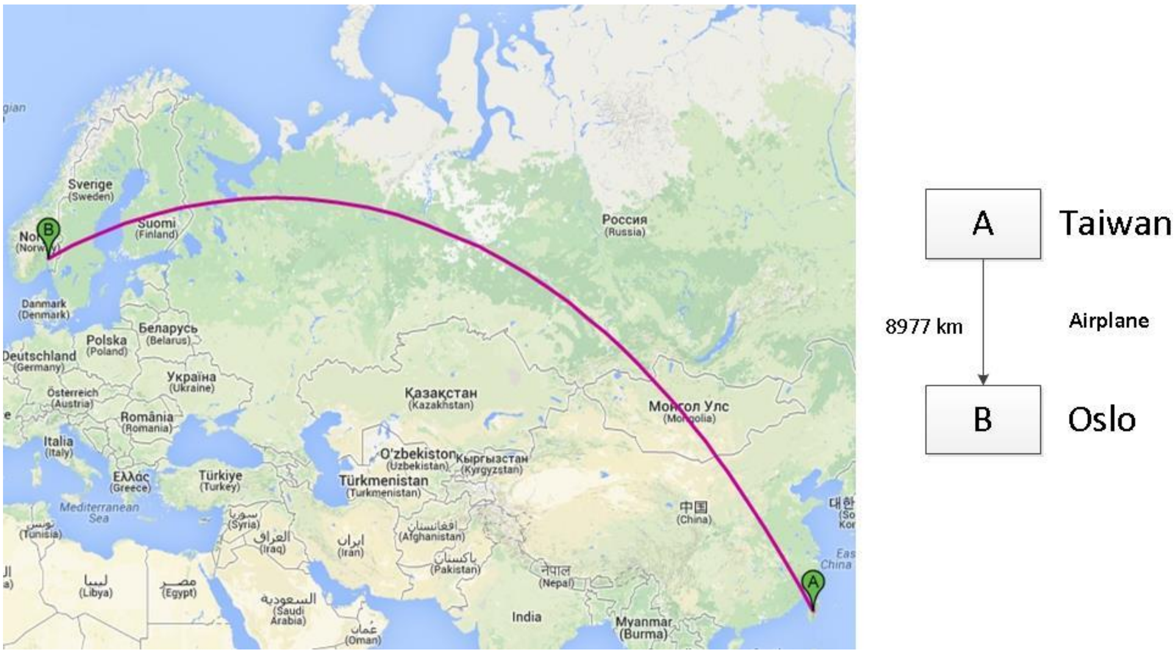

Figure 10: Distribution network for eBook readers. Source: Own illustration based on NTM 2014b.

The analytical framework for eBook reader distribution gives a systematic overview over the data collected. In table 19 the different data used in the research are presented in the second column.

Analytical framework	**EBook Reader distribution**
Weight of goods transported	1 eBook reader = 1 kg
Modal split	Airplane, HGV, train and LGV
Total km	9,522.7 km

Table 19: EBook reader distribution data. Source: Own illustration.

Table 20 displays the transportation and mode selection in the distribution phase for eBook readers. The first column displays the origin of the transportation mode. The second column displays the destination of the transport mode displayed in third column. The fourth column displays the distance each transport mode travels during the supply chain for conventional books.

Transport from	**Transport to**	**Mode selection**	**Distance (km)**
Taiwan Taoyuan international airport (TPE)	Oslo Airport Gardermoen (OSL)	Airplane	8,977
Oslo Airport Gardermoen (OSL)	Warehouse	HGV	42.4
Warehouse	Cargo center	Electrical train	330
		Diesel train	105
		HGV	58.6
Cargo center	Electronic shop	LGV	9.7

Table 20: Transportation in distribution of eBook readers. Source: Own illustration.

The report from NTMs professional calculator for eBook reader distribution is attached at the end of the thesis in appendix D.

Emissions from HGV eBook reader distribution are listed in table 21 below.

HGV Emission	*Amount*	*GWP*	*CO_2e (kg)*
Carbon dioxide (CO_2) (kg)	104.2	1	104.2
Nitrous dioxide (N_2O) (g)	7.93	310	2.46
Nitrogen oxides (NO_x) (g)	292.8	0	0
Carbon monoxide (CO) (g)	189	1.9	0.36
Methane (CH_4) (g)	96.61	21	2.03
Particulate matter (PM) (g)	4.20	n/a	n/a
Sulfur dioxide (SO_2) (g)	52.10	n/a	n/a
Hydrocarbons (HC) (g)	107.2	n/a	n/a
Total	-	-	**109.05**

Table 21: Emission from HGV from Oslo airport, Gardermoen (OSL), to Alnabru.

The NTM professional freight calculator reports 104.4 kg CO_2e from the HGV transportation, while the calculation shows 109.05 CO_2e. The error here is 4.65.

Emissions from intercontinental belly freighter aircraft are listed in table 22 below.

Aircraft Emission	*Amount*	*GWP*	*CO_2e (kg)*
Carbon dioxide (CO_2) (kg)	319,200	2.7	861,840
Nitrous dioxide (N_2O) (g)	10,120	310	3,137.2
Nitrogen oxides (NO_x) (g)	1.230e6	0	0
Carbon monoxide (CO) (g)	301,700	1.9	573.23
Methane (CH_4) (g)	314,800	21	6,610.8
Particulate matter (PM) (g)	3,916	n/a	n/a
Sulfur dioxide (SO_2) (g)	199,300	n/a	n/a
Hydrocarbons (HC) (g)	359,100	n/a	n/a
Total	-	-	**872,161.23**

Table 22: Emission from Intercontinental aircraft. Source: NTM 2014b, Williams 2007.

The calculator reports 330,100 kg CO_2e from the aircraft transportation, while the calculation shows 872,161.23 CO_2e. The error here is 542,061.23. The main reason for this high error could be that the NTM may not have changed the GWP value for CO_2 from 1 to 2.7. If the GWP value for CO_2 would not have been changed in the table above the total CO_2e would have been 329,521.23, which gives a smaller error of 578.77.

Total emissions from the distribution phase:

$$GWP = Aircraft + truck + electrical\ train + diesel\ train + van =$$

$$CO2e = 872{,}161.23 + 109.05 + 3{,}456.16 + 1{,}129.3 + 2.45 = 876{,}858{,}19$$

As mentioned earlier it's assumed that an eBook reader weights 0.176 kg.

$$\frac{876{,}858.19}{1000kg} = \frac{876.86}{1000g} = 0{,}88 \times 176g = 154.88$$

Distribution of one eBook reader has 23.38% contribution to the total emission of the life cycle for electronic reading, and contains 154.88 CO_2e.

12.2.3 Usage of electronic books

The usage of an electronic book depends upon the emission regarding the electricity used while reading an eBook on an eBook reader device.

$$Electricity_{reading}\ (Kozak\ 2003)$$
$$= \frac{64{,}500\ words}{text} \times \frac{min}{175\ words} \times \frac{hour}{60\ min} \times \frac{11\ Watts}{1} \times \frac{kW}{1000\ Watts} \times \frac{3.6MJ}{kWh}$$

$$= 0.24MJ$$

Air emission (EPA 2014):

$$0.24MJ = 0.165\ kg\ CO2e$$

$$CO2e = 0.17\ kg$$

Reading an eBook has 0.03 % contribution to the total emission of the life cycle for electronic reading, and contains 0.17 CO_2e.

12.2.4 'End-of-life' for electronic book readers

An eBook reader needs to be replaced after approximately four years. This means that the eBook reader will start its life cycle over again after four years. This phase is left out of the analysis because of time limitations.

12.3 Total emission

12.3.1 Conventional book

The equation of the total emission from the supply chain (except raw material and 'end-of-life' phase) of conventional books is calculated below. The equation is based on calculations from chapter 12.1.1 and 12.1.2.

$$\sum CO2e = Printing + Distrbution + Usage + 'End - of - life' =$$

$$\sum CO2e = 23.90 + 2.33 + 0 + 0 = 26.23$$

The total CO_2e from all phases analysed for the supply chain for a conventional book consists of 26.23 CO_2e.

12.3.2 Electronic book reader

The equation of the total emission for the supply chain (except raw material and 'end-of-life' phase) of electronic books is calculated below. The equation is based on calculations from chapter 12.2.1, 12.2.2 and 12.2.3.

$$\sum CO2e = Production + Distrbution + Usage + 'End - of - life' =$$

$$\sum CO2e = 507.4 + 154.88 + 0.17 + 0 = 662.45$$

The total CO_2e from all phases analysed for the supply chain for an eBook reader consists of 662.45 CO_2e.

12.4 Energy use-time profile

The LCA performed in chapter 12.1-12.3 will be used as data for the construction of the energy use-time profile. One profile will be made for the supply chain for the conventional book and one profile for the supply chain for the eBook reading device and reading electronic books.

12.4.1 Energy use-time profile for a conventional book

Time and energy use for each activity in the supply chain for the conventional book are accessed from the LCA. Table 23 displays the time and energy used for all the different activities in the supply chain for conventional books. Overall, the activities in the supply chain take 12.33 hours to complete.

Activity	Printing	Distribution	Usage	Waste	Total
Time (hours)	0.033	8	4.3	0	12.33
Energy use (%)	91.12	8.88	0	0	100

Table 23: Time and energy use data by activity in the SC for conventional books. Source: Own illustration based on Harrison and van Hoek 2011.

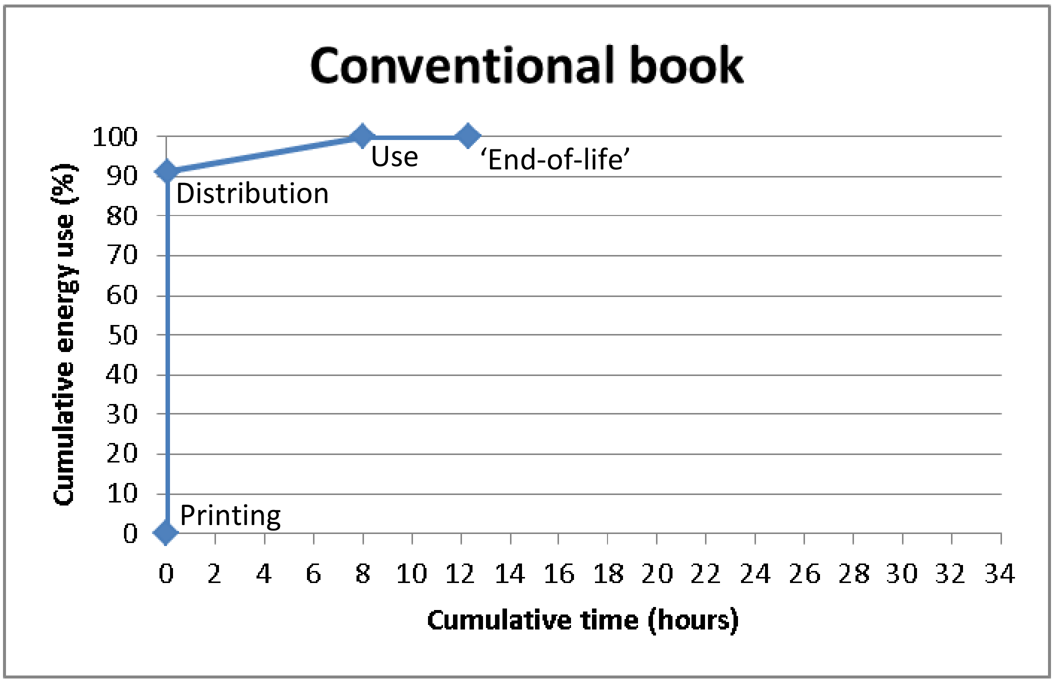

Figure 11: Energy use-time profile for conventional books. Source: Own illustration.

The profile shows that the production stage accounts for 0.27 per cent of the process time up against 91.12 % of total energy use, which indicates that this stage are not related linearly. The steep vertical line at the production stage indicates that it occur more energy use over a shorter period of time. By focusing on this line a reduction in energy use can be achieved. The distribution stage accounts for 64.86 % of the process time and for as little as 8.88 % of the total energy use. The line here is horizontal, which means that it's more time consumed then energy used. The reading of the conventional book accounts for 34.87 % of the process time, but don't use any energy at all. This stage is horizontal and it occurs since there are zero energy used and a higher utility of time. At the end the 'end-of-life' phase accounts for 0 % of the process time and at the same time 0 % of the energy use. In the supply chain for conventional books it is in the printing stage that there can be a higher improvement in the energy use. This means that to be optimal the printing stage should use less energy over the same period of time it use today.

12.4.2 Energy use-time profile for an eBook reader

Time and energy use for each activity in the supply chain for the eBook reading device are accessed from the LCA. Table 24 displays the time and energy used for all the different activities in the supply chain for eBook readers. Overall, the activities in the supply chain take 33.6 hours to complete.

Activity	**Production**	**Distribution**	**Usage**	**Waste**	**Total**
Time (hours)	1	26.5	6.1	0	33.6
Energy use (%)	76.59	23.37	0.03	0	100

Table 24: Time and energy use data by activity in the SC for eBook readaers. Source: Own illustration based on Harrison and van Hoek 2011.

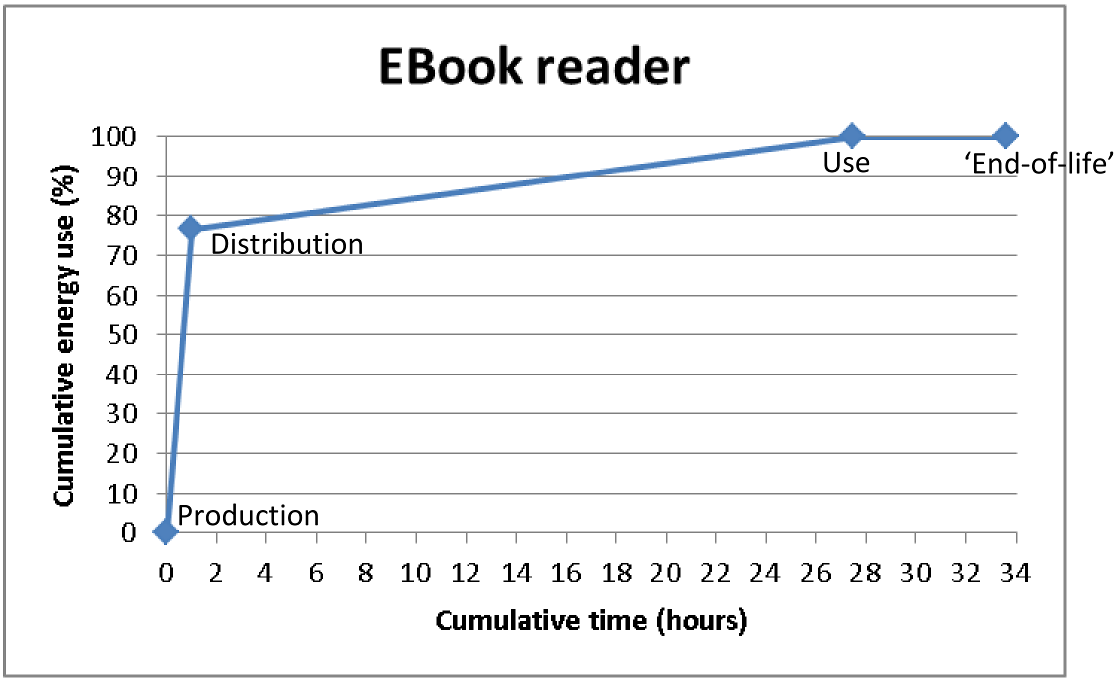

Figure 12: Energy use-time profile for an eBook reader. Source: Own illustration.

The profile shows that the production stage accounts as little as 2.98 per cent of the process time, up against 76.59 % of total energy use, which indicates that this stage are not related linearly. The steep vertical line at the production stage indicates that it occur more energy use over a shorter period of time. By focusing on this line a reduction in energy use can be achieved. The distribution stage accounts for 78.87 % of the process time and 23.38 % of the total energy use. The line here is long and horizontal, which means that it's more time consumed then energy used. By focusing on this line a reduction in time can be achieved. The reading of the electronic book accounts for 18.15 % of the process time, and use 0.03% of total energy use. This stage is horizontal and it occurs since there are zero energy use, and a higher utility of time. At the end the 'end-of-life' phase accounts for 0 % of the process time and at the same time 0 % of the energy use. In the supply chain for eBook readers it is in the production stage that there can be a higher improvement in the energy use, and in the distribution stage it can be a smaller improvement in the time used. This means that to be optimal the printing stage should use less energy over the same period of time it use today.

12.5 Findings and discussion

This chapter is going to answer the research questions from chapter 3.1.

12.5.1 Difference in distribution pattern

The distribution pattern for the conventional book is shorter in time and distance than the distribution pattern for the eBook reader. Distributing the conventional book from Oslo to Molde takes 8 hours and consists of five different transportation modes. The reason why eBook readers have a longer distribution phase lies in the fact that the production facility is located in another country, Taiwan. For the eBook reader it takes 26.5 hours to transport it from Taiwan to Molde, and exists of six different transportation modes.

When comparing these two book options the main difference between them are distance and time. The distribution pattern is the same for both products from the node at Brings cargo center at Alnabru near Oslo. Both products are being co-transported from this node to the node at Brings cargo center in Årødalen near Molde. From this node they are transported to the store they will be sold at in the Molde area. Table 25 displays the difference in the distribution pattern between a conventional book and the eBook reader with the two factors distance and time. The second column displays the conventional books' performance regarding the two factors, while the third column is displaying the eBook reader's performance. The last column is displaying the actual difference between the two book options both in numbers and percentages.

Factor	*Conventional book*	*EBook reader*	*Difference*
Time (hours)	8	26.5	18.5 (69.8 %)
Distance (km)	515	9,522.7	9,007.7 (94.59 %)

Table 25: Difference in distribution pattern between the two book options. Source: Own illustration.

It can be observed from table 25 that there is a difference of 69.8 % on the time consumption between the two book options. The distribution of the eBook reader is taking 18.5 more hours than distributing the conventional book. There is also a higher difference of 94.59 % in the distance travelled between the two book options. The high percentage comes from the 8,977 km longer route the eBook reader has to travel with airplane from Taiwan to Norway, and additionally 30.7 km from the airport to the cargo center where both products are distributed together to Molde, altogether this is a difference of 9,007.7 km longer distribution route for the eBook reader then for the conventional book. The reason for the difference, both in distance and in time, is already mentioned and arise from the fact that the eBook reader are being distributed from Taiwan in comparison to the conventional book which starts the distribution phase in Oslo.

12.5.2 Difference in total CO_2e

The total CO_2e from the supply chain (except raw material and 'end-of-life' phase) of both book options is displayed in the table 26. The second column displays the conventional books performance regarding CO_2e, while the third column is displaying the eBook reader's performance. The last column is displaying the actual difference between the two book options both in number and percentage.

Factor	*Conventional book*	*EBook reader*	*Difference*
CO_2e	26.23	662.45	636.22 (96.04 %)

Table 26: Difference in energy consumption between the two book options. Source: Own illustration.

Buying one conventional book consists of 96.04 % less CO_2e compared to buying one eBook reader device to read one electronic book. There are 636.22 more CO_2e emission regarding the eBook reader in comparison to one conventional book. The main reason why eBook readers have higher CO_2e is because of the use of aircraft transportation in the distribution stage, and another reason is that there are more parts to assembly in the production stage compared to the conventional book

As mentioned earlier there is a difference between the total CO_2e in the distribution stage when comparing the NTM professional calculators' values and the values from the calculations conducted in chapter 11. When applying the values from the calculator in the analysis instead of the values from the calculation already conducted in the LCA the emission from the distribution stage will slightly decrease for the eBook reader, with 95.95 CO_2e. For conventional books the change are as minimal as 0.01 CO_2e. These differences are minimal, and will therefore not be investigated further.

12.5.3 Conventional book vs. Electronic book

After performing the LCA the comparison between conventional and electronic books shows a higher difference in the energy consumption between the two book options. An equation which divide the total CO_2e from both book options show that the eBook reader need to consist of at least 25 books to compensate for buying an dedicated reading device instead of reading conventional books.

$$\frac{\sum CO2e\ for\ an\ eBook\ reader}{\sum CO2e\ for\ a\ conventional\ book} = \frac{662.45}{26.23} = 25{,}26$$

The result from the LCA shows that it is positive for the environment to buy an eBook reader if the consumer likes to read books. The consumer need to read at least 25 books in the four year period of the eBook readers' lifespan. This is 6 books each year and approximately 0.5 books every month, which means that the consumer should buy an eBook reader if it is planning to read one book every second month or more.

12.5.4 Carbon saving

The first step for a greener supply chain is to reduce the carbon emission. The best option to do this in the supply chain for both book options will be to change from fossil fuel to renewable energy. This particular change will lead to lower CO_2e in the distribution stage, and therefore will give a lower outcome in total emission for the phases in the supply chain investigated in this thesis for both book options.

After comparing the conventional book and an eBook reader up against each other the carbon savings for choosing an eBook reader instead of conventional books are increasing for every eBook bought after eBook number 25. Take one example where the consumer reads one book each month the breakeven point between the two book options will be two years after the purchase of the eBook reader. Assumed that the consumer continues to read one book every month for the next two years then the eBook reader will save the environment for 629.52 CO_2e over this period of time. This exact carbon saving will be achieved if the consumer choose to buy a dedicated eBook reader to read its books on instead of buying one conventional book every time that the consumers reads one book each month, over a four years period. The more books the consumer reads the more the environment will gain from it, and more CO_2e will be reduced.

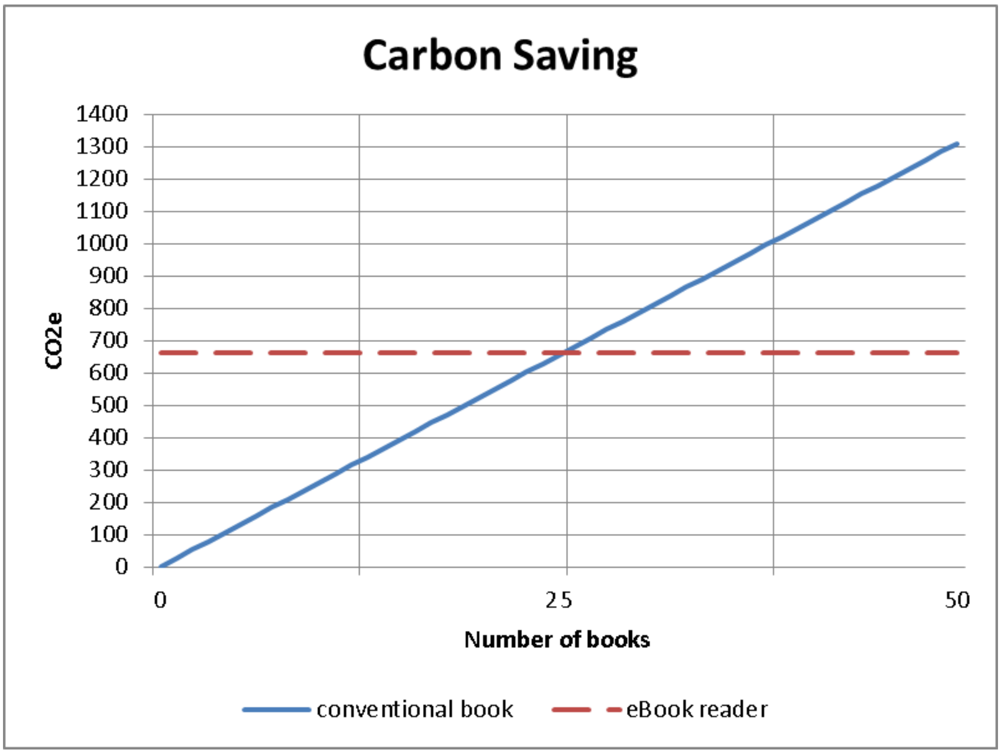

Figure 13: Carbon saving between conventional books and an eBook reader. Source: Own illustration.

Figure 13 illustrate the carbon savings that can be gained depending on how many books the consumer buys. The breakeven point is where the red and blue line crosses in the graph above. The breakeven point is at 25 eBooks, and all eBooks bought after this point will save the environment for CO_2e. Each eBook bought after eBook number 25 is saving the environment for 26.23 CO_2e each.

12.6 Further research

Further research that can be in interest to perform, to be able to look at how the findings from this research will change, are listed below.

- Collect and use more recent measures of the emissions for the production methods for both book options
- Take into account how consumers borrow other peoples books, both private and from public libraries
- Perform an LCA over a five years period, where the consumer buys a new eBook reader after four years
- How the return of unsold books in bookshop will affect the results from the analysis performed in this thesis
- Include personal transportation for the consumer when travelling from home to a shop to buy the product, and back home again
- Measure the carbon savings when transportation modes are changing from fossil fuel to renewable energy

13. Conclusion

The purpose of the thesis was to compare the environmental difference between buying one conventional book versus one dedicated eBook reader device to read electronic books on. The research and the analysis performed can provide companies and consumers with information and calculations to perform better environmental decisions in deciding between the two book options.

During the research many assumptions has been set. Contribution from firms with newer emission data has been difficult and the availability has been poor. Many companies were willing to help, but none of them had been measuring the emissions from production of the two products and therefore where not able to contribute with any data for the thesis. Because of this previous research has been used in the research where no new data where able to be obtained. The research questions established in chapter 3.1 where answered and analysed with the data collected.

The thesis has been focusing on the production, distribution and usage phase in the supply chain for conventional books and eBook readers. The distribution phase is part of the findings for all of the four chapters in the discussion in chapter 11, which indicates that the distribution phase has a big impact on the environment. When comparing an eBook reader with a conventional book the findings from the research proves that for the eBook reader to be compatible with conventional books, in a sustainable matter, the reader must contain over 25 eBooks over a four-year period to be considered as the greener option. If a consumer is reading more than 0.5 books each month buying an eBook reader will be the greenest option. When buying eBooks instead of conventional books each eBook bought after book number 25 are saving the environment for 26.23 CO_2e for every new book bought.

The main result from the comparative LCA performed between an conventional book and an eBook reader to read electronic books on are too encourage the consumer to buy an eBook reader device if the purpose is to read at least one book every second month over a four year period. If the consumer do not read that often, or are unsure that he/she will do that, the best outcome for the environment will be to buy conventional books instead.

Reference list

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Appendices

A: Forecast for eBooks until 2015

Period	t	Demand	Sxy	Sxx	b	a	^Dt	error
2005	1	64 333						
2006	2	30 554						
2007	3	7 257	-321 665	1	-321 665	529 941	21 933	14 676
2008	4	3 737	-285 380	6	-47 563	129 175	7 142	3 405
2009	5	3 785	-248 010	20	-12 401	145 379	-7 649	-11 434
2010	6	10 863	-739 565	50	-14 791	66 307	-22 441	-33 304
2011	7	19 370	-1 053 531	105	-10 034	71 858	1 622	-17 748
2012	8	207 379	-1 244 201	196	-6 348	60 120	9 336	-198 043
2013	9		3 825 072	336	11 384	71 976	174 433	174 433
2014	10		12 072 510	540	22 357	-18 334	205 231	205 231
2015	11		12 714 405	825	15 411	-88 233	81 292	81 292

B: Emission from LGV <3.5 ton

Tables for

Van diesel

Max cargo load, ton:	1.5
Category:	Van
Vehicle description:	Dieseldriven van<3.5 ton, Euro 3
Cargo quantity, ton:	0.45
Road category:	Urban roads
Traffic category:	Stop+Go
Load factor in %:	30
Fuel consumption in l/km:	0.168
Fuel type:	Diesel
Fuel quality:	Diesel Europe (low sulphur)
Artemis notation:	LCV Diesel N1-III
Source:	NTM Int Road Europe 081222.pdf
Last updated	Fri Mar 19 10:34:43 CET 2010

Emissions	Gram per tkm		Gram per tkm		Gram per vehiclekm		Gram per vehiclekm	
	Tailpipe	LCI-data [1]	**Total**	Variation	Tailpipe	LCI-data	**Total**	Variation
Carbon dioxide, CO_2 (total)	976	59	**1035**	130% - 85%	439	26	**465**	130% - 85%
Carbon dioxide, CO_2 (fossil)	976	59	**1035**	130% - 85%	439	26	**465**	130% - 85%
Nitric oxides, NOX	2.68	0.05	**2,73**	130% - 85%	1.21	0.02	**1,23**	130% - 85%
Hydrocarbons, HC	0.17	0	**0,17**	130% - 85%	0.08	0	**0,08**	130% - 85%
Methane, CH_4	0	0	**0**	130% - 85%	0	0	**0**	130% - 85%
Carbon monoxide, CO	0.93	0.02	**0,95**	130% - 85%	0.42	0.01	**0,43**	130% - 85%
Particles, PM	0.2	0	**0,2**	130% - 85%	0.10	0	**0,1**	130% - 85%
Sulphur dioxide, SO_2	0.01	0	**0,01**	130% - 85%	0	0	**0**	130% - 85%

Energy use	MJ per tkm		MJ per tkm		MJ per vehiclekm		MJ per vehiclekm	
	Tailpipe	LCI-data	**Total [2]**	Variation	Tailpipe	LCI-data	**Total [2]**	Variation
Energy (renewable)								
Energy (fossil)	13.37		**13,37**	130% - 85%	6.01		**6,01**	130% - 85%
Energy (nuclear)								

[1] LCI-data is valid for pure petrol without any blending with ethanol

[2] No LCI-data is available for energy use for production of fuel, divided on origin. Therefore only energy use at tailpipe can be presented.

C: Conventional book distribution report exported from NTM professional freight calculator

	CO_2 total [kg]	CO_2 fossil [kg]	CO_2 biogen [kg]	CO_2 equivalent [kg]	SO_2 [g]	CO [g]	HC [g]	CH_4 [g]	NOx [g]	N_2O [g]	PM [g]	Energy [MJ]	Diesel B5 - EU [l]	Electricity [kWh]	Diesel B0 - EU [l]
Truck with trailer 34-40 t															
Vehicle (tank to wheel)	65.43	62.29	3.144	63.55	0.4242	122.3	1.996	0.04991	182.2	4.242	1.747	890.9	24.95		
Fuel (well to tank)	>6.682	6.682	>0	8.724	35.63	8.552	72.16	66.82	20.49	1.247	1.158	160.4			
Sub total	**>72.11**	**68.97**	**>3.144**	**72.27**	**36.06**	**130.8**	**74.16**	**66.87**	**202.7**	**5.489**	**2.905**	**1051**	**24.95**		
Electric train															
Well to wheel	3319	3319	0	>3479	19110	1320	23.26	6412	6223	>0	75.44	71290		6286	
Sub total	**3319**	**3319**	**0**	**>3479**	**19110**	**1320**	**23.26**	**6412**	**6223**	**>0**	**75.44**	**71290**		**6286**	
Diesel train															
Fuel (well to tank)	98.83	98.83	0	126.0	609.2	135.4	1137	1056	352.0	2.437	20.31	2437			
Vehicle (tank to wheel)	991.7	991.7	0	997.1	6.282	5654	1565	57.17	19790	13.51	376.9	13540			377.1
Sub total	**1090**	**1090**	**0**	**1123**	**615.5**	**5789**	**2702**	**1113**	**20140**	**15.94**	**397.2**	**15980**			**377.1**
Van															
Vehicle (tank to wheel)	2.162	2.058	0.1039	2.070	0.01402	0.1319	0.07420	0.001649	7.998	0.04123	0.2474	29.43	0.8245		
Fuel (well to tank)	>0.2208	0.2208	>0	0.2882	1.177	0.2826	2.384	2.208	0.6770	0.04121	0.03827	5.298			
Sub total	**>2.383**	**2.279**	**>0.1039**	**2.359**	**1.191**	**0.4145**	**2.458**	**2.209**	**8.675**	**0.08243**	**0.2856**	**34.73**	**0.8245**		
Grand total	**>4484**	**4481**	**>3.248**	**>4677**	**19760**	**7241**	**2802**	**7594**	**26580**	**>21.52**	**475.9**	**88350**	**25.78**	**6286**	**377.1**

D: EBook reader distribution report exported from NTM professional freight calculator

	CO2 total [kg]	CO2 fossil [kg]	CO2 biogen [kg]	CO2 equivalent [kg]	SO2 [g]	CO [g]	HC [g]	CH4 [g]	NOx [g]	N2O [g]	PM [g]	Energy [MJ]	Jet A-1 [kg]	Diesel B5 - EU [l]	Electricity [kWh]	Diesel B0 - EU [l]
General belly freighter, cargo transport																
Craft (tank to wheel)	294500	294500	0	297300	46740	265000	25170	1500	1.152E6	9548	>0	4.122E6	93480			
Fuel (well to tank)	24730	24730	0	32740	152500	36690	333900	313300	78330	577.1	3916	618400				
Sub total	**319200**	**319200**	**0**	**330100**	**199300**	**301700**	**359100**	**314800**	**1.230E6**	**10120**	**>3916**	**4.741E6**	**93480**			
Truck with trailer 34-40 t																
Vehicle (tank to wheel)	94.54	90.00	4.543	91.83	0.6130	176.7	2.885	0.07211	263.2	6.130	2.524	1287		36.06		
Fuel (well to tank)	>9.654	9.654	>0	12.60	51.49	12.36	104.3	96.54	29.61	1.802	1.673	231.7				
Sub total	**>104.2**	**99.65**	**>4.543**	**104.4**	**52.10**	**189.0**	**107.2**	**96.61**	**292.8**	**7.932**	**4.197**	**1519**		**36.06**		
Electric train																
Well to wheel	3319	3319	0	>3479	19110	1320	23.26	6412	6223	>0	75.44	71290			6286	
Sub total	**3319**	**3319**	**0**	**>3479**	**19110**	**1320**	**23.26**	**6412**	**6223**	**>0**	**75.44**	**71290**			**6286**	
Diesel train																
Fuel (well to tank)	98.83	98.83	0	126.0	609.2	135.4	1137	1056	352.0	2.437	20.31	2437				
Vehicle (tank to wheel)	991.7	991.7	0	997.1	6.282	5654	1565	57.17	19790	13.51	376.9	13540				377.1
Sub total	**1090**	**1090**	**0**	**1123**	**615.5**	**5789**	**2702**	**1113**	**20140**	**15.94**	**397.2**	**15980**				**377.1**
Van																
Vehicle (tank to wheel)	2.162	2.058	0.1039	2.070	0.01402	0.1319	0.07420	0.001649	7.998	0.04123	0.2474	29.43		0.8245		
Fuel (well to tank)	>0.2208	0.2208	>0	0.2882	1.177	0.2826	2.384	2.208	0.6770	0.04121	0.03827	5.298				
Sub total	**>2.383**	**2.279**	**>0.1039**	**2.359**	**1.191**	**0.4145**	**2.458**	**2.209**	**8.675**	**0.08243**	**0.2856**	**34.73**		**0.8245**		
Grand total	**>323700**	**323700**	**>4.647**	**>334800**	**219000**	**309000**	**361900**	**322400**	**1.257E6**	**>10150**	**>4393**	**4.830E6**	**93480**	**36.88**	**6286**	**377.1**