Engineering Solutions for the Environment

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Welcome to PPU215 Research Methodology in Production Projects, Spring 2020

Carrying out a MSc thesis project is easy to take for granted as being the last thing students do before they graduate at a technical university. For many, the usual perception is that an industrial company provides a 20-week project with specific tasks, a clear aim and scope, letting the students use familiar methods to arrive at an incontestable answer. But reality is seldom that clear-cut and many thesis workers find that the project is far from well-defined when they begin working, and they must spend time deciding on a reasonable scope to complete in the given time. Beyond that, many informed decisions have to be made.

Thesis work as a learning activity is required by Chalmers as a sign that students are able to use evidence and engineering methods to contribute to a company or society in a sustainable and ethical way. Looking at the range of problems that thesis workers address, the different types of organizations initiating the projects, their specific demands that sometimes collide by the university requirements, etc., a sound toolbox of research approaches is a big help.

Accordingly, the course *PPU215 in Research Methodology Production Projects* aims to develop students' *professional* and *scientific* skills by working on a research project to answer an open-ended research question. The students started by identifying an engineering problem and defining a research question which formed the basis for their group project. They worked in groups of five or six students to practice project planning, time management, teamwork, various forms of communication and ethical considerations in engineering (*professional development*). They answered their research question using a triangulated approach combining literature studies, quantitative and qualitative methods (*scientific skills*). At the end of the course, all groups presented their research project with a conference paper and oral presentation at the *'PPU215 Conference: Engineering Solutions for the Environment'*.

Introduction to the Conference Committee

Organisation

Division of Production Systems
Department of Industrial and Material Science (IMS)
Chalmers University of Technology
Visiting address: Hörsalsvägen 7A, M-building (5th floor), S-412 96 Göteborg

Conference Chair

Mélanie Despeisse	Assistant Professor	IMS Production Systems

Organising Committee Chair

Arpita Chari	Doctoral Student	IMS Production Systems

Local Organising Committee

Xiaoxia Chen	Doctoral Student	IMS Production Systems
Clarissa Gonzaléz	Doctoral Student	IMS Production Systems
Ninan Theradapuzha Mathew	Doctoral Student	IMS Production Systems

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PART 1 – ENERGY

Group 1.
The Environmental Potential of 4th Generation Nuclear Power

Victor Björk, Ludvig Blomgren, Hugo Brokelind, Vilma Fernström, Teuta Qorri

Group 1

bjorkv@chalmers.se
ludblo@chalmers.se
hugobr@chalmers.se
vilmaf@chalmers.se
qorri@chalmers.se

Abstract

The energy sector is slowly shifting towards CO2-neutral sources of energy due to the increasingly perceivable effects of climate change. Nuclear power possesses this characteristic. This study compares the environmental impact of the 4th generation of nuclear power to previous generations. The assessment was performed through three studies: a literature study, a qualitative study and a quantitative study. The comparison was performed considering four different aspects; fuel source, reactor technologies, waste management, and safety. The results show that the reactors of the 4th generation will have the potential to use reprocessed waste products due to new reactor technologies and that a closed fuel cycle can be achieved. An additional benefit of the mentioned technology is its potential to increase safety. Furthermore, uranium mining, conversion, and enrichment constitute 49 % of CO2 emissions of today's nuclear fuel cycle. These are potentially redundant processes in 4th generation nuclear cycles.

Keywords: Environmental impact · Nuclear Energy · Generation-IV.

1. Introduction

The growing trend today within energy generation is reducing carbon emissions. This drives the development and integration of carbon-neutral energy sources in the electricity grid [1].

Energy generated with nuclear power is considered environmentally sustainable meaning that relatively small amounts of carbon emissions are generated in the process [2]. However, nuclear reactors are fueled by radioactive elements, such as uranium, which generates safety issues throughout the supply chain.

The latest development in the field of nuclear power systems is known as the 4th generation. The term does not only refer to the nuclear power plants, but to an entire nuclear system including fuel procurement, fuel treatment and fuel disposal. One of the main characteristics of this 4th generation is the increased fuel utilization and the possibility to create a closed nuclear fuel cycle [3].

Researchers and practitioners find themselves in an ongoing debate on whether 4th generation nuclear power systems could be a viable replacement for the current practices and a reliable source of energy generation [3]-[5]. Other technologies for renewable energy sources are going through rapid development. The growth of the 4th generation of nuclear technology requires accelerated growth to become an active participant in this competitive environment [6].

This study identifies the need to understand how could the 4th generation of nuclear technology contribute to reduced environmental impact. To achieve the desired objective, a comparison between the 4th generation and previous generations of nuclear power is performed.

This contributes to the ongoing debate on nuclear energy and brings clarity to the subject of expansion or decommissioning of nuclear power plants in the future.

1.1 Aim

The aim of this study is to determine how 4th generation nuclear power compares to previous generations in terms of environmental impact. The aim has been formulated into a research question presented below.

Research Question. How do 4th generation nuclear reactors differ from previous generations regarding the potential environmental impact?

1.2 Scope and Delimitations

In this section, the scope and delimitations of the research study are defined.

Scope. This project seeks to find differences between the 4th generation and previous generations of nuclear power, in terms of environmental impact. To achieve this, four categories were identified through a preliminary literature

screening: fuel source, reactor technologies, waste management and safety. The mentioned aspects will be considered as guidelines to further develop a literature study, a qualitative study and a quantitative study.

Delimitations. This study has been conducted as part of a collaboration with the course PPU215 - Research Methodology in Production projects, at Chalmers University of Technology with predetermined research topics. Consequently, the authors are not experts in the research topic and also face limitations related to the given time frame. Specifically, only secondary quantitative data has been collected and the level of detail has been kept at a manageable level. As part of the data gathering strategy, experts were contacted to conduct interviews. These activities were performed through online resources to comply with the safety requirements for COVID-19.

2. Methods

This chapter describes the methods used during the project to answer the research question. The study followed an exploratory research design [7]. It was a suitable strategy since the research topic dealt with concepts and technologies which are not yet implemented and only partially tested.

The research strategy consisted of the application of mixed methods. Three types of studies were carried out: a literature study exploring current published literature on the topic, a qualitative study where experts in the field were interviewed, and a quantitative study based on collected secondary data. Exploring different data sources facilitated data triangulation, thus strengthening the credibility of the study [8].

2.1 Literature study

Write The search was performed by exploring different databases to find relevant literature. The chosen databases were CORE, Chalmers Library, Scopus, and Web of Science. Literature published before 2005 was generally avoided, to find updated information about 4th generation reactors. The selected keywords are specified in table 1. To expand the search, references in papers already found were screened to a limited extent. Literature reviews and State-of-the-Art studies were preferred over papers with detailed and specific contributions.

Table 1. Keywords used in the literature study.

Keywords
“Nuclear power” AND “Generation IV”
“Nuclear power” AND “Generation IV” AND “Reactor”
“Nuclear power” AND “Generation IV” AND “Performance”
“Nuclear power” AND “Generation IV” AND “Safety”
“Nuclear power” AND “Generation IV” AND “Fuel”
“Nuclear power” AND “Generation IV” AND “Literature Review”
“Generation IV reactors” AND “Compared to” AND “Safety” AND “Second generation”
“Nuclear power” AND “Generation IV” AND “Safety” AND “Second generation”

2.2 Qualitative study

The collection of qualitative data consisted of interviews with experts in the field of nuclear power. The interviews were semi-structured, with clear agendas and open-ended questions were formulated in advance. The interview structure allowed to emphasize on the interviewee’s thoughts [8]. A list of potential interviewees was derived from the authors found in the previous literature study. A documentary about renewable energy airing on national television [9] also led the way to potential interviewees. Four experts were chosen and contacted for interviews based on a variety of expertise. The interviewees and their respective professional titles are displayed in table 2.

Table 2. Interviewees of the qualitative study.

Interviewee	**Professional titles**
Interviewee A	Post-doctorate in Chemistry, Chemical technology, and Nuclear Chemistry.
Interviewee B	Senior researcher at a department of space, earth and environment.
Interviewee C	Professor at an institution of Nuclear Chemistry.
Interviewee D	Professor at a department of physics

The interviews were transcribed, and the information was divided into categories. To enhance the categorizing validity, half of the team created separate categories on each interview and summarised one list for each transcription [8]. The categories could then be compared to the literature study. The effects of categorizing are summarised by Burnard [10] to make sure all aspects are covered and validate the results. By quantifying the qualitative interviews through this method, hidden communicated contents could be discovered in the transcript. By re-reading the transcripts the risk of data loss is minimized and by structuring, the key elements can be

extracted which is of great importance in the qualitative analysis [8]. The information collected from the interviews was then compared to the results of the literature study.

2.3 Quantitative Study

Research on nuclear power is inherently complex and the project's preconditions entailed a slim time frame. Therefore, the quantitative study was not centred around primary data collection. Instead, secondary quantitative data from the Energy Information Administration was collected from Statista. The focus was primarily on the carbon emissions of the nuclear life cycle. The focal point was chosen based on that the 4th generation nuclear fuel cycle significantly reduces the need of uranium mining and enrichment processes. Articles on Life cycle analysis (LCA) of current nuclear power fuel cycles were found in the database ScienceDirect. The LCA data included carbon emissions from uranium mining, enrichment, and conversion. The retrieved data enabled the possibility to estimate the reduction of carbon emission based on an implementation of 4th generation nuclear power systems. Data quality and validity was ensured by using articles found in academic journals and databases [8]. Furthermore, a data-triangulation process was performed by validating several information sources, collected during the previous literature study and qualitative study. The data was analysed and handled through the statistical software JMP to create graphs, visualizing the results of the quantitative analysis. A set of graphs were created and modified to include different patterns to make it easier for the viewer to discern the datasets in the graphs from each other.

3. Results

In this chapter, the results from the literature study are initially presented followed by the results from the qualitative and quantitative studies. Fuel source, reactor technologies, waste management, and safety are the aspects which have been investigated in terms of potential environmental impact for the studies. These factors were chosen based on an early search for information on nuclear energy where a majority of the findings were focused on one of the aspects.

3.1 Literature study

In this section, the results of the literature study presented according to the four previously mentioned aspects.

Fuel Source. Nuclear reactors today solely generate energy from the isotope of uranium 235 [11]. Natural mined uranium consists of 0.7% uranium 235 and the rest is uranium 238. Most reactors today operate at around 3-5% uranium 235, which can be achieved by enrichment of the mined uranium [12]. The composition of used fuel, the waste products, is usually around 94% uranium, 5% fission products, and 1% Plutonium and other transuranic elements. The uranium and Plutonium may be recycled [13].

Some reactors today can reuse parts of the waste, called nuclear reprocessing [14]. However, multiple types of recycling technologies are still being researched. The objective of the 4th generation regarding the fuel is that plutonium and other waste products should be effectively reused. This consideration could potentially achieve a closed fuel cycle, minimize the waste products, lower the half-life, and to get more efficient use of the uranium [15]. A closed fuel cycle refers to the reprocessing and reuse of used fuel from the nuclear reactors [14].

Fuel re-usage is also considered more sustainable as the Carbon emissions related to nuclear power are primarily related to the mining and refinement of uranium ore when the energy generated by fossil fuel is used in the process [2].

Reactor Technologies. The first prototypes of nuclear reactor systems are classified as the 1st generation and the last reactor was closed in 2015 [16], [17]. Today's reactors belong to the 2nd generation, with a few exceptions, and were generally built during the initial industrialization of nuclear power. The dominating reactor technology is Light-Water Reactors (LWR), but there are several different types of reactor technologies available. The 3rd generation reactors are further refined LWR: Advanced LWR. However, there are only a handful of them in operation today. The distinction between the first three generations differs slightly between authors [3], [16].

The 4th generation is a system of reactors and fuel-cycle facilities that fulfil a number of criteria in terms of safety, economics and resource efficiency. One of the main criteria to classify as the 4th generation is that the system does not generate any long-lived radioactive waste [3].

Breeder reactors are the underlying concept of the 4th generation and are the key to closing the fuel cycle. A breeder reactor produces more fissionable material than it consumes, which opens the possibility to reuse today's stored obsolete fuel. This results in better fuel utilization and a significantly reduced half-time of waste, which is possible in fast reactors [3]. In their review of current nuclear power 4th generation research, Abram and Ion [16] found six reactor concepts that potentially could fulfil the criteria of the 4th generation. Westlén [3] states that two of the reactor technologies are the focus of today's development: the sodium-cooled fast reactor and the lead-cooled fast reactor. The remaining four are still subjects of research but at a more theoretical level.

3.1.3 Waste management. The storage time of the waste is a high relevance factor since the waste is radioactive and thereby harmful. Recent research suggests that the storage time of the fuel from 4th generation reactors is considerably shorter than that of previous reactors. In the 4th generation reactors, used fuel can be reprocessed in a closed loop and then used again [18].

For the 4th generation, the remaining waste will still need to be stored, but the quantity is lower. Also, the waste has a

shorter half-life time, meaning the radioactive isotopes in the material disintegrate faster, having the same radioactivity as naturally occurring uranium after just a few hundred years [3]. The radio-toxic waste from the earlier generation reactors that are used today needs to be isolated for over 100,000 years [19].

3.1.4 Safety. The safety of nuclear reactors of today has been improved during the last 30-40 years and constant progress is made on their in-built active safety systems. Since 2000 nuclear power plants (especially the 3rd generation) are specialized in a simplified safety system [20].

Three new goals are introduced for the 4th generation power plants. The goals are as follow [21]:

- Energy system operations will excel in safety and reliability.
- Energy systems will have an extremely low likelihood and degree of reactor core damage.
- Energy systems will eliminate the need for offsite emergency response.

One of the six 4th generation reactors is the molten-salt reactor. This reactor's radiation safety is stable because of its sealing of fission and fuel products as well as its system to purify the fuel composition. Moreover, safety analysis is often considering the accidents of reactor power loss, meaning high power and temperature spikes when an electrical shutdown is executed. The 4th generation reactors will have enhanced control of these fluctuations in the event of power shortages, thus having safer and more stable reactors [22].

3.2 Qualitative study

The results of the qualitative study are structured under the same categories as the previous results, focusing on fuel source, reactor technologies, waste management, and safety.

Fuel source. Interviewee A and C both confirmed that the cooling technology used in 4th generation nuclear reactors allows the neutron flow in the reactors to be increased to cleave all types of heavy nuclides which is not possible in previous generations. Consequently, it is possible to utilize fuels other than uranium (235&233) and Plutonium (241&239) in the reactors and the fuel enrichment process is no longer needed. These statements confirm previous findings in the literature study [13]. Interviewee D confirms previous interviews, that the 4th generation will be able to fissure other isotopes than uranium-235, this will result in more efficient use of the mined uranium and a closed fuel cycle. Interviewee B explains that by implementing the 4th generation nuclear reactors globally, a large increase of enrichment will be necessary to get enough plutonium.

Reactor Technologies. Interviewee C claims that the technology for 4th generation nuclear power already exists and the reactors are realizable today. 4th generation reactors and systems have not been realized because there are few incentives for it. Specifically, the low cost of uranium. Interviewee D describes that by using 4th generation fast reactors, the amount of waste will be less. While Interviewee A claims that the amount will stay unchanged.

Waste management. Interviewee A, B and C confirm the information found earlier on the decreased storage time of waste from 4th generation due to the decreased half-time of it, estimated to around 1000 years [3]. Interviewee C also claims underground storage of the waste is fully conceivable.

Safety. Interviewee A and C both recognized in their interview that the goal of the 4th generation nuclear reactor was to introduce a safer technology within nuclear power which is in accordance with the literature findings [21]. They also briefly explained why the reactors would be considered safer due to smart construction and built-in protection. For instance, in liquid lead cooled reactors, lead and uranium have a more similar density. In the case of an accident, the two elements would mix. Since lead is a natural protection against radiation, the consequences would be less severe. Interviewee D was also acknowledging the fact of enhanced safety in an event of power loss, which was considered by the literature [22] to be the main aspect to analyse in the safety evaluation of nuclear power plants.

3.3 Quantitative study

Interviewee C suggests that Sweden can eliminate its need for mining, conversion, and enrichment of uranium by implementing a 4th generation nuclear power system and a closed nuclear fuel cycle. On the contrary interviewee B does not believe that uranium mining could be completely discontinued. However, fuel utilization is increased with 4th generation systems and in the best-case scenario are mining activities completely discarded [15].

LCA data from Poinssot et al. [23], suggests that uranium mining, conversion, and enrichment make up 49 % of carbon emissions of the nuclear fuel cycle. Mining stands for almost 100 % of human toxicity and ecotoxicity caused by the nuclear fuel cycle. The same study concluded a 17 % percent decrease in natural uranium use and a significant reduction in carbon emissions in a twice-through fuel cycle compared to a once-through fuel cycle.

Figure 1 shows the trend of mining uranium and how it has fluctuated since the year of 2002. The data could suggest nuclear power and fuel are increasing in demand.

In figure 2 it can be appreciated that mining is one of the main contributors to greenhouse gas (GHG) emissions by nuclear power. This is in accordance with the information previously found during the literature study. Namely, the main contributors to carbon emissions within nuclear power systems are uranium extraction and the emissions which occur during the construction of the power plants [2].

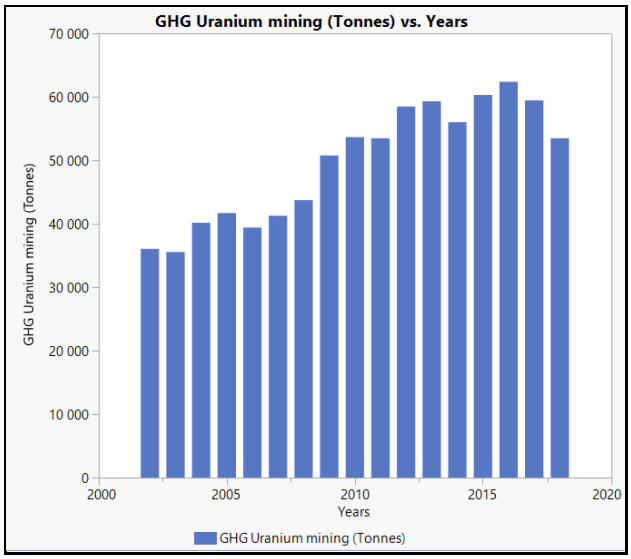

Figure 1. Ton mined uranium per year globally [24].

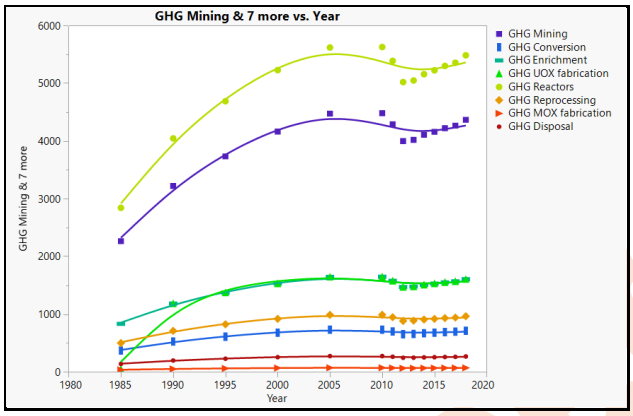

Figure 2. Nuclear lifecycle process GHG emissions [23],[24].

4. Discussion

In this section, the results of the research project are discussed along with the quality and any limitations of the data.

4.1 Interpretation of Results

Towards the end of the research project several advantages and disadvantages of 4th generation nuclear power was identified.

It was assumed that the implementation of 4th generation nuclear power will make uranium mining redundant due to utilizing reprocessed waste as fuel. This assumption was discussed during several of the interviews and the answers were contradictory. Interviewee A explained that the goal is to produce fuel entirely from depleted fuel from previous nuclear power generations. However, we cannot disregard that newly mined uranium will to some extent be needed to supply the 4th generation nuclear plants.

Since the reprocessing of depleted fuel must be upscaled, the 4th generation nuclear power may entail new sources of carbon emissions. However, the magnitude was not possible to estimate due to a lack of information on the new reprocessing process.

For the environmental impact in terms of reactor technologies, the difference between the 4th generation and previous generations does not seem to be significant based on the research. The main technical difference is the cooling medium utilized which for the 4th generation nuclear reactors could also imply a higher degree of safety. The new cooling medium enables fission of various types of heavier nuclides. Consequently, using present nuclear waste as fuel is possible through reprocessing. Furthermore, enrichment of natural uranium becomes redundant. However, in the interviews, it was mentioned that establishing nuclear power plants along with reprocessing facilities would be expensive.

Through the utilization of reprocessed fuel, it is also possible to significantly decrease the half-life of the radiotoxic waste. Consequently, the storage time of radioactive waste is significantly reduced. This means that the 4th generation has an advantage within the aspect of waste management. With greatly reduced half-life, the storage of nuclear waste becomes less complicated. One of the goals of the 4th generation is safer reactors and some technical advances within the research area suggest that they will be. However, in terms of operations experience, previous generations of nuclear energy systems have the upper hand.

In conclusion there are numerous enablers and inhibitors to the 4th generation nuclear power when comparing to the previous generations. We have chosen to summarize the findings from the project in enablers and inhibitors of 4th generation nuclear power in table 3.

Table 3. Enablers and inhibitors of 4th generation nuclear power in terms of environmental impact.

Aspects	Enablers	Inhibitors
Fuel source	Use of reprocessed waste	Unexpected carbon emissions due to reprocessing.
	Less or no uranium mining/carbon emissions	
Reactor technologies	Nuclear fission of various types of heavy nuclides	Expensive facilities
	No enrichment needed	
Waste management	Significantly reduced half time of waste	Still radioactive waste to be stored
	Significantly reduced storage time	
Safety	Safer technology	Lack of operating experience

4.2 Method and Data Uncertainties

During the literature study, comparing the different generations of nuclear energy in terms of safety proved to be difficult. The knowledge within the area is missing substance as it is rather subjective. No fixed numbers could be found, such as risk percentages for the different nuclear generations.

Generally, the interviewees of the qualitative study did not contradict each other in terms of the benefits of the 4th generation nuclear power. It is recognized that this may be because some of the interviewees work within the same field at the same or related institutions. The input from the interviewees does however corresponded well to what was found in the literature and thus seemed relevant to the study. However, each interviewee emphasized different drawbacks of 4th generation, where the drawbacks are mainly inhibitors of the realization of the technique. Some pointed to political reasons, while others argued for high costs and cheaper alternatives.

Some of the questions asked during the interviews were perceived as difficult to answer because they were not within the interviewee's specific field of research. In retrospect, more specific questions should have been asked since the interviews were kept rather general and did not dive into the subject at depth.

The results of the qualitative study covered some of the knowledge gaps found during the literature study and strengthened the credibility of previously collected information.

In the quantitative study, during the construction of the graphs, it was assumed that the carbon emission per kWh was constant and thus did not fluctuate with time during the years presented in the graphs which in reality is unlikely. The rates of carbon emissions per kWh are based on data from the French nuclear power industry between 2007-2010 [23]. The quality of the data is therefore currently reliant on a few quantitative data sources. To strengthen the credibility of the data, the best solution would be to find further quantitative data sources concerning the carbon emissions by nuclear power systems.

Regarding the quantitative study, it is also recognized that there may be other areas within the nuclear life cycle which release carbon emissions that have not been included in this report.

4.3 Future research

For future research, further investigation of fuel separation and reprocessing is needed to confirm that depleted fuel is enough to power 4th generation reactors.

When considering the realization of the 4th generation nuclear power, the research project unravelled information about inhibiting powers that may cause a cutback in the research. As the realization of constructing and running the nuclear plants demand a market of investment actors, the project suggests an unwillingness for companies to make such investments. The untested technology and the high cost of manufacturing is not a risk that investors are willing to pay. This information appeared during the qualitative analysis when interviewees stated their belief regarding the future of the 4th generation nuclear power.

5. Conclusion

The aim of this project was to examine the potential environmental impact of the 4th generation of nuclear power and thus answering the research question: *"How do the 4th generation nuclear reactors differ from previous generations regarding the potential impact on the environment?"*. The answer to the research question is summarised in the following lists.

Fuel source.

- The 4th generation of nuclear power has more fuel options such as reprocessed waste.
- The potential use of reprocessed fuel also means that the carbon emissions related to uranium mining could be decreased.
- The assumption of decreased carbon emissions is however not entirely reliable as reprocessing could potentially increase carbon emissions within the nuclear power life cycle.

Reactor technologies.

- The use of new cooling mediums within the 4th generation nuclear reactors is what allows the reactors to cleave heavier nuclides and thus utilize different fuels. This in turn makes the enrichment of uranium process redundant.
- The use of natural convection could also be utilised in the reactors to circulate the cooling medium through the reactor to cool it down.

Waste management.

- The 4th generation reactors will be able to utilise reprocessed waste in several cycles before the fuel is fully depleted. The increased use of the fuel decreases the half-life of the waste. Consequently, the radiotoxicity of the waste will not last as long.
- Because of the decreased half-life, the fuel can be stored more easily as the storage units do not need to last for as long as they do today.

Safety.

- With the reduced halftime of nuclear waste from the 4th generation nuclear systems, the possibility for safe final storage is more viable than previously.
- The potential use of natural convection for circulation of the cooling medium means the reactor core could still cool down if the electricity were shut down.
- There is a lack of experience in operating 4th generation power plants. This is a risk that needs careful consideration before implementation.

- The 4th generation safety regulation would be even stricter.

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Group 2.
Potential for wind energy in Sweden

Axel Magnusson, Harshad Kurrewar, Nagarajan Kumaresan, Quintus Westberg and Ruiqi Chen

Group 2

maaxel@student.chalmers.se
quiwes@student.chalmers.se
harshad@student.chalmers.se
ruiqi@student.chalmers.se
nagkum@student.chalmers.se

Abstract

The significance and development of wind power have risen considering its low expenses of generation and zero-carbon electricity generation source. This paper gives a systematic review of where onshore wind energy generation potential lies in Sweden. To answer this question, monthly cost and wind power information from Nord Pool, interviews with experts, and literature information is examined on wind power influence, how land accessibility can change the decision and which portion of Sweden is having progressive potential for wind power. Results showed that northern Sweden had more potential for wind energy development, which results from baseload power production, land availability in different regions, and air quality. However, the Swedish power generation framework additionally profits by adaptability of hydropower, nuclear, and fossil fuel. Furthermore, the political aspect also drives the strategic plan of where to establish a successful wind energy onshore.

Keywords: Socio-economic, Wind energy, Potential.

1. Introduction

Since the industrial revolution, the world has used proven technology, fossil fuel generation, to support energy consumption [1]. In the light of current economic, environmental, and political pressures, many of the world's countries have transformed part of their energy generation into renewable energy sources such as solar, wind, and hydropower. A great deal of effort is needed to reduce the carbon footprint that exists in the world today [2].

In 2015, a meeting was held in Paris [2] where different countries were assigned carbon dioxide levels they should follow. This meeting was a turning point for many nations. It created changes politically but also in many countries as they developed their power generation through renewable energy sources. The price of fossil fuels increased, even though there are large amounts of energy reserves included. In Sweden, there has been a great development in renewable energy. Today, Sweden contributes as much as 11% of its energy generation through wind power. According to the European Union, the targets for future development are that energy generation via wind power in Sweden should reach 27% of the total generation. Sweden and the other Nordic countries have a high potential for a sharp increase in wind power as the Nordic climate is more adapted to wind power compared to solar power [3].

Wind power is still facing economic and social issues that lead to extended processes [4]. Common social problems are the impact of noise frequency and the area occupied by wind farms. High noise levels disturb people living nearby and huge wind farms are not visually appealing [5]. Other relevant social issues include groundwater resources, cultural resources, and surface water. Economic issues are often related to political, technical, and even social factors. Common problems are the high price of plant location, the price adjustment of nearby properties, the cost of transporting electricity, and the availability of production traffic [1].

1.1 Project aim & Research question

The sustainable development potential in wind power in Sweden has been synthesized and reviewed. The potential development scenario in social, economic, and environmental impact will be analyzed. To achieve the project's aim, an empirical study will be conducted using various data collection methods. The study includes research group data, interviews with researchers in the business, scientific journals, and power generation industry data.

The research question to be answered reads, *"What are the socio-economic challenges faced by the industries in establishing strategic planning in the realization of wind energy generation?"*

1.2 Limitations

The project is limited to research in social and economic aspects linked to the wind energy potential in Sweden. The project has been limited by the lack of data in the subject as research in renewable energy has recently become an important topic. The project is based on Sweden's potential for wind energy which results in further data restrictions. The project is also restricted to a duration of 8 study weeks.

2. Methods

The methods of the study consisted of a literature study, qualitative analysis, and quantitative analysis. The reliability and validity of analysis were ensured by the triangulation method as briefed in Figure 1.

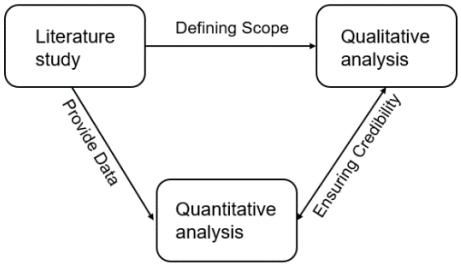

Figure 1. Triangulation method [6].

2.1 Literature study

The purpose of the literature study was to create broader knowledge about the research subject. To ensure that the references were relevant to the topic and of high quality, some filtering was carried out. The search engines were carefully selected and Scopus, Web of Science, Google Scholar were used. To filter out irrelevant content, conference papers or peer-reviewed scholarly articles were required. A time filter of 15 years was used to study the subject from 2005 to 2020. In order to find articles related to the subject, the author's keywords were searched. The keywords, which were based on the topic and the research question, were listed in Table 1.

Table 1. Keywords used for literature study.

Keywords	
Wind Power	Sweden
Energy	Economic
Potential	Industry
Cost	Renewable
Social	Review

2.2 Qualitative study

To analyze the current situation from the economic and social aspects, qualitative analysis was performed by interviews. Two professors from Chalmers, who had research experience on renewable energy and wind power, were approached. **Professor A** is a chair in Environmental Systems and Risk, Div. Environmental Systems Analysis, Technology Management, and Economics. **Professor B** is a project manager for research in electric grid power technology, who had experience working as a wind power operator for many years. The interviews were conducted online via Zoom.

Based on the findings from the literature, the following questions were framed for the interviews:

What are the key parameters that are to be considered for deciding the location for wind field installation?

What are the advantages of having an offshore wind farm compared to onshore wind farms?

Which is advantageous, having a wind turbine at the level of forest or having a wind turbine above the forest level? What factors determine the height of the wind turbine be installed?

How are the government policies supporting wind energy production?

What are all the social, political, economic changes that can effectively increase the production of wind energy?

What are the challenges faced by the companies that potentially delay a wind energy project?

What is your opinion on installing small-sized wind turbines on every rooftop?

2.3 Quantitative study

To complement the literature study and qualitative data compilation previously carried out, a quantitative data collection was conducted. For this project, a primary data collection wasn't possible due to the difficulties of performing their own sampling and experiments on the topic. Instead a secondary data collection is carried out using the sources from Nord Pool Group [7], SMHI (the Swedish Meteorological and Hydrological Institute) [8]. Nord Pool Group, the leading power market in Europe, provided the data concerning the cost of energy generation and the production of wind power in Sweden [7]. Energimyndigheten (Swedish Energy Agency) provided the data on the wind power generation by different areas in Sweden [9]. The secondary data from the scientific paper Shahid et al [10] was collected on the land available for wind energy installations in Sweden.

The purpose was fulfilled using time-series data as it explains how the past price levels and the chosen parameters affect the price level and find a significant factor which encourages Sweden for the establishment of wind power generation. This was done through price and wind power data provided by Nord Pool Group [2].

JMP was used to find a significant factor for the economics of wind power generation using JMP. Sweden was divided into four regions starting from north to south. A Comparison of different regions was done to find the most encouraging place for the establishment of wind farms using Excel.

For good visualization of analyzed data and in order to be self-explanatory and not misleading, all graphs had the same consistent scale and the figures were made to allow color-blind people to be able to separate the different bars.

3. Results

In the following chapter the results will be presented from the literature study, qualitative analysis, and quantitative analysis.

3.1 Literature Study

Articles concerning the situations of wind energy all over the world provided information about the socio-economic issues in general. Diógenes et al. (2020) [11] researched on barriers to onshore wind energy implementation in a system review, which indicated that the main barriers were inadequate consideration of externalities, uncertain and unsupportive governmental policies, and insufficient grids.

The level of acceptance or rejection for wind project from the locals circulated around issues like reduction in land values because of the wind turbine, which were of greater concern to the land-owners, the spike in electricity prices, as an environmentalist- consideration for birds, public controversies, disturbances caused to the general public like noise pollution, shadow cast, electromagnetic interference, and safety concerns [12]. These concerns fused as social, economic, socio-economic, socio-technical, political issues that hindered a wind energy project. In addition to the above-mentioned factors, according to Peter Enevoldsen and et al, [13] there was a generalized mindset of people called NIMBY (Not In My Back Yard) and it was classified into four categories as seen in Table 2.

To avoid these concerns, the investors usually preferred establishing wind farms in forest locations as there was less opposition from the locals, favorable energy policies, and also because Sweden was one of the heavily forested regions in the world [4], which was evident from Table 3.

Nuclear power in Sweden was facing high resistance from the public and the government. According to Sanghyun Hong, if wind energy is capable of generating a total power of 154 GW/year and combining with gas power and hydroelectricity could produce a total of 427.1 TWh/year against a total demand of 143.7 TWh/year could completely replace the nuclear power [14] with Sweden having the highest number of installations onshore installations in Europe [4].

By the year 2018, Sweden had a total investment of €3.7bn in on-shore wind power which was 11% more than the year 2017 accounting for 63% of renewable energy investments at the

EU-level, making Sweden the second largest investor in Europe. The government also distributed a premium of 70 million SEK to municipalities per annum to assist the transition to renewable energy and to achieve the national renewable target of 100% renewable electricity production by the year 2040 [11].

Table 2. Classification of NIMBY.

NIMBY	Mindset
NIMBY1	Positive attitude to wind power installations in general, but negative attitude to installations in the immediate vicinity.
NIMBY2	Generally negative attitude towards wind power.
NIMBY3	Positive attitude to plans to develop wind power, which change to negative when there are plans to install wind turbines in the vicinity.
NIMBY4	Negative attitude to the planning procedure rather than to wind power.

Table 3. Forest region proportion.

Country	%
Denmark	13,5
Sweden	38
Finland	75
UK	12

3.2 Qualitative study

Qualitative analysis was carried out through interviews based on the questionnaire to capture the pragmatic views on social and economic aspects for the potentiality of wind energy in Sweden.

The first interview was with Professor A, according to him, the key parameters for the establishment of wind farms included the connectivity of roadways to the project site as all the materials for the construction needed to be transported through roadways. The project site should also have good connectivity to a qualified electric power grid which could

transport the electricity produced by the wind turbines. These parameters often tended to surmount the project cost, as constructing a power grid would consume both time and capital. In-case of offshore wind turbines, legal acceptance from the government became a critical parameter as it emerged as a defense issue when it was installed in the marine regions [15].

Social issues embodied the acceptance of the locals living in the vicinity of the project site. There was a general notion among the public against wind turbines called NIMBY [13]. According to Professor A, this could be sorted out by compensating the people in the locality, and the investors should maintain a good relationship with the locals which would reduce the delay in the project. Additionally, Professor A added that the intensity of wind was widely distributed along the whole of Sweden with higher intensity centered in the northern part compared to the southern part. And seasonal changes also impacted the efficiency of the turbines [15].

The second interview was with Professor B. According to her, obtaining a permit from the government was one of the major concerns of the investors. The government issued the permit considering the distance between the wind farm and the locals dwelling in that area, as wind turbines produced noise and shadow which was considered as a disturbance by the locals. The government also acknowledged the presence of endangered species in the locality. Even though obtaining a permit was tedious, one positive note was that the permits could be obtained for the full wind field in the specific location [16].

Government supported renewable energy production by setting a target. Now, the government has set a target to increase wind energy production to 25% by the year 2040 [11]. Professor B accorded that technological improvements could increase the efficiency of the turbines which could reduce the number of wind farms. The downside of this would be, the technology of the old turbines would become obsolete and would need replacement by the technologically advanced ones which in turn would require new permits. When asked about the possibility of rooftop wind turbines, Professor B juncture that the turbines would increase the cost of electricity and it would also create a lot of vibrations making it difficult to reside [16].

Professor B pointed out that the population was varying across Sweden and the northern part of Sweden had a high potential for wind energy generation whereas the consumption was more in the southern part and vice versa [16]. This was in accordance with Professor A [15].

3.3 Quantitative study

When investigating the socio-economic aspect regarding wind power possibilities in Sweden, three different factors were considered when evaluating the quantitative results i.e. cost, local inhabitancy and wind potential. Those aspects resulted in three results where the best potential location in Sweden for the future of wind power.

The data collected was compiled as quantitative findings of the project. In figure 2, the monthly average price of electricity in Sweden during the time period April-2016 to April-2020 was shown, with price in SEK on vertical axis and time on horizontal axis. This price was to generate one MWh of electricity. The data used for this study was provided by Nord Pool [7]. From figure 2, it could be noticed that the average price of electricity varies from 150 SEK to 550 SEK. It could be clearly said that the average cost of electricity with respect to time was decreasing with two significant falls in Dec-18 and Dec-19. To check if wind power was significant for this change, the monthly average wind power generation in Sweden during the time period dec-2017 to feb-2020 was shown in figure 3, with power generation in MWh on vertical axis and time period on horizontal axis. From figure 3, it could be seen that wind power generation was increasing with respect to time. It was clear from the figure that significant change in wind power generation in Dec-18 affected the price of electricity.

To further visualize the relation between power generation and average price a bi variate fit was generated using JMP. From figure 4, the amount of power generation was improved, but there is still more variation in it.

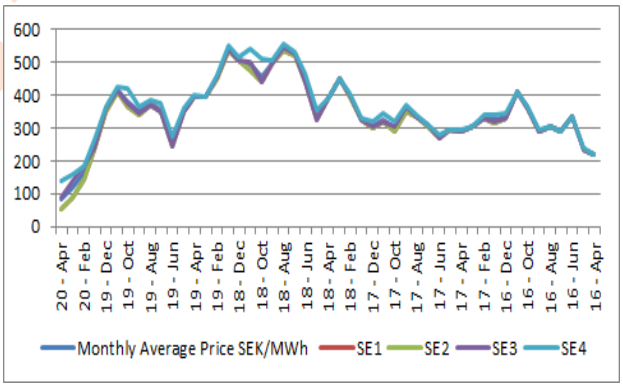

Figure 2. Monthly cost of producing wind power in SEK/MWh in Sweden April-2016 to April-2020.

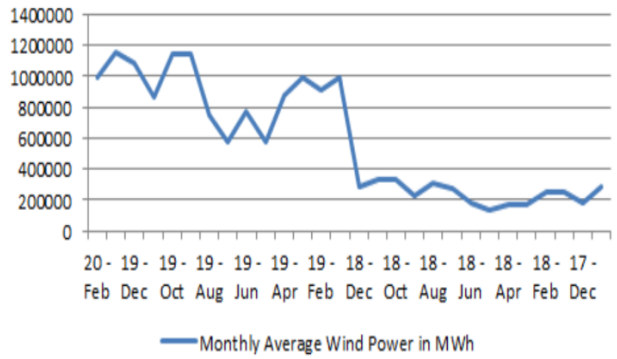

Figure 3. Monthly wind power generation (MWh) in Sweden from December-2017 to February-2020.

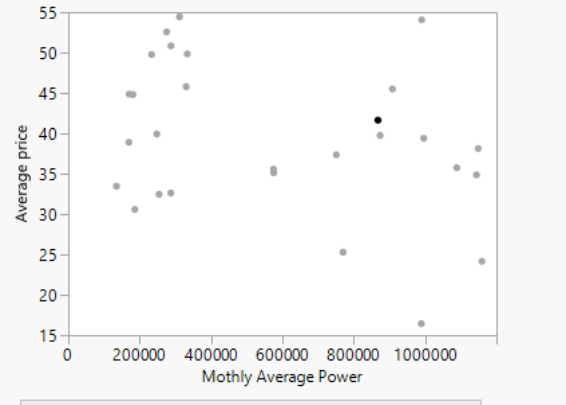

Figure 4. Bivariate comparison of Monthly Average Price (SEK/MWh) with Wind Power Generation (MWh).

In Figure 5 the data was presented that were received from Nord Pool divided in the north (Luleå and Sundsvall) and south (Stockholm and Malmö) of Sweden [7]. In figure 5 the day- ahead-price was presented in SEK/MWH under the time period April-2020 back to April-2016. From figure 5 the graph displayed a general higher cost in SEK/MWH to produce energy in the south compared to the north. The price gap between the north and the south has increased drastically this year, but it could also be seen that the overall cost has decreased for both. However, the graph indicated that there was a bigger potential to generate energy from wind power in the northern region regarding the total cost of producing energy.

Figure 6 presented data of the wind energy generation in Sweden by area received from Energimyndigheten [17]. The data was displayed and divided into four different areas, Luleå, Sundsvall, Stockholm, and Malmö which as mentioned in figure 6 was divided in north and south of Sweden. Four years of collected data was processed and analyzed which has resulted in visual trends. As figure y showed, the Stockholm area was producing the most energy from wind, and Luleå was producing less. Luleå however had a clear increasing trend of wind energy generation.

Figure 7 showed the results of land area available in percentage for onshore wind energy in four counties using a restriction scenario, in which shoreline protection zones, defense areas, protected areas, and buffer zone limits to single residual houses were excluded [10]. Skåne and Stockholm, the southern counties of Sweden, had more excluded areas than the northern counties including Norrbotten and Västernorrland.

Wind speed measurement and its data analysis was an important task to know the average wind speed available in the area where the company was willing to establish the wind farm. This measurement affected the height of wind turbines and power systems required for it. As figure 8 showed, the wind speed in the south area was higher than that of the north.

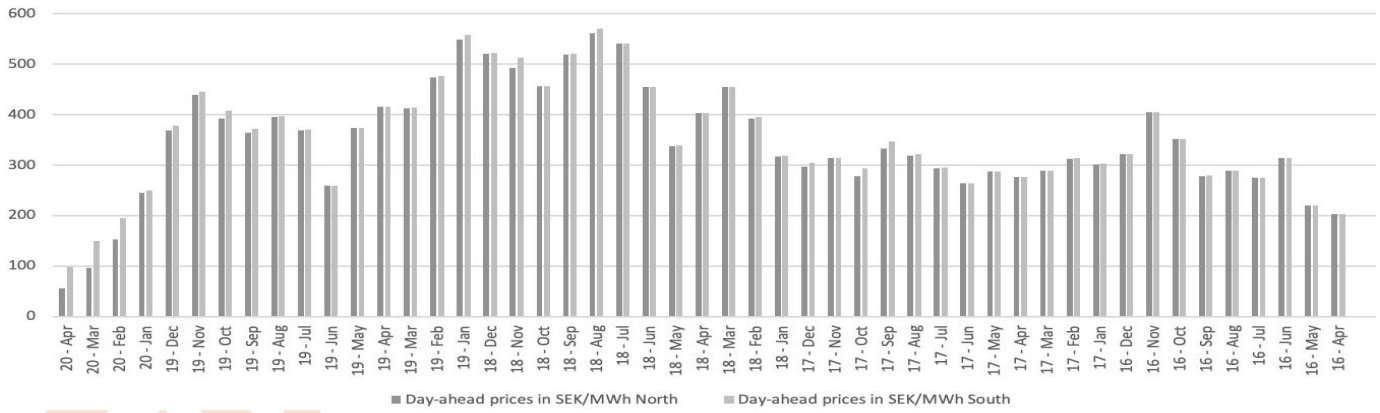

Figure 5. The cost of producing wind power in EUR/MWh comparing south & north of Sweden.

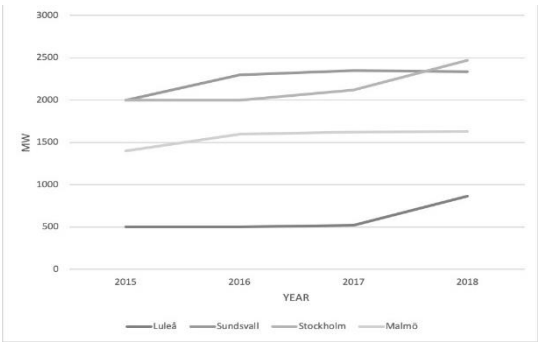

Figure 6. The trend of energy generation from four different areas in Sweden in MW between 2015 – 2018.

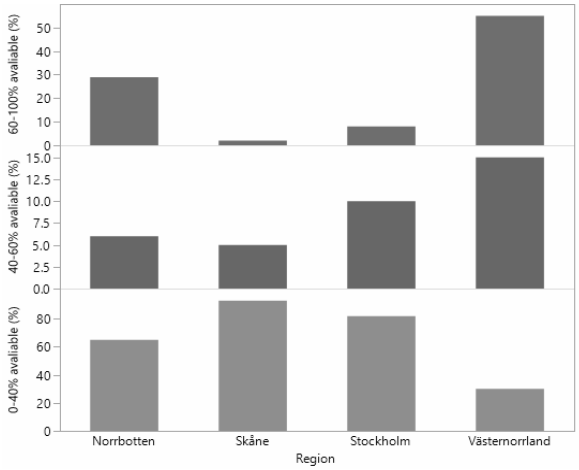

Figure 7. Land area distribution of each county in terms of (%) of the total area based on land availability (0-100%) [10].

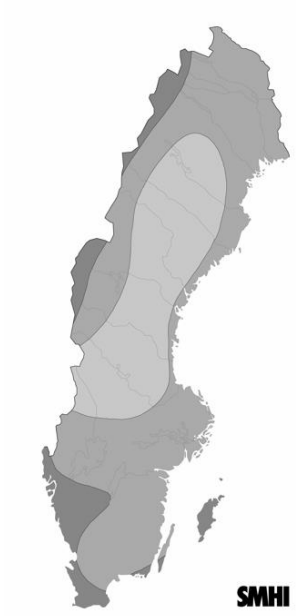

Figure 8. Wind speed distribution in Sweden (the darker color indicates higher wind speed) [8].

4. Discussion

4.1 Qualitative and quantitative study

From the literature study, it was clear that the northern part of Sweden has a high potential for wind energy. Interviewees reflected over information saying that the distance to a nearby electrical grid which will greatly affect the electricity price and often stakeholders' involvement is lacking, as there are high investment requirements and potential time delays for the project. One of the major issues concerning the delay of the project is, obtaining permits from the government for turbine erection which is surprising. The reason behind this could be a more pressing issue of the permits getting expired [16]. According to professor B, to achieve the target set by the government for 27% renewable energy from wind power by 2040, new technologically advanced wind turbine needs to be installed which again requires permits. Both conditions of generating more power from wind and industries not having permits are contrasting. Further research must be done in this part of the challenge. Today's technology is not cost-effective and social acceptance is low [11]. This means that the wind turbines must be placed in the forest to avoid the social problems and time delays by people, but it destroys wildlife in the air and increases the complexity of maintenance. From a long-term perspective, it will be economical as the environment will improve, resulting in a reduced carbon footprint [2]. As a result of these changes, the total temperature of the earth will be lowered, leading to less natural disasters, increased lifespan of people and animals, and more sustainable society. This is done through renewable energy for a sustainable future [18].

The data used for quantitative study of price and wind power gives correlation among each other (figure 2). However, the price of electricity is a cumulative cost of all the power generation sources and thus more analysis has to be done to see the exact effect of wind power generation. Furthermore, the cost analyzed is monthly basis however to see the volatility of cost, analysis must be done in more denomination. Volatility of price is surprising finding; the standard deviation of monthly average price is 9.97. Time-series analysis of power generation gives clarity of wind energy penetration. However, the standard deviation of average power generation is too high in north than in south of Sweden which encourages further look into the seasonal variation and wind speed which are significant factors for feasibility of wind farms. Bivariate graph of comparing wind power with average cost gives a good relation. While with increase in power generation, the variation is still high, further study about this volatility must be conducted to confirm the results.

The area that had the most potential from a socio-economic aspect is northern Sweden. Sweden's northern part according to figure 5 is the less expensive region to generate energy from wind power. The mentioned assumptions also correlate with figure 6 where the trend of the increasing wind energy generation clearly shows that the most northern area, Luleå, is producing more nowadays. Besides, figure 7 shows that the land availability of the northern area is significantly more than that of the southern area due to single residential houses, which also contributes to the potential of wind energy in northern Sweden. However, there are some obstacles that need to be taken into consideration, one of which is infrastructure of power transmission and distribution [19]. This was confirmed with qualitative results. What's more, because of the large area of protected areas, Norrbotten has the largest area of land but with smaller land availability than Västernorrland [10].

On the other hand, those issues could have been avoided if the wind potential graph (figure 8) was the guideline for where

the potential in Sweden is. Figure 8 clearly shows that the most wind is on the southern part and coast areas of Sweden. Offshore wind power fields could therefore be more potential but there are some even larger errors that appear when investigating the potential of offshore wind power. The reason why research has not been done on offshore wind power is because today's policy is very weak to promote its development potential [20] and therefore there is less

information available. There are also some economic and social factors that contribute to difficulties in the implementation of offshore wind turbines [21]. Establishment costs of wind farms are considerably more expensive and power grids to transport electricity are more difficult to install. This means that there are economic aspects that interrupt the process. Several social aspects are linked to offshore wind turbines, for example, the acceptance among humans is greater and the sound impact is small, according to Söderholm et al [20].

4.2 Methods and uncertainties

Qualitative study. The research question is to explore socio-economic challenges of industries in establishing wind power generation. However, the interviews we conducted are with professors and coordinator of research institutes. This reflected into most of the questions related with social aspects. The outcome of this will be a different type of data to interpret.

The interviewees may be biased in their thoughts and answers regarding wind power generation as they are working to promote renewable energy. The reliability of their answers can be questionable. Furthermore, interviewees can also answer more in the direction of work they are doing for wind power. Information can be presented in a different way which may differ with respect to time and between people.

Quantitative study. Nord Pool can only provide the data used for quantitative analysis that is from two different periods. The data give a good reasonable view of trends in price and power. However, the data is further to be investigated to find the exact price effect due to wind power generation. The analysis is limited as the number of wind turbines and wind speed available over a period of analysis is not available.

5. Conclusion

The paper's purpose was to investigate the socio-economic challenges regarding wind energy generation in Sweden. The problem formulation was conducted to the research question *"What are the socio-economic challenges faced by the industries in establishing strategic planning in the realization of wind energy generation?"* To investigate this challenge further, the paper established a triangulation method where the literature study, qualitative analysis, and quantitative analysis were connected to ensure reliability and to validate the results.

The qualitative analysis resulted in strengthening the main points from the literature study regarding how the wind power aspect is viewed from a socio-economic perspective. It was clear that the location of a turbine is decided by several factors such as legal acceptance, infrastructure, social acceptance, wind potential, and cost. The quantitative analysis was done where data from wind farms in four different areas of Sweden was collected and summarized. By interpreting our three most crucial factors, the most favorable location in Sweden could be located regarding a socio-economical view but there is a

tradeoff. The data was mainly divided into four areas from north to south. To establish where the socio-economic challenges could be handled most efficiently and become the most profitable SEK/MWh, location, land availability, and wind potential were compared.

The results showed that the lowest SEK/MWh potential was in the northern part of Sweden as well as this part with more land availability. There is already an upgoing trend in wind power generated energy ongoing which could mean that the infrastructure in the north is rising. There is also an ongoing turbine increase in Sweden that lowers the price of energy in general which also could indicate and motivate for a bigger establishment that could provide a more solid stream of energy. The trade-off or disclaimer is that the most favorable wind potential is in the southern part of Sweden, but due to the high population and the general higher cost of producing energy the socio-economical aspect is not in favor. Further research is needed and the political aspect regarding sustainable energy needed to fully be able to create a strategic plan of where to establish a successful wind energy park. However, the research visualizes where the potential is regarding all mentioned factors from a socio-economic view.

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Group 3.
A comparative study on how renewable energy generation technologies impact sustainability

Sreehari Batni Ravindranath, Madhav Bhallamudi, Roberto Costanzo, Marie-Mädli Kivimäe, Henrik Wiberg

Group **3**

sreehari@student.chalmers.se
rsai@student.chalmers.se
robcos@student.chalmers.se
kivimae@student.chalmers.se
henwiber@student.chalmers.se

Abstract

Access to electricity is an important contributor to social and economic development. The lack of electrification in rural areas in India have in recent years increased the demand for decentralized and sustainable power sources. This study therefore aims to compare environmental, economic and social sustainability aspects for solar, wind and hydro power generating systems in India. The study uses a triangulation method by combining findings from literature, four interviews with experts and a quantitative study. The study resulted in a comprehensive comparison, illustrating differences between the technologies. The combined findings imply that all the technologies contribute significantly to sustainability, but in different ways. Instead of focusing on which technology to use, the study highlights the importance of considering how the technologies are used and implemented.

Keywords: Renewable energy generation · Sustainability, India.

1. Introduction

Electricity is one of the driving forces for economic development and social equality. In 2011, almost one third of the population in India did not have access to electricity [1]. Access to clean and safe electricity represents an essential step for the economic and social development of rural remote areas in India, villages completely devoid of electricity services. Implementing electricity in these places can lead to rapid and significant improvements in economic conditions, food stocks, education, healthcare services and a vital improvement in standard of living in general [2].

Many social motivators for implementing electricity in rural areas could be identified. Electricity will ensure stable education of high quality [2]. It will promote local manufacturing activities [2]. The efficiency and reliability of agriculture operations, food storage and food processing technologies will improve considerably [2].

Another important motivator for electricity implementation concerns health. Electricity will make the healthcare system safer, efficient and more reliable [2]. Due to the lack of electricity, vaccines cannot be stored in remote areas of India because correct conservation cannot be guaranteed. However, it is especially in these areas that common viruses such as measles and rubella have not yet been eradicated [3]. Therefore, the provision of vaccines even in these extremely remote areas is essential to prevent children from losing their life due to preventable diseases [3]. Refrigeration will ensure local storage of vaccines, keeping them at the right temperature and humidity conditions even in tropical areas [3].

The social challenges mentioned above highlight the importance of the implementation of sustainable power generation technologies in remote areas of developing countries

1.1 Research question

Given the importance of renewable energy in remote areas, this study aims to examine how different renewable power generation technologies – hydro, solar and wind – compare against each other, in terms of sustainability, when implemented in remote areas of India. Sustainability is considered from the triple bottom line perspective, an approach that takes into account environmental, social and economic capital factors [4].

The project aims to answer the following research question (RQ): Considering the triple bottom line approach as a yardstick, how do different renewable power generation technologies compare against each other, when implemented in India?

1.2 Scope and delimitations

It was decided to limit the research to only three energy-generating technologies (hydro, solar, wind) due to time constraints. Additionally, the comparison between the three technologies has been further narrowed, focusing less on energy storage systems and the electric grid. An even more exhaustive and comprehensive comparison between the three technologies would have required deeper initial knowledge on the subject and a longer time-frame.

The paper uses literature, qualitative and quantitative studies to answer the RQ. The quantitative study relies only on secondary data due to time constraints.

The research project does not aim to determine one optimum solution. It represents a comparative study that highlights the advantages and disadvantages in implementing different technologies, taking into consideration specific territorial factors.

2. Methods

This research project uses the triangulation method [5], which consists of a literature study, a qualitative study and a quantitative study described in the following sections. The purpose of the three conducted studies is to provide a comprehensive understanding and answer the research question.

2.1 Literature study

A literature review was conducted with an aim to gather background information about sustainability aspects of renewable energy technologies (solar, wind and hydro) implemented in developing countries. Chalmers discovery system was used to search in various databases including scopus and mendeley. Specific keywords have been considered to find the relevant articles through the databases with the aid of strings (and/or). The results from the search were also filtered to include only articles that were published in 2015 or recent. Following keywords have been used for the search strategy:

- Renewable energy generation
- Sustainability
- Sun, Hydro, Wind
- Decentralized
- Developing countries

2.2 Qualitative study

The qualitative study consisted of four semi-structured Zoom video interviews. The aim was to fill in the knowledge gap identified in the literature study and gather in-depth information. The interview candidates were researchers and professors from Chalmers University of Technology with comprehensive knowledge in the renewable energy field. The interviewees and their current position are presented in Table 1.

Table 2. Table captions must be placed above the tables.

Interviewee	Font, size and style
Interviewee A	Researcher at Electric Power Engineering and Electrical engineering
Interviewee B	Affiliated Professor at Environmental Systems Analysis/Technology Management and Economics
Interviewee C	Professor at Electrical engineering
Interviewee D	Professor in Sustainable Electric Power Production

The interviewees were requested to grant their approval to record. Afterwards, the recordings were transcribed to text. To structure the data, the transcripts were analysed and the ideas from the interviews were written out on separate notes. Thereafter, related ideas were sorted into groups and summarized in Table 2 under the results section. To increase the credibility of the coding method used, the ideas and created categories were discussed with other members of the group, provoking a debate.

2.2 Quantitative study

The quantitative research aims to collect and analyze relevant data to establish correlations and explain discrepancies amongst the different renewable technologies.

Data on equivalent greenhouse gas emissions from life cycle assessment (LCA) studies, preferably from India, were collected in order to evaluate the environmental impact. ScienceDirect and ResearchGate databases were used to search for relevant studies. Only studies which evaluate the complete life cycle of the system were included. The means of the different technologies were compared by an analysis of variance (ANOVA) test incorporated in the JMP Pro software.

In regard to the economic factors, capital expenditure and the levelized cost of energy (LCOE) were evaluated. The data were gathered primarily through reports from the International Renewable Energy Agency (IRENA) [6] and to analyse the capital expenditure data, linear regression approach was used as it gives the relationship between one dependent variable and one or more independent variables with the aid of Microsoft Excel.

Considering the social aspect of sustainability, the employment ratio (job generated per unit of energy produced) was evaluated. The data were gathered primarily through reports from IRENA [6] and Microsoft Excel was used to analyse the collected data.

3. Results

This section presents the findings from literature study, qualitative analysis and quantitative analysis.

3.1 Literature study

The literature study provides an overview of the importance of the renewable energy technologies, constraints for the

implementation of the renewable energy, a brief assessment of the renewable technologies and provides a widened scope of future implementation of the technologies.

The importance of renewable energy. Different studies discuss the importance of renewable energy and the main reasons for which renewable energies must be set up in developing countries like India [7]. Arunachalam, Pedinti and Goel state that the economical aspects of sustainability are benefitted by establishing the decentralized distributed generation stations (DDGs) in India [7]. The authors also mention that setting up a DDG station near the consumer helps in avoiding the transmission and distribution losses [7]. Arunachalam, Pedinti and Goel also emphasises on the setting up DDGs and selection of renewable sources based on the geographical location in India [7]. Almeshqab and Utsun state that access to electricity can eliminate the existing issues related to the environment, economy and social aspects of sustainability and increase the income of impoverished communities [8].

Barriers for implementing renewable energy. Several studies have investigated potential barriers faced when implementing renewable energy in India and neighbouring countries [9-12]. Economical, political and environmental aspects have been ranked in the top five barriers in various studies [9-12].

Luthra, Kumar, Garg and Halee especially highlights initial investment cost as the most important barrier [9]. Strong policies and economic incentives by the government are also described by several as important tools to use to overcome political and economic barriers in developing countries [12-13]. Gottschamer and Zhang have mentioned another general barrier which is technological lock-in, where a combination of policy and societal factors prevent new renewable technologies from entering the market [13]. This could e.g. include oil companies lobbying or promoting the use of more fossil-based alternatives [13].

A case study investigating future scenarios of renewable energy usage in Bangladesh highlights the importance to manufacture the technologies locally, to promote both employment opportunities, economy and societal development [14]. Singh and Pal mention that one of the biggest barriers in India for renewable energy sources is the scarcity of suitable land, especially for solar panels [15].

Evaluation of different renewable technologies. Evaluation of different renewable energy technologies has been presented in various articles [16-17]. Katre and Tozzi present the use of a multi-tier framework to evaluate technical sustainability [16]. Katre and Tozzi state the limitations of the framework which mainly include acquiring data at the installation level and the cultural barriers in the fieldwork perspective [16]. Li, Geng and Li have proposed a sustainability assessment index system that discusses factors influencing the environment and health aspects [17]. Li, Geng and Li also states in his article that hydroelectricity has a positive impact on sustainability and on the other than solar and wind have a negative relationship with sustainability which is supported by his analysis from the data in G-20 countries [17].

Future implementation of renewable technologies. Mittal, Ahmed and Koli have compared and researched on availability of various renewable sources and how to enhance their implementation in the future [18]. The share of renewable energy in terms of generation capacity is predicted to increase in the future [18].

3.2 Qualitative study

Four interviews were conducted for the qualitative study. The results are presented in the following section. The interviewees are referenced according to Table 1.

Barriers. From the interviews it emerged that when it comes to evaluating the barriers, it is crucial to distinguish between systems that already exist and have to be updated and systems to be built. Interviewee C stated that building a new system is easier than retrofitting it because more freedom on the type of components to select is allowed. It is also possible to test new technologies and then choose the perfect fit between loads and generation, to always keep the balance in power.

Interviewees A and B pointed out that the main barriers to implement renewable energies in rural areas in developing countries include a heavy upfront investment, lack of infrastructure and required competence for maintenance operations. Furthermore they added that implementing new technology might redistribute the resources in the community and change power structures in this society.

Main benefits and drawbacks. The inputs from the interviews regarding the benefits and drawbacks of implementing solar, wind or hydro power in rural areas are summarised in Table 2. The factors analysed include technical features, economical, environmental and social sustainability.

Interviewee C mentioned that, from a technical point of view, the three technologies are different. It was pointed out that hydro provides a natural way to preserve energy in the mass (inertia). That's why, often, in reports concerning the integration of renewables from the association of all transmission system operators in Europe (ENTSO-E) hydro is not considered as a renewable power generation method. Solar and wind, instead, present some similarities.

Table 1: Summarized results regarding the benefits and drawbacks of implementing renewable energy in rural areas.

	Solar	**Wind**	**Hydro**
Upfront investment	Low/Medium. Many small investments possible	High	High
Maintenance requirements	Very low	High. Components wear and tear very frequently. Specific skills for maintenance operations.	Fairly easy, higher than solar, lower than wind.
Installation	Easy installation	Requires specific competence	Requires specific competence and it is time-consuming
Infrastructure	Not necessary	Medium/Large need for infrastructure	Medium/Large need for infrastructure
Scalability	Easy. Solar panels are in modular sizes.	Different wind turbine sizes are available.	Depends on the size of the river.
Power generation requirements	Sun. A disadvantage of a night time.	Wind	The river might have seasonal effects.
Power generation amount	Low/Medium	High	High
Energy production control	Low. Risk of spilling the energy - impossible to reuse the solar radiation later without having batteries.	Low. Risk of spilling the energy - possible to avoid energy overproduction by shutting off the turbine. Can not use the energy afterwards without having batteries.	High. Water usage can be controlled without spilling energy. Delivers a constant amount of power in the system, that can be controlled by opening and closing valves.
Environmental sustainability	Rare materials used to produce panels. Requires batteries. A lot of land is needed for large solar plants.	Extensive use of copper (not rare, but limited resource). Requires batteries. Blades are made from carbon fibre, which can be burned so they would not contribute to landfill. Furthermore, blades might hit animals (birds and insects), but the newest developments have included bat mode.	Dams have a huge environmental impact, create a lot of methane gases and require land. It can be very invasive on the territory and destroy entire natural habitats. Dangerous for animals (fishes). Small rivers can be added beside the dam to allow fishes to pass through. Dam replaces the need for a battery. Provides the system with inertia, that is a way to store energy in the mass that can be released to the power system.
Social sustainability	During the interviews, nothing specific was mentioned on how solar generation contributes to social sustainability.	Noise generation by wind turbines requires restricted areas. Houses should be located at least 1km away from the plant.	Shared resource - water resource is limited. Might open an opportunity for fishing, which contributes to the local/regional food supply. On the other hand, when building a dam, some people might lose their agricultural land.
Local engagement	Small. It does not contribute as much to economic development.	Medium	High. It requires water management, which also benefits social management.

Interviewee A brought up that wind turbines generate noise and there is a need to restrict some areas, which might affect social sustainability. Hydropower was mentioned to be different compared to solar and wind power because it can be classified as a shared resource. Interviewee B and C added that for hydro power a dam that restricts the flow of water is normally needed to store water during rainy periods and to use it more evenly over time. Controlling the flow affects the villages downstream. If the dam puts areas underwater, then people might be forced to move. So the social impact could be that someone's land is occupied. On the other hand, interviewee B mentioned that a dam can open a possibility for fishing, thus supporting local food supply. Other problems may be that people living in downstream villages cannot have access to water because it is all stored by the dam. Interviewee D argued that wild animals might face the same problem. Moreover, farmers cannot continue their agricultural production and breeders cannot feed animals.

From a social sustainability point of view, the interviews showed that the main benefits are associated with having electricity in the community rather than a specific energy source. An interesting result that emerged during the interviews was that the social benefits depend on how the technology is implemented. To illustrate this, Interviewee B mentioned the *light for education project* implemented in a small village about 100 km from Bangalore, India [1]. Solar panels were installed on the school roof and the households were given a light system with a battery. The battery could be charged during the sunny day time for free in the centralised solar charging system in the school only by students. This initiative promoted youth education because village families could only get light by allowing their child to go to school [1].

From an environmental perspective, interviewee A and C specified that solar and wind would require a battery storage system, while building a dam replaces this need. Interviewee C added that once batteries break or end their life, they pose a risk of pollution. Interviewee D asserted that if batteries are made recyclable from the beginning, it is then possible to reuse 70-80% of old materials. After 5 to 10 years, only 30% of new materials need to be bought.

From an economic perspective, interviewee A pointed out that solar power has the advantage that panels can be installed modularly and it has a low need for infrastructure. Interviewee B claimed that wind and hydro require a high upfront investment, but also contribute more to local engagement.

Overall sustainability. The overall sustainability, in terms of the triple bottom line, is not easy to evaluate. Interviewee C recognised material usage as a measure that is gaining interest when it comes to evaluate the overall sustainability of a technology. Specifically, interviewee C outlined that the type and quantity of material used for a specific component, the amount of energy that the material is able to generate compared to others and the way in which the material is procured are all important parameters that define sustainability.

Interviewee D asserted that mining of rare earth elements can have a huge impact on all the three pillars of sustainability. It is not uncommon that mining activities are performed by children in developing or underdeveloped countries. However, interviewee D highlighted that it can also be done following ethical rules, not exploiting child labour. Interviewee D concluded that the overall sustainability is mainly a matter of economy and planning.

3.3 Quantitative study

From the quantitative study, a collection of parameters have been analysed from the three aspects of sustainability. In regard to the environmental aspect, equivalent CO2 emissions throughout the complete life cycle were investigated and similarly, LCOE, capital expenditure and employment ratio were investigated for the economical and social aspects respectively.

Environment. To investigate the environmental impact of the technologies, greenhouse gas equivalents from LCA studies were gathered [19-28]. The data includes power generation systems with capacities ranging between 1-25000 kW. The data-set also contains solar panels made out of different materials and hydro systems of both reservoir and run-of-river systems.

As seen in Figure 1 and Table 3, the 95% confidence interval of each technology mean overlaps. Based on this, it is not possible to determine that there are any significant differences between the means of the power generation methods. Looking at Figure 2, it is, however, possible to see tendencies of relationships. Equivalent CO2 emissions e.g. appear to depend both on the capacity and type of hydro system used.

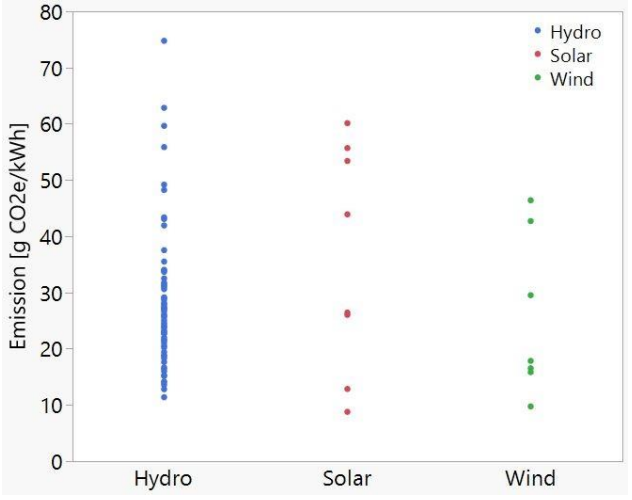

Figure 1: Scatterplot of equivalent CO2 emissions for hydro, solar and wind

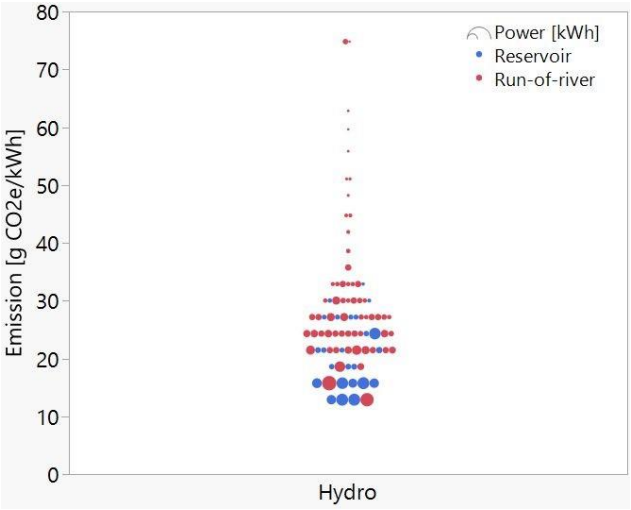

Figure 2: Scatterplot of equivalent CO2 emissions for hydro, illustrating type by color and capacity by size of scatter

Table 3: Data from ANOVA test

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Hydro	84	28,2609	1,4482	25,386	31,136
Solar	8	35,8850	4,6927	26,570	45,200
Wind	7	25,4857	5,0167	15,528	35,444

Economy. For the economic aspects, the LCOE factor was used to identify the cost-effectiveness of renewable energies. Figure 3 illustrates the estimated LCOE, sourced from the Energy Information Administration [29]. From the presented data, it can be assumed that the cost per kWh is higher for solar which can have a negative effect on the economic factor.

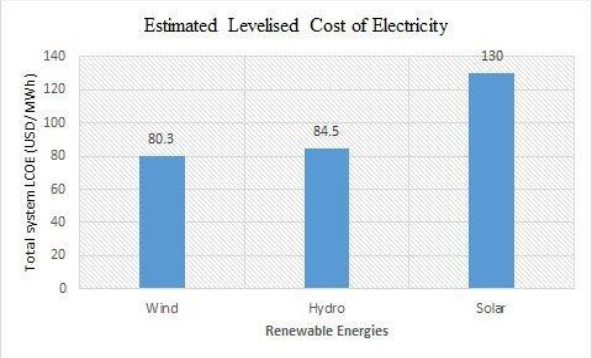

Figure 3: Estimated LCOE

Studying the data collected about capital expenditure forecast [30], it can be predicted from Figure 4 that solar and hydro power generation have an edge over wind energy generation in terms of capital investment, resulting in a positive impact on economic sustainability.

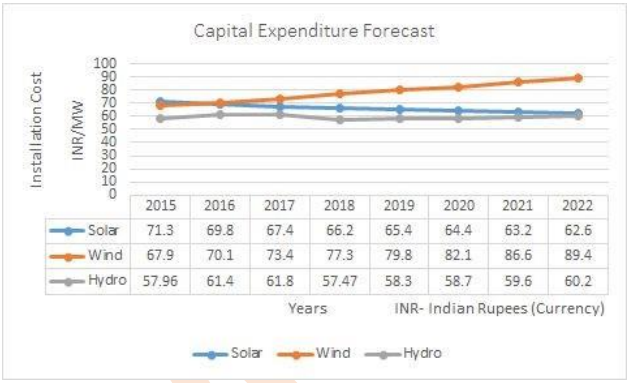

Figure 4: Capital expenditure

Social. Based on global data from IRENA about employment and total energy produced by each sector, employment ratios for several years were calculated [5]. The results, shown in Figure 5, illustrate that solar creates more employment opportunities per kWh, compared to hydro and wind.

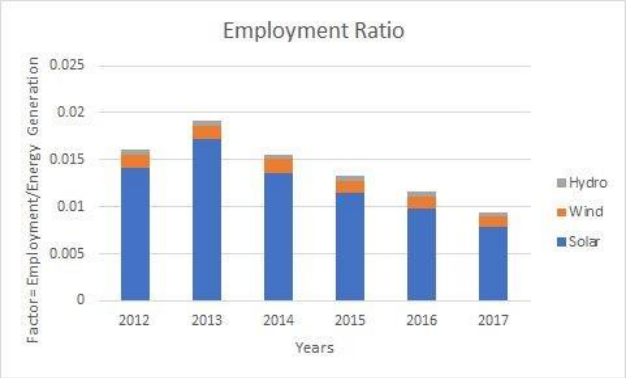

Figure 5: Calculated global employment ratios per year

4. Discussion

This section will focus on discussing the interpretation, implications and uncertainties of the results.

4.1 Interpretation of results

Although all renewable technologies contribute to social sustainability, it is interesting to compare them to determine the optimal technology to be installed in a specific geographical location.

An interesting insight from the interviews is that solar power's maintenance requirements are low, while wind

turbines components wear out frequently and require more maintenance. Therefore, one could expect that the use of wind power would create more job opportunities in remote areas and, consequently, increase well-being.

On the other hand, the data collected in the quantitative study for the employment ratio show a different trend. Solar power creates more job opportunities per kWh, but this could be explained by a lower amount of energy generated by solar panels. However, it is worth clarifying that no relationship has been found between job opportunities that are created due to the technology implementation and the employment rate of local inhabitants. It is likely that the job opportunities directly related to the plant's implementation, e.g. maintenance operations of the production units, require personnel with technical skills, coming from outside the community. However, with electricity being introduced in remote areas, it is reasonable to assume that both local development and the number of employment opportunities will increase, even outside of power generation.

Literature study and interviews introduce several barriers that need to be overcome when implementing renewable energy technologies in remote areas. Heavy upfront investment cost mentioned in the interviews aligned with the findings of Luthra, Kumar, Garg and Halee, identifying initial investment cost as one of the most important barriers [9].

From the interviews conducted for the qualitative study, it emerged that there are interconnections between social and environmental sustainability. As reported in the results, building a hydro plant might, at first glance, mainly have an environmental impact. However, the construction of a dam could open up new fishing opportunities and give the possibility to irrigate crops. The downside is the occupation of the land for the inhabitants living nearby and the serious impact on the environment and on local animal species. Such interconnections need to be studied and evaluated thoroughly to encourage positive interactions and avoid negative interactions.

As reported in the qualitative study results, in order to evaluate the overall sustainability of a renewable power generation technology, it is essential to evaluate the material usage. The entire life cycle of the material, from cradle to grave, should be assessed and the procedures followed for all the processes involved should be identified. If all procedures are categorized as sustainable and ethical, the technology can be classified as sustainable. This assessment should take into account all the components of the plant. Attention should be paid not only to electricity generation, but also to energy transportation, distribution of the loads and energy storage. To conclude, it is the combination of all these factors that define the global sustainability of a system.

4.2 Methods and data uncertainties

The collection of secondary data from remote places of India proved more difficult than expected. Especially the availability of quantitative data was limited. All three sustainability aspects evaluated in the quantitative study, therefore, involve global data to varying degrees. However, social sustainability proved to be especially difficult to measure quantitatively regardless of the location of the collected data, mainly because of a lack of common indicators to benchmark.

Furthermore, results from the interviewees may be biased as some of the experts mentioned that they have little or no experience with the renewable projects implemented specifically in remote areas in India, although some examples were based on projects implemented in remote areas in other developing countries.

Even though general conclusions can be drawn, there is a need for more regional and technology-specific data to draw definite conclusions. As a result, further data collection of each technology and specifically in India is suggested.

4.3 Potential implications of results

One of the potential implications of the study is that it illustrates that the overall sustainability appears to depend more on how the system is implemented, rather than which technology is used.

In addition, the study presents the complexity and comprehensiveness of comparing sustainability aspects of power generating systems. The study demonstrates interconnections between environmental and social sustainability. To understand this fully, more research is required.

5. Conclusion

The study aimed to compare environmental, economic and social sustainability aspects of solar, wind and hydropower generation implemented in remote areas of India.

The study could not identify any significant difference between the equivalent CO2 emissions of the compared technologies. The study could, however, show that on a global scale, solar power is more expensive per kWh, while wind power generally has a higher initial investment cost. Globally, solar proved to create significantly more employment opportunities per kWh than wind and hydro power.

Furthermore, the qualitative study resulted in a table summarizing benefits and drawbacks regarding sustainability and some technical aspects of each technology. The table can, to some extent, be used as an overview when considering either wind, hydro or solar.

The environmental findings indicated that there might be other aspects than the choice of technology affecting the environmental impact. For hydro, the size and possibly the specific type of system appear significant.

All of the findings combined imply that the impact on sustainability appears to depend more on how the technology is implemented rather than the choice of technology.

The study contributes to a general understanding of the complexity and comprehensiveness of evaluating different power generating technologies and sustainability aspects.

To conclude how the size and different subcategories of technologies affect sustainability, more samples would be needed. Another major limitation was the lack of regional data for India. To collect and evaluate more regional and technology-specific data could, therefore, be seen as a potential area of further research.

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PART 2 – MOBILITY

Group 4.
The Environmental Impact Of Car Sharing

Gustav Axelsson, Rahul Gowda Bangalore Rudre Gowda, Oscar Elm, Edvin Johansson, Guru Prasath Sivakumar and Karl Westmark

Group **4**

gusaxel@student.chalmers.se
rudre@student.chalmers.se
oscarel@student.chalmers.se
jedvin@student.chalmers.se
pguru@student.chalmers.se
wekarl@student.chalmers.se

Abstract

With an emerging car sharing market, there is a need to research to understand the effects of car sharing on the environment. The purpose of this paper is to come up with a possible answer to the question "Can an increase in the car sharing market affect car usage and in turn affect the environment?". To answer this question, a literature study, a market survey and an interview with an expert have been conducted. The results from these studies show that if car sharing will reduce the total distance travelled by car and if e-car sharing services are used, it will be beneficial for the environment. Due to the limited time and data that was available, it is not possible to answer whether car sharing will reduce the total amount of distance travelled by car. Thus, the research question can not be answered with 100% certainty.

Keywords: Car sharing · Car usage · Environmental impact.

1. Introduction

The basis for the research project is presented in the first chapter. Background, research questions, and limitations are stated.

1.1 Background

The concept of product-service systems or servitization is currently booming in the transport industry. Servitization is a concept where the products are sold as a service instead of a one-off sale [1]. Major manufacturers like Rolls Royce, Toyota, Volvo, etc., are shifting and adopting this new trend with concepts such as 'Power By the Hour', 'Sunfleet', and 'Care by Volvo'. In the current market where service is becoming increasingly important, the world is also facing major environmental problems, with the constant rise in global warming and greenhouse emissions the increasing trend in manufacturing of thousands of vehicles is not favouring the environment in any way. There is an increasing trend in the number of cars being manufactured every year [2] and with this, we put the environment at greater risk by depleting natural resources. New business models need to be developed and adopted to avert the environmental crisis which we will face if we continue in the existing path. One cannot help but think if the concept of servitization is beneficial to the environment or not. Car sharing comes under the concept of servitization where an individual can take advantage of a car without holding responsibilities such as ownership, maintenance, insurance, etc. With rapid growth globally, the market for car sharing is expected to be valued around USD 6.5 billion by 2024 [3].

1.2 Research question

The purpose of the research is to further analyze the concept of servitization, particularly car sharing and its environmental effects. This paper will determine the answer to the research question: "Can an increase in the car sharing market affect car usage and in turn affect the environment?" To answer the research question we have performed a literature study and followed a mixed-method research approach. This paper complies with information from various data sources to arrive at the answer to the previously stated research question. It was observed during the literature study that there was a lack of information concerning the car sharing market in Sweden and hence quantitative data is gathered from the general public of Sweden to predict how the car sharing market might unfold based on the responses.

1.3 Limitations

Since the research project started in April 2020, due to global pandemic COVID19, the entire research project was carried out remotely which affected a lot of fieldwork; also, we were unable to interview experts from industry as their working hours were limited. The project had strict time limitations which affected the project in general, but especially the conducted surveys.

2. Method

The process of how the literature, qualitative and quantitative data was found and how it was sorted out is described in the following section.

2.1 Literature study

The literature study had criteria for the publication date set after 2014 to receive the most recent and relevant data. The papers were searched for in the following databases: Chalmers online library, Google Scholar, Scopus and Web of Science.

The literature selection process started with finding relevant titles and reading the abstract to discover whether the content was appropriate for the research. If the content was appropriate, it was read more carefully; otherwise, it was excluded.

The literature study included 24 articles, hence is a quite small quantity, but it enlightens the number of usable articles available in different databases. In general, the literature covers the studied topic well, though it will presumably need to be complemented with different types of data, which can be collected through quantitative or qualitative surveys.

2.2 Qualitative study

To collect qualitative data, a questionnaire of six carefully chosen open-ended questions were compiled to receive relevant and useful information. The option of having a formal interview was given to ensure that the responders did not feel pushed to answer the questionnaire in a way that they disliked. The questionnaire is presented in Table 1.

Table 1. Interview questions

Questions	
1.	What are your opinions on car sharing?
2.	How do you think car sharing services will develop in Sweden?
3.	What do you think the environmental impact would be if the market for car sharing increases?
4.	Do you think that car sharing is benefiting the environment in comparison to private car ownership? If so, how does it benefit?
5.	In our early literature study, we found that mainly young and educated people use car sharing services. Why do you think this is the case?
6.	How do you think the production of cars will be affected if the car sharing market increases?

To enable the collecting of the information needed, a list of experts within the subject area was contacted. The intention was to find experts with different perspectives regarding our topic. Covering both Ph.D. students and teachers at Chalmers, and also people working in the car sharing industry. The people contacted at Chalmers where people believed to know about car sharing in Sweden and its environmental impacts. They were also kindly asked to suggest names of people who were even more suitable.

2.3 Quantitative study

After the literature study and the qualitative study, a knowledge gap within the Swedish car sharing market was found. In a try to fill this gap, a survey was conducted to collect quantitative data.

The quantitative analysis was conducted through a survey by Google forms and the survey was shared via social media such as Facebook and LinkedIn. The survey was also sent to a Ph.D. student who shared it with his colleagues. To fill in the knowledge gaps regarding the Swedish market, a total of 14 different questions were provided to be answered. The questions can be found in table 2. They were formulated to get a broad overview of the usage of car sharing in Sweden today.

Table 2. Survey questions

Questions	
1.	What is your gender?
2.	What is your age?
3.	Which city are you currently living in?
4.	What is your education level?
5.	Do you own a car?
6.	Are you using car sharing services today?
6a.	If yes, how often are you using car sharing services?
6b.	If yes, what are the different car sharing services that you have used?
6c.	If no, what's the reason?
7.	Do you think car sharing is beneficial for the environment?
8.	If you knew that car sharing had environmental benefits, would that change your usages of the services?
9.	Please state for what purpose you would use car sharing services?
10.	In-case of using car sharing, what type would you like to use?(Electric/Fuel-powered)

11.	When using a car sharing service, which aspect would be the most important for you?

3. Results

The results from the literature study, the quantitative and qualitative study are presented in this chapter.

3.1 Definition of car sharing

When doing research it is important to establish the definition of the subject. The Following citations are definitions of what car sharing is. These definitions were seen as the basis for this research.

"Car sharing is a membership service available to all qualified drivers in a community. No separate written agreement is required each time a member reserves and uses a vehicle. The car sharing companies offer to their members the access to a dispersed network of shared vehicles 24-hours, 7 days a week. It should be highlighted that the trips are not shared between drivers, only the vehicles are shared at different times by different drivers" [4].

"Compared with leasing, the unique characteristics of car sharing mainly come from two aspects. First, the expense is calculated in a smaller unit of time, specifically speaking, per minute or hour, while the unit of a leasing period is generally day or month. This feature generates a pooling effect—one shared car can serve several customers in a single day. Second, when using shared cars, customers are only charged by either a per-unit-of-time price, per-unit-of-distance price, or both"[5].

3.2 Literature study

Through the literature study, a range of interesting articles was found in different databases such as Scopus, Web of Science, and Google Scholar. There are a lot of published articles regarding car sharing, but with different perspectives such as behavioural, technical, and environmental.

Greenhouse gas emissions within the transport sector can be lowered through four categories. Technical, legislative, infrastructural, and behavioural. The last category is changing the way of using vehicles, such as shifting to car sharing from traditional ownership [6].

3.2.1 Technical aspect

The transport sector contributed to 23% of the global CO2 emissions in 2010. This percentage is continuously increasing and one needs to use alternative ways of transport to reduce this percentage. Carsharing, if used effectively and efficiently, can be the strategy to reduce CO2 emissions [7].

A reduction of greenhouse gas emissions by 3-18% could be achieved by an average member with car sharing, but many aspects affect the emission. Under the wrong circumstances, car sharing could even increase emissions. The wrong circumstances involve using very old conventional vehicles with a high emission rate for car sharing. There is an urge that the focus should be to reduce the automobile usages instead, either by carpooling, utilizing the space in each car or by better use of public transportation [8].

A simulation explains the benefits of implementing e-car sharing in the city of Fortaleza in Brazil. VAMO is the scheme and part of the Fortaleza 2040 Plan which was adopted by the city of Fortaleza to provide an alternative and better means of transport through e-car sharing. The success of car sharing schemes is dependent on the cooperation between the public and private sectors. Car sharing requires support from the government to provide public land to use as charging stations and parking spaces. If the government promotes e-car sharing services by increasing the awareness of environmental problems and provides subsidies for the employees to use e-car sharing services, then there would be a great reduction in carbon emissions. The government should make aggressive policies such as banning older conventional vehicles by increasing the retirement rate of combustion vehicles and increasing the electric vehicle market by promoting the use of electrical vehicles. According to the simulation results, by 2040, if the government continues to support VAMO by favouring the use of an e-car sharing scheme, the VAMO car fleet will increase, the number of electric cars will increase to a great extent and due to this in aggressive scenarios, there will be 29% reduction in CO2 emissions. The results of the simulation can be seen in Figure 1, where BAU represents the Business As Usual scenario and P1-P15 represents various scenarios where the retirement rate of old vehicles and the VAMO growth rate are continuously increased. [9].

Experimental design – policy analysis.

		Increasing VAMO growth rate by:			
		0%	50%	100%	150%
Increasing old vehicle retirement rate by:	0%	BAU	P4	P8	P12
	25%	P1	P5	P9	P13
	50%	P2	P6	P10	P14
	100%	P3	P7	P11	P15

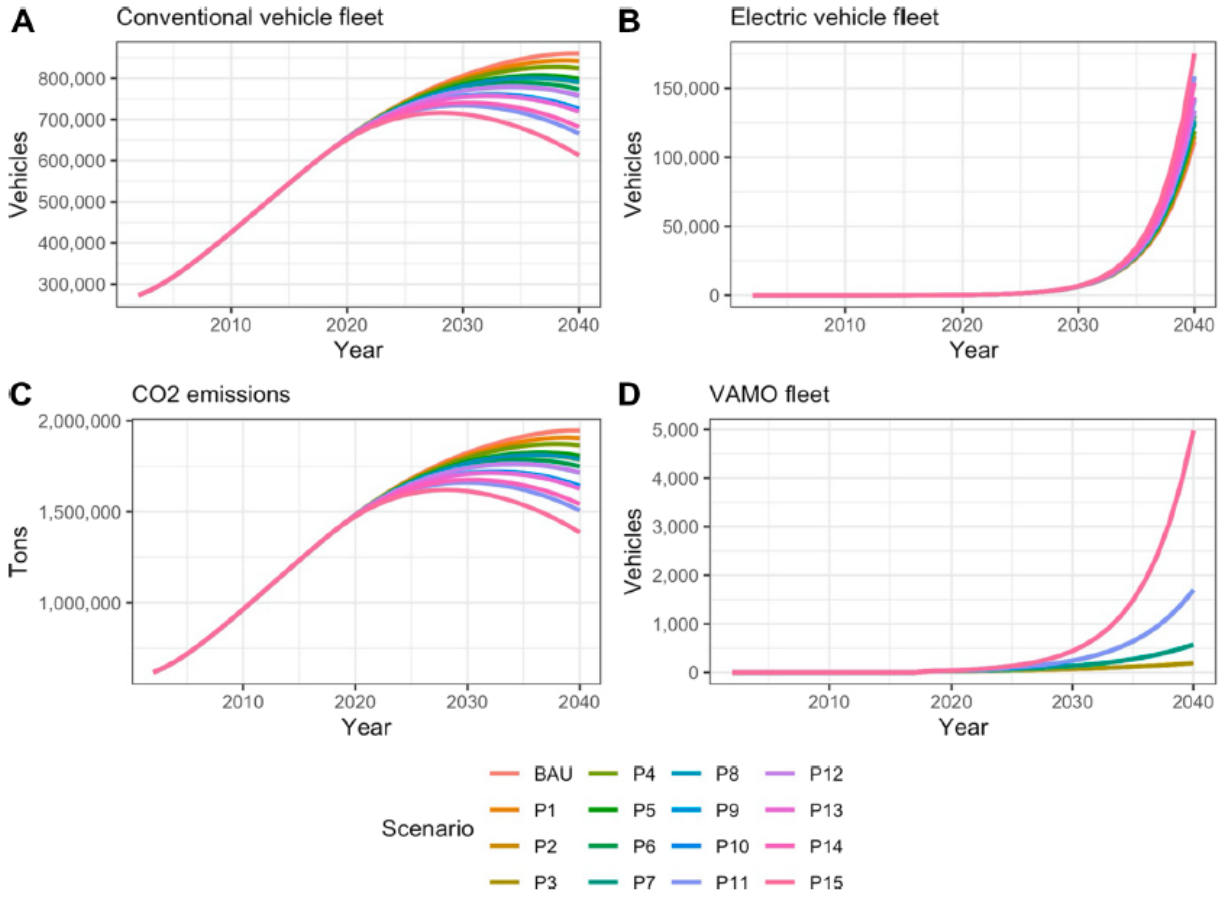

Figure 1. Simulation results [9]

Switching to car-sharing (conventional vehicles) can reduce private car ownership in the ratio of 6:1 [10]. This would help in reducing 0.6kg of CO2 emission per kilometre if the distance is travelled using car sharing. But in general, people focus only on tailpipe emission and tend to forget the emissions due to the production of vehicles, energy etc. Car sharing could benefit the environment not only by reduced CO2 emission but also by minimising energy consumption. A case study was performed in the Lisbon city of Portugal for the analysis of the energy and environmental impact of car sharing. In this case study, the emissions were classified into two categories namely fuel tank to wheel stage (TTW) and well to tank stage (WTT). TTW accounts for fuel consumption and emission involved in moving a vehicle and WTT accounts for expended energy and emission involved in bringing the fuel from the source to the utilization stage. The sum of TTW and WTT is known as well to wheel (WTW).

To find the best car-sharing method for reducing the negative impacts on the environment, two technology-based scenarios were considered, where scenario 1 is replacing the conventional vehicles with hybrid vehicles while scenario 2 is replacing it with electric vehicles. From Figure 2, it can be understood that there is a significant reduction in energy consumption (35% or 47%) and CO2 emission (35% or 65%) only if scenario 1 or scenario 2 is introduced [10].

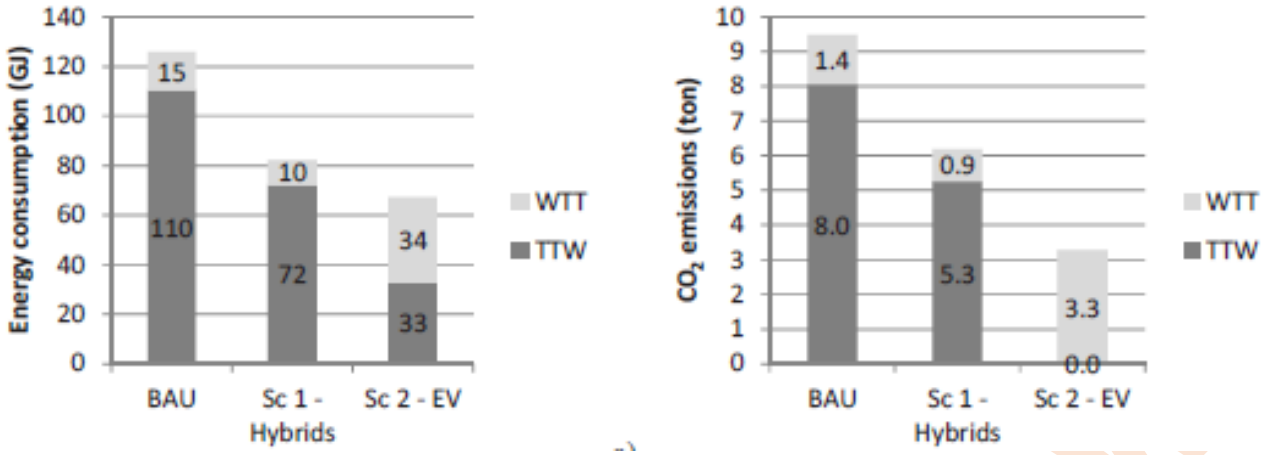

Figure 2. Energy consumption and CO2 emissions [10]

3.2.2 Behavior aspects

Studies have shown that consumers' view car sharing as a more environmentally friendly means of transport when compared with private car ownership [11] and that the environmental aspects are a great driver for the consumers to use car sharing [12]. Car sharing is more popular in cities with higher green party votes and cities with high educational levels [13].

Surveys have been conducted in different countries around the world, and one survey from Italy showed that there is an increasing market in Italy and that mainly young people, environmentally conscious people and people with education tend to use car sharing services [14]. A Chinese study also showed that there is an increasing market for car sharing in China and this study also showed that mainly young people use car sharing services [15].

Environmental benefits from the car sharing market mainly depend on the size of the market and people's acceptance of car sharing. It has been revealed that the car sharing market is mainly linked to age, gender, and education level. People who are young and highly educated prefer to use car sharing as they are aware of the environmental benefits [16].

The two major changes in behaviour that car sharing results in are the distances travelled and the changes in ownership, these both aspects can have a major impact on the CO2 emissions [17], [18], [19], [20]. People that use car sharing own 30% fewer cars and drive 15-20% fewer kilometres when compared to prior entering the car sharing service. However, the shared car in most cases replaces the second or third car in the household [19]. Car sharing can replace traditional trips with privately-owned cars and thus reduce the total amount of car ownership. 40% of car drivers can consider replacing some of their usual car trips with the car sharing, however not replacing their car ownership. Only 20% of car drivers can consider eliminating their car ownership if car sharing was available nearby. This indicates that car sharing isn't an obvious solution to reduce car ownership [21]. However, there is a potential that 50% will postpone their car purchase if they were using car sharing. This delay in car purchases will decrease private car ownership [22].

Increasing usage of car sharing services has a clear correlation with other sustainable means of travel, such as walking or taking the bike. This would reduce the total amount of car usage and thereby reduce CO2 emissions [23].
There is however a problem with increasing car sharing usage because this could result in less demand for public transportation [18]. Especially when public transportation is insufficient [24].

Changes in private transportation behaviour can have both positive and negative impacts on the environment and greenhouse gas emission, see Table 3.

Table 3. Positive and negative impacts on the environment

Scenario	
1.	People switching from private vehicles to car sharing with high fuel-efficient cars
2.	People shifting towards car sharing from public transport
3.	People who had plans of car ownership in future opting car sharing.

Scenario 1 & 3 will help in emission reduction while scenario 2 will increase the emission. Thus by using car sharing, CO2 emission from the road transportation sector could be reduced by 1.2%. The amount of private car ownership decreases due to car sharing, the number of miles

travelled did not decrease as the distance travelled by non-car owners increased. Thus greenhouse gas emission due to the shift from public transport to car sharing exceeds the greenhouse gas emission reduction of unproduced cars [3].

3.3 Qualitative study

During the literature study, it was found that there is a lack of information and data regarding the Swedish market in particular. The missing information and data could be retrieved by conducting surveys that target the Swedish market.

The qualitative study was performed by interviewing one person with great knowledge of car sharing and its potentials to reduce the environmental impact of car usage. The ambition was to interview several people with great knowledge about car sharing in Sweden, but unfortunately only one among the many people who were contacted was willing to answer our questions through an online meeting. This was Frances Sprei who is an Associate Professor in Sustainable Mobility at the Department of Space, Earth and Environment, Physical Resource Theory at Chalmers University of Technology [25].

The answers to the questions in Table 1 were provided by Frances and they are summarized and stated below in Table 4.

Table 4. Interview answers by Frances Sprei [25]

Question	
1.	Car sharing has good potential to reduce the environmental impacts caused due to the transportation sector. But how large that effect is, isn't very well known. Car sharing is an important piece of the puzzle in order to realise a society without vehicle ownership. Other aspects are also very important to consider, such as how the availability of other transportation alternatives and infrastructure affects car sharing.
2.	Car sharing in Sweden is currently in an interesting place. The car sharing market has been dominated by one actor, Sunfleet. But they are transforming into a new company, "M" which has a different business strategy focusing on being more exclusive. How this will change the car sharing market will have to be analysed later on due to the ongoing shift right now.
3.	It depends a lot on what vehicles are being used, but it does not need to be smaller and fuel-efficient cars. It rather has to be a car that people have a good use for instead of a fuel-efficient car. But if all car sharing vehicles are big and enable a larger transportation volume, the environmental benefits might not exist. So in order for car sharing to have a positive environmental impact, there has to be a big variety of car models. But the size of the impact is not very well studied in Sweden. Car sharing will also result in people shifting their mode of transport from public transportation to car sharing which will cause an increase in car usage. But studies show that the total effect of car sharing will still be positive and reduce car ownership.
4.	Yes, most studies show beneficial environmental effects of car sharing. The important question is how big those benefits are and how easy is it to increase car sharing and scale it up. The main benefit is that car sharing can reduce the amount of car usage, if you don't own a car and have to pay every time you use it, you are more likely to reduce your car usage. But if you need to use a car to commute to work, car sharing won't be your first choice because the business model is not adapted for frequent use.
5.	Yes, that is often the case with car sharing. For example, families with kids are less likely to use car sharing due to the requirement of special car seats. So there are groups or categories of people where car sharing is less suitable.
6.	Some studies show that total car production will decrease but not very much. Car sharing would result in fewer cars circling on the streets, but they would be used more frequently. A privately owned vehicle has a utilization rate of 1-3% while a car sharing vehicle would have a maximum utilization rate of up to 30%. The vehicles used in car sharing are therefore expected to have a shorter lifetime and a higher turnover rate. The production of vehicles might not decrease as much as the number of vehicles in circulation.

The result from this qualitative study both aligns with the results from the literature study and complements the missing information and data regarding the Swedish market. Frances confirms the potential environmental benefits of car sharing, but that the way to reach those benefits isn´t clearly staked out. The development on the Swedish market depends mostly on the transformation of Sunfleet to "M" and how the business strategy will be reconstructed. As Frances said, a car sharing fleet that only consists of large exclusive cars, will not be as environmentally beneficial as a car sharing fleet with a large variety of car models. The environmental benefits of car sharing will increase if the market size increases and the production of cars will not be reduced to a great extent as the turnover rate of vehicles which are used in car sharing is higher because of the increased utilization rate.

3.4 Quantitative study

A total of 158 responses were collected to the survey. Majority of the participants were between the ages 18-35, currently living in Gothenburg and are studying or had studied at University level. The most interesting results will be presented below.

From Figure 3 it can be seen that 22% of the participants and in the follow-up question they were asked how often they are using car sharing services. From this, it was found that 56% of these 22% only use the services once a year.

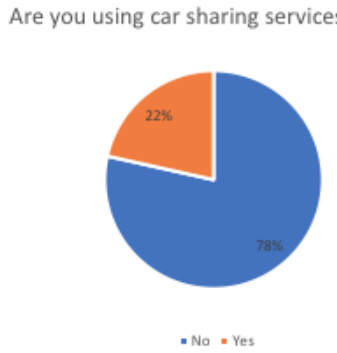

Figure 3. Containing results from the survey, "Are you using car sharing services today?"

Another interesting result from the survey was that 92% of the participants thought that car sharing is beneficial for the environment while only 2% thought that it is not. These results are presented in Figure 4.

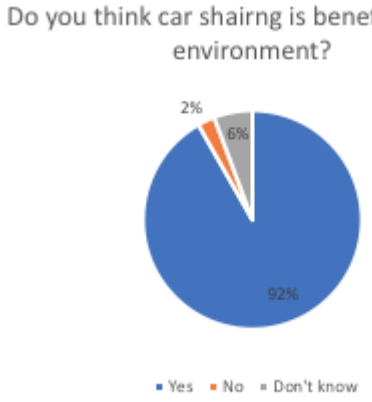

Figure 4. Containing results from the survey, "Do you think car sharing is beneficial to the environment?"

However, on the question "If using car sharing services, what aspect would be the most important for you?" only 4% answered that the environmental aspect was the most important for them. The result of this question can be seen in Figure 5.

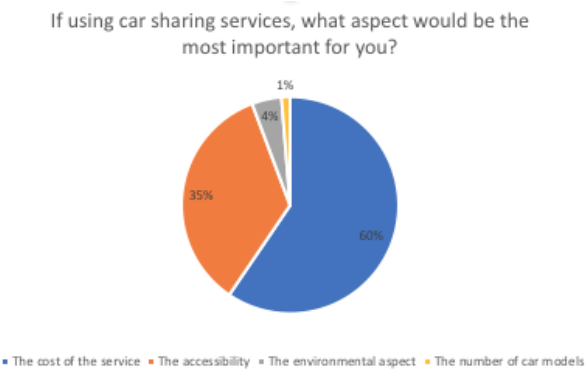

Figure 5. Containing results from the survey, If using car sharing services what aspect would be the most important for you?"

Also, when being asked if their usage of the service would change if it was confirmed that car sharing indeed was beneficial for the environment the opinions were very split. This can be seen in Figure 6.

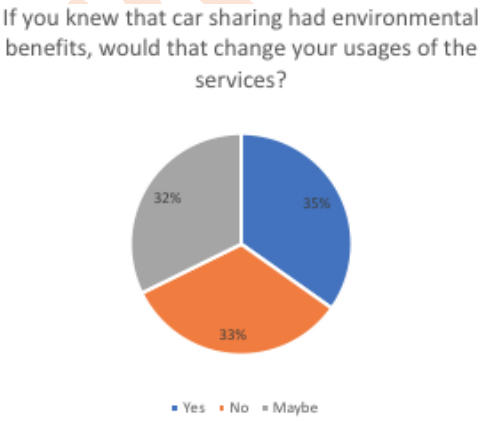

Figure 6. Containing results from the survey, " If you knew that car sharing had environmental benefits, would that change your usage of the services?".

4. Discussion

Regardless of using a privately owned vehicle or a vehicle from a car sharing service, the CO2 emissions will be prominent. Only if e-car sharing services are adopted, the CO2 emissions can be cut down. For car sharing to be environmentally beneficial, it has to change and reduce our total usages of cars. Interestingly, the information provided in the results, that people who use car sharing services also tend to use more environmentally friendly means of travel, such as cycling and walking. However, it is also shown that if there is a lack of well functioning public transport, the usages of cars could even increase with car sharing. This means that car sharing could be a piece of a great puzzle, for people to become more environmentally conscious, together with a well functioning infrastructure and public transportation, it could reduce the total amount of car usage.

The results from the literature study show that it is mainly younger people that use car sharing services and it also

seems to be more popular for people that vote for green parties. This implies that there is a common opinion that using car sharing services is more environmentally beneficial than owning a car. This is also indicated by the results of the quantitative study. To the question "Do you think that car sharing is beneficial for the environment?" 92% answered yes. However to the question "If using car sharing services, what aspect would be the most important for you?" only 4% answered the environmental aspect. The cost and accessibility were found to be way more important. To make even more people use car sharing, car sharing companies need to make the service cheaper and more accessible. The environmental aspects may not be enough to make people use the service instead of owning a car.

The findings from the studied literature are seen as reliable due to the high amount of articles stating similar findings on the subject car sharing. The articles were found in different online libraries and different educational platforms, which further confirms the reliability of the articles.

The project was executed with a narrow time limitation, which impacted the results of the methods. Due to these limitations, the quality of the result from the quantitative data collection is debatable. With only 158 respondents from a very limited group, it is hard to say something certain about car sharing in the Swedish market. If the purpose would have been to investigate the car sharing market for young, educated people in Gothenburg the data would have been of higher quality. However, some strong trends could be seen, and these can be compared with both the results from qualitative results and with the findings from the literature study.

Due to the current situation of lack of time and COVID-19, there was a problem with getting in touch with knowledgeable people for interviews for the qualitative questionnaire. Only one person had the opportunity to answer the questions. Due to this, the result from the qualitative interview can be questioned, and that the result has low reliability, even though the person was a Professor at Chalmers. Additional interviews would have been necessary to be able to call the qualitative result reliable.

4.1 Further research

Several studies have shown the beneficial effects of implementing e-car sharing instead of conventional car sharing. E-car sharing could be seen as a gateway for shifting people's mindset from using conventional cars to use electric cars. However, private ownership of electric cars and e-car sharing is outside the scope of this project.

People's preference to use car sharing is mainly dependent on the cost and accessibility rather than the environmental aspects, highlighting that the transition from car ownership to car sharing is not easy. Legislation and infrastructural decisions could facilitate this transition. Further research is required to discover the motivation required to enable this transition.

5. Conclusion

Car sharing can be beneficial for the environment, but only if it reduces the total amount of distances travelled by car, that is, people have to decrease car usage. Hence a key issue is to change people's behaviour and make people decrease their car usage. The result showed that an increasing car sharing market could potentially change people's behaviour and make them use other green means of transportation.

Regarding the research question: "Can an increasing car sharing market affect car usage and in turn affect the environment?" To answer this question accurately more data on the subject is needed. There is evidence that points to car sharing being beneficial for the environment, and some sources say that it's not certain if it is. An increase in car sharing usage could increase other means of transportation, such as walking or cycling, but sources also state that public transportation could decrease when car sharing usage increases. However, the studied literature showed, in general, a positive attitude towards car sharing and that it is environmentally beneficial.

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Group 5.
Mapping CO2eq emissions in Li-ion battery manufacturing for Electrical Vehicles

Olle Andersson, Ludvig Brodén, Axel Camitz, Olga Hansson, Filip Jonsson

Group 5

ollean@student.chalmers.se
brodenl@student.chalmers.se
camitz@student.chalmers.se
olgah@student.chalmers.se
filjonss@student.chalmers.se

Abstract
This paper describes the results from quantitative and qualitative studies where lithium-ion battery (LIB) manufacturing for electrical vehicles and its emissions was mapped. It was shown that up to 40 % of CO2-equivalent emissions in the life cycle of electrical vehicles are produced during manufacturing. This makes the mapping of the manufacturing process important for the overall reduction in emissions by making it possible to know what has the greatest effect. The quantitative study consisted of gathering emissions data from scientific papers and the qualitative of investigating what parts of the process should be improved. It could be concluded that the cathode production causes 36.2 % of the total emissions and the parts of it where drying is involved consumes the most energy.

Keywords: Electric vehicle · Lithium-ion · Process mapping.

1. Introduction

Cars contribute to more than 30% of the total CO2eq emissions in the entire transportation sector [1]. Electric vehicles (EV) have been sold as a solution to reduce these emissions but it has been discussed whether or not that's the case. The greenhouse gas emissions produced during the manufacturing of electric vehicle batteries is up to 40% of the total emissions in a vehicle life cycle [2]. A significant part of the emissions generated by EV's comes from the manufacturing of the batteries and further specified mainly from the cell manufacturing and energy sources during it [3] [4].

The project aims to map the manufacturing process of the batteries used in EVs in order to evaluate which steps in the manufacturing process that contributes most to CO2 emissions.

Research question:

- Which steps in the manufacturing process contribute to most of the CO2 emissions?

The sources used in the *quantitative study* went through a screening process where the quality and relevance determined if they could be included. A set of criteria had to be evaluated for every source. The criteria are stated below.

- The authors seem to have a background within the field of either LCA or battery manufacturing. It can also be a secondary source where it refers to another paper where this is true.
- The stakeholders of the source have to be identified and what interests they have in it being spread. If the reason is other than providing quality information that helps science and sustainability then discarding the source should be considered.
- It is clear where the source retrieved its information and those sources, in turn, fulfil these criteria.
- The information from the source is preferably confirmed with another if it is a secondary one.

The sources used to hold up to the standards set and are therefore deemed to reach the desired standard. Some of the sources write in detail what specific types of battery contribute to emissions and it is hard to make general conclusions with the sources considered in this project. Since the project is directed to the mapping of the process the best way of conducting the quantitative data collection would be observations of the process in real-time. However, the limitation of this particular project is that the project extends through quite a short period of time. Therefore, the literature study and the data from it has some limitations on how extensive it can be. Every source would be traced back to get first-hand data in an ideal case but that is not possible within the scope of this project.

2. Methods

This section describes the methods used in this project. Three studies were used to answer the research question: literature study, quantitative study and qualitative study.

2.1. Literature study

The foundation of method strategy for this paper to collect data and information is based on a literature search. The search for relevant paper for the study objectives was achieved by keywords as Production NEAR/ battery AND emission/ car battery production/ Lithium batteries AND environmental impact/lithium battery AND CO2/. The databases that were used to collect data and information Chalmers library, Google Scholar and Scopus.

2.2. Qualitative study

Interviews questions were formulated based on the study objectives. The purpose of the questions was to understand trends on the current and future battery research development, both when it comes to the battery itself and the production process. Back up found the information in other papers and get new information and see where it is most interesting and needed to do delimitations. Following questions were specified:

- In general, when it comes to the research in the area of battery cells, where is the main focus being placed nowadays? Is it range, battery size, emission, etc.?
- What about production specifically, does the manufacturing process differ greatly within different brands or battery types?
- Do you have some cooperation with electrical vehicle manufacturers when it comes to emission levels? Is it easy to get good, transparent data?
- Are there any suppliers that are more preferred by vehicle manufacturers? What countries the production sites of these suppliers are placed at? Is it both R&D and production? Or only production? Or only R&D?
- What part of the production process of batteries can you point out as the one most responsible for CO2eq emission?

The interview questions were directed to and delivered to researchers within the field of Lithium batteries in the form of direct messages and phone calls. The questions were also only presented to academic researchers at Chalmers due to the low activity within the manufacturing industry [5].

2.3. Quantitative study

The quantitative study strategy was to collect and use secondary data from different research papers that visualized data of CO2eq emission of different steps in the manufacturing process of batteries.

3. Result

The result presents the outcomes from the literature study, quantitative study and qualitative study. A production process of the battery cell was mapped and the process steps and components that contribute to most of the CO2eq emission are pointed out.

3.1 Literature study

The production of Li-ion batteries is increasing. Thus, researchers in the field emphasize the need of recycling material in order to make the battery production an environmental and sustainable option to combustion cars [6]. Research in the subject concludes that remanufacturing of lithium-ion batteries is feasible and that there is money to make from it [7]. However, it is highly depending on how the market of used batteries look and what the price for them is. If the EV industry would consider using refurbished materials great emission reductions should be expected [8].

New manufacturing strategies and technology can be used to reduce cost and carbon emissions of manufacturing of Li-ion batteries. By printing parts of the batteries with polymers, they can reduce the need of expensive and CO2eq impacting material. Thus, showing the potential and criticality of new and innovative technology. The result hypotheses that a reduction of 150% in some steps of the process is possible [9].

3.2 Production Process Mapping

A manufacturing process of electric vehicle batteries can be divided into three steps: battery materials, battery cell manufacturing and battery pack assembly [10]. The main focus was put on the battery cell manufacturing. This has been taken as a delimitation due to the short period of time available for the research.

Although Electrical vehicles now have been on the market for some time there is still no standardized design or production method of battery cells [11]. Depending on the design of the internal structure of a battery cell the manufacturing process of the lithium-ion battery cells can vary. However, several common steps are listed below. The level of detail in the descriptions of lithium-ion battery cell production varies among different sources. The process can in general be divided into three steps:

Electrode manufacturing;
Assembly of the cell;
Forming and testing [12].

These steps can be further split into component level with the main parts:

Anode;
Cathode;
Electrolyte filling;
Separator;
Packaging;
Rest of the components [13].

The mentioned components are produced in the following steps:

Mixing and Coating. At this stage several components are mixed to build a so-called slurry that is later on combined with a solvent (can be water-based or organic). The result is the coating put onto the aluminium and copper foils. Coating plays an important role in the capacity level of the cell.

Drying. The coated aluminium and copper foils are dried in a certain temperature that has an important impact on the adhesion of the coating to foils.

Calendaring. Electrodes are compacted when being rolled, the thickness is reduced. The load is thoroughly controlled in order to avoid fissures.

Notching. Electrodes are cut to the required width and rolled again.

Stacking. Separate sheets are stacked in the following order: anode, separator, cathode, separator, etc. Adhesive tape is usually used for fixation of sheets to each other.

Welding and sealing. Separate parts of the cell housing are welded and sealed.

Electrolyte injection and wetting. Electrolyte filling and wetting takes place.

Final sealing. The openings left for the electrolyte filling are now welded and sealed.

Dry room conditioning

Pre-charging. At this stage lithium-ion cells are formed. Since the battery cells are being pre changed and important layers of the battery cell are formed [12], [10], [14].

3.3 CO2 Emission Data – Quantitative Study

When looking at the global warming potential of each production step it is obvious that the cathode production has the highest level of global warming CO2eq emission on the component level. It reaches up to 36% of the total emission for battery cell manufacturing. Battery packaging shows the next highest result for the CO2 emission followed by the anode and the rest of the components. The separator is a component that is positioned lowest in the emission ranking [15]. This component is in most cases not produced by battery suppliers and often outsourced [12]. Table 1 demonstrates detailed information on the emission results for every significant part of each step [15].

Table 2 shows that cathode is responsible for the highest emission levels even when it comes to some different types of battery cells. For example, LiMn204 and LiFePO4 [13].

When looking at the materials and production steps it can be determined that the variation of CO2 has in previous studies been conducted to a range from 39 to 192 kg CO2eq/kWh [16].

As seen in Table 3. The different steps have varying impacts on energy consumption and the most contributing factor is related to the drying process, which can be seen in Figure 1.

Table 1. GWP kg CO2 eq. Production of 1 kg Li-ion battery. Data from D. a Notter et. al., 2010

Total Li-ion battery	**GWP kg CO2 eq. %**
Battery pack	**26.8**
Printed Wiring Board	14.3
Reinforcing steel	3.53
Three conductor cable	1.39
Anode	**14.5**
Copper	5.65
Graphite	5.75
Rest anode	3.11
Separator	**4.29**
Cathode	**36.2**
Aluminium	21.3
LiMn2O4	13.8
Rest cathode	1.06
Ethylene carbonate	**3.09**
LiPF6	**6.47**
LiF	**0.428**
PCL5	**1.42**
Mn2O3	**6.06**
Li2CO3	**2.25**
Conc. Lithium brine	**0.109**

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Table 2. Emission comparison of two battery type production. Data from Marques et. al., 2019

	Manufacturing Energy Cell Battery Manufacturing GW (kg CO2eq.)					
	Anode	*Cathode*	*Electrolyte*	*Separator*	*Other Components*	*Packing*
LiMn2O4	221	633	164	74	107	426
LiFePO4	1104	2127	165	12	1610	1765

Table 3 The energy usage of different steps in battery manufacturing.

Battery manufacturing	Energy usage
Mixing and coating	1 %
Drying	38 %
Calendaring	2 %
Notching	4 %
Stacking	5 %
Welding and sealing	1 %
Electrolyte injection and wetting	1 %
Final sealing	4 %
Dry room conditioning	43 %
Pre-charging	1 %

Battery materials	
LMO	16 %
Al current collector	7 %
Graphite	6 %
Copper current collector	16 %
Carbon black	10 %
Binder	4 %
LFP	8 %
Ethylene carbonate	1 %
Separator	1 %
Cell container	3 %
Battery management system	9 %
Cooling system	5 %
Packaging	14 %
Battery pack assembly*	**Negligible**

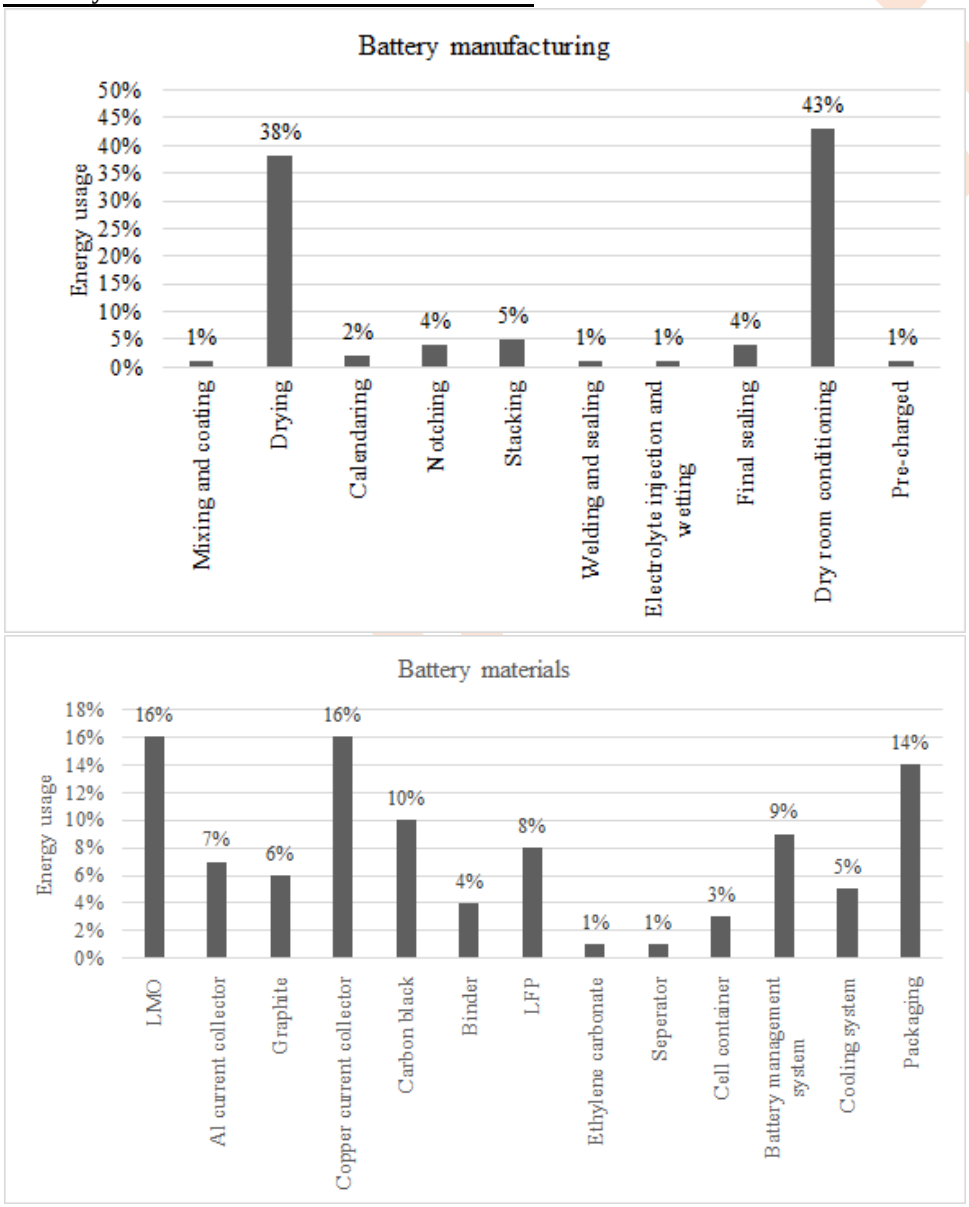

Figure 1. Visualization of the from Table 3

The *data* process mentioned in Table 3 is the manufacturing of a LIB to a Nissan car. Table 4 shows on the contrary how much the steps can differ depending on what specific type of LIB is manufactured [17].

When it comes to the energy used for manufacturing, there is some information available suggest that Chinese suppliers of LiFePO4 reach CO2eq emission levels of almost three times higher than the European ones [13]. This data is presented in Table 5. The CO2eq emissions from energy manufacturing in China can be further broken down and depending on the source of fossil fuel used to manufacture the energy the emissions can vary from 95 to 44 CO2eq/TJ [18].

3.4 Qualitative Study

The interviews which were planned to be held over distance were not received well by the subject of the interview. It was noticed that the researchers either: Did not have time as more urgent matters had to be dealt with in the current situation. Felt that they had a lack of knowledge to provide a qualitative answer to the questions. Mentioned that they did not wish to voice their opinion on the matter. Thus, no real data for the analysis were found in the qualitative study. Rather, it was found that the subject of manufacturing of lithium batteries either lacked enough research to provide qualitative answers or that the findings were in a too early stage to be published.

4. Discussion

The section discusses the collected information and the results from the analysis. It also discusses the limitations and struggles with the subject.

As previously mentioned, the process in which batteries are produced can vary quite some bit. Depending on, what type of LIB, what the battery will be used for and where the battery is produced. Thus, it is important to observe the findings of this report in the context which they are presented. The findings are not suitable for broad generalizations due to the variations mentioned above. Though some similarities were observed in the manufacturing process, the result might vary but can roughly be estimated to indicate which process contributes the most to CO2eq emissions.

Some researchers claim that more empirical evidence is needed to map and evaluate the manufacturing methods and that the manufacturing processes depends on geographical location. Thus, it is hard to generalize on manufacturing strategies.

More research is needed to theorize how new technology can be proven viable. Both in an ecological sense but also in an economic. Further problems related to LCA were also found which point out the hardship of doing a useful analysis of the manufacturing process.

If the results are to be further analysed it can be seen that the energy intensive part of the production process contributes the most to the CO2eq emissions. This factor differs depending on where the battery is produced. Since energy can be derived from many sources there will be a geographical difference on its impact.

The latter part that varied were the different types of batteries. By using different materials, which require more or less processing the CO2eq emissions will vary. Though, when looking at different kinds of batteries the relationship between energy usage and CO2eq emissions seems to dissipate, at least in the cathode production. Which can be considered the most important part of the manufacturing process in a CO2eq perspective.

Another interesting finding in the area of LIB manufacturing is the need for more clarification and standardisation of processes. The area as of now is too disperse and regulators and manufacturers have lot to gain by standardizing processes and performance indexes.

5. Conclusion

It was discovered that the manufacturing of batteries at component level can be divided into six main groups, anode, cathode, electrolyte filling, separator, packaging, rest of the components. These are the main parts of the most common li-ion battery types and by knowing how much CO2eq emissions are connected to each one is key in mapping the process.

Another finding was that the manufacturing of cathodes causes most of the CO2eq emissions in the process while the most energy is consumed during the drying processes.

The CO2eq emission differs between different types of materials also where the batteries are manufactured has a significant impact. Manufacturing batteries in European countries contribute less to CO2eq than manufacturing in China. This difference is significant and can have a major impact in the future to minizine the global CO2eq emission.

Researchers within the field of batteries for electrical vehicles that were asked to participate in an interview stated that they don't have enough knowledge in the area. It can be concluded that it is hard to find people with the right knowledge willing to participate in interviews.

Table 5. Emission data comparison for different locations (China and EU). Data from Marques et. al., 2019

	Manufacturing Energy, GW (kg CO2eq.)	
	China	*EU*
LiMn2O4	85	35
LiFePO4	1856	742

Table 4. Energy consumption in cathode production. From Dai et. al., 2015.

Cathode	Energy consumption (mmBtu/ton)	(Preparation step)		Major factors to consumption	Contribution (%)
		Energy Consumed (mmBtu/ton)[b]	Contribution to Total (%)		
NMC	135	4.5	3	Nio	40
LMR-NMC	100	3	3	CoO	30
LCO SS	150	2.6	2	CoO	88
LCO HT	251	32	13	CoO	53
LFP HT	48	35	71	LFP (prep)	71
LFP SS	39	6	16	Fe3O4	40
LMO	26	15	56	LMO (prep)	56

[b] Full fuel cycle energy calculated in The Greenhouse gases, Regulated Emissions and Energy use in Transportation, GREET from purchased energy values reported herein.

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Group 6.
The Climate Impact of High-Speed Rail

Oskar Burgman, Maria Börjesson, Ludvig Hedin, Jincheng Kang, Anna Kindlundh, and Bharath Reddy Mandara

Group 6

annakin@chalmers.se
burgman@chalmers.se
hedinl@chalmers.se
kang@chalmers.se
mandara@chalmers.se
marborj@chalmers.se

Abstract

The aim of this paper was to investigate the environmental impact of passenger travel by high-speed rail, mainly in terms of carbon dioxide emissions. This was accomplished by performing a literature study on the subject as well as consulting experts on the topic for their opinion. The main findings were that the up-front environmental costs of high-speed rail are higher than competing means of transport, but the operation has a lower environmental cost which results in high-speed rail in one case becoming climate neutral after 60-100 years of operation. Much of the data gathered is from theoretical models and a small number of real-world examples so it is likely to change as further developments and research are done.

Keywords: high-speed rail · climate · emissions.

1. Introduction

1.1 Background

Climate change has over the past years become a topic discussed on a daily basis. The need to decrease the environmental impact is recognised by international organisations such as The United Nations. The Paris Agreement from 2015, is an effort by the United Nations to keep global warming below an increase of 2° C compared with the pre-industrial level. To stagnate the rise in temperatures, the emissions of greenhouse gases such as carbon dioxide (CO_2) needs to be limited [1]

The increasing awareness of climate change is influencing the way people live their lives and how they travel. With reports about how travel by car, bus, or airplane is emitting large amounts of CO_2, travelling the same distance by railway is being pitched as more climate-neutral as trains often are powered by electricity [2].

Travel time and accessibility could affect the tendency to opt for going by train instead of airplane or car. The development of more efficient railways where the travel time can be reduced would make sense if there are environmental benefits. Many countries have so-called high-speed rail (HSR), which is a system that enables train operation at speeds higher than regular railways, this usually means speeds over 250 km/h [3].

The environmental impact of the implementation of HSR needs to be evaluated to determine if it is beneficial. In the current scenario, the production of HSR requires a high volume of traffic and personnel participation and the emissions caused due to construction and maintenance activities are high. Furthermore, the emissions caused can be counterbalanced through reduced need for maintenance of roads, airports, cars, etc [4].

1.2 Research questions

The aim of this research project is to investigate if the construction of HSR is advantageous from an environmental perspective. The research question that is answered by the project is “What is the climate impact of the HSR, and what are the main contributing factors to it?”. With exploratory research, a comparison of the positive and negative effects of HSR could hopefully help decision-makers in governments, as well as companies make more wise and well-motivated decisions in the future.

1.3 Delimitations

Due to the limited time-frame, the research project focuses on comparing HSR to air traffic, since it is one of the transport sectors associated with the largest environmental impact. Furthermore, the metric of interest is delimited to CO_2 emissions to simplify the comparisons. Local environmental effects caused by the manufacturing and maintenance of HSR are discussed.

1.4 Literature study

The climate impact of HSR can be divided into three stages: production, maintenance, and end-of-life. According to a life

cycle assessment of the railway between Tours and Bordeaux in France the production and maintenance stages have an equal negative impact on the environment [5]. In the first-mentioned the roadbed, the rails and the civil engineering structures are the biggest contributors and in the second one rail is by far the most affecting component [5]. Because of the recycling in the end-of-life, this stage results in a positive impact on the environment [5]. There are several methods for calculating the environmental impact and the International Union of Railways have in a report compared ten of them [6]. They, for instance, conclude that railways with tunnels and bridges on less than 30 % of the distance count for 50 tonnes of CO_2 per km and year.

Travel by HSR has demonstrated the potential to attract travellers who formerly travelled by air and car, in most cases leading to reduced direct emissions of greenhouse gases from vehicle propulsion. The literature shows that a large life cycle emissions reduction was expected to be found in Sweden by the construction of HSR [4] [7]. This comes from a shift from truck to rail freight and a shift from air and road travel to HSR travel [4]. Besides, a substantial share of emissions due to construction of the new rail could be counterbalanced through the reduced need for building and maintaining roads and airports, and for manufacturing cars [4].

If an increase in the number of HSR travellers will reduce the climate impact, it is interesting to look at how the availability of HSR affects commercial air travel. Introduction of HSR on routes where air travel already is an option has in many cases lead to fewer flights. However, how successful the shift depends partly on the route distance. Medium distance routes appear to have the most advantages for HSR travel [8].

HSR has often been welcomed as environmentally friendly alternatives for road and air transport systems. But locally, along the tracks of the HSR, concerns and protests have been strong in some countries. Concerns and anxieties with adverse environmental and social risks and impacts of HSR are related to both the construction and geographical layout of these infrastructural systems [9]. The local communities also worried about significant land-use change and consequences for landscape and biodiversity as well as environmental and human health consequences of the daily HSR operation, including noise, vibration, radiation, electro-magnetic pollution, accidents, visual and air pollution [10] [9].

Different studies indicates that HSR investments may compensate infrastructure construction burdens and mitigate CO_2 emissions [4] [11] [12]. However, those reports also emphasise that the high sensitivity of the results to certain variables, such as passenger's demand as well as construction burdens. In order to balance the annual emissions from the railway construction, the traffic volumes need to be over 10 million passengers annually. Besides, most of the traffic diverted from other modes must come from aviation and the lines cannot involve extensive use of tunnels [13]. One study analysed the contribution of the HSR project in the Basque Country, to energy consumption reduction and to climate change mitigation by means of a simplified life cycle assessment. It concluded that the reduction of greenhouse gas emissions and energy savings should not be used as a general argument in favour of investing in HSR infrastructure [14].

2. Method

2.1 Literature study

A preliminary literature search strategy was employed where each group member induvidually searched on academic search engines like Google Scholar and Scopus. The search was based on keywords such as: *high-speed rail, climate, emissions, life cycle assessment, air traffic*. Due to the continous advancements in the research regarding the subject no literature sourcers older than 10 years were used. Also, peer-reviewed schorlarly articles, conference proceedings and statistics reports were preferred. Altough types of less reputable literature such as popular articles could be used if they were deemed reliable, with reputable author and publisher etc. All suitable literature found was added to a common bibliography together with a short description for easier navigation.

2.2 Quantitative

The data was collected by investigating research papers used in preliminary literature study, to collect the findings most relevant to the research question. Thereafter, another iteration of literature study was performed to expand the findings and to answer the main questions quantitatively. To analyse and visualise the results, the statistical software JMP was used.

To find the differences in climate impact amongst HSRs and airplanes worldwide, five HSR lines and an airline in Europe were selected for comparison. The data on carbon footprints per-passenger for different HSRs and airlines was gathered via literature study. The HSRs and airlines examined: the Tohoku Shinkansen in Japan [15], High Speed 1 in the United Kingdom [16], LGV Mediterranée in France [17], Taipei-Kaohsiung in Taiwan, China [17] Beijing-Tianjin in Mainland China [17] and European flight [17]. The data of the CO_2 emissions based on occupancy rate was collected from a report on a Chinese HSR line (Beijing-Shijiazhuang) [18] and visualised to illustrate the effect better. Data on how the environmental balance is influenced by CO_2 emission and energy consumption, associated with infrastructure, construction and maintenance was visualised by four different scenarios [14].

2.3 Qualitative

The collection of the qualitative data was done via e-mailing relevant people and agencies related to the East Link Project in Sweden, set to be the first HSR in the country. Three open-ended questions connected to HSR and the East Link Project were asked.

- Which are the strongest arguments for and against the East Link Project?
- Do you think that the net environmental effect of the East Link Project will be positive?
- Do you think high-speed rail will be preferred by travellers over plane, especially for trips such as Stockholm - Gothenburg?

Among the respondents, as seen in Table 1, were two coordinators at different municipalities for the East Link Project, along with Naturvårdsverket (Swedish Environmental Protection Agency) and Trafikverket (Swedish Transport Administration). Both coordinators had several years of experience at their positions and key positions within the project. The answers were then summarised and interpreted.

Table 1. List of experts interviewed and their background.

Name/Agency	Experience	Responsibility
Expert 1	Development secretary at Flens municipality for 27 years.	Coordinator for East Link Project in Trosa municipality last 7 years.
Expert 2	Project manager for intelligent transportation system projects at Sweco for 6 years.	Coordinator for East Link Project in Nyköpings municipality last 7 years.
Trafikverket		Responsible for long-term infrastructure planning for transports (road, rail, shipping, and aviation)
Naturvårdsverket		Responsible for proposing and implementing environmental policies.

3. Results

3.1 Qualitative

After interpreting the received responses, some points could be concluded. One of the main arguments from Expert 2 for HSR is that it is more efficient than other means of transportation. Although there is a large negative environmental impact from the construction of the project, Expert 1 mentioned it is thought that this environmental debt will be recompensated over time due to the increased efficiency of HSR. It is also argued that the public will prefer HSR upon other means of transportation because of factors such as increased speed and safety. This part is crucial because to repay the environmental debt caused by construction people will have to switch from more climate intensive means of travel to HSR. Both Expert 1 and Expert 2 highlight another positive side effect of the increased capacity of the passenger rail system that comes with the East Link Project. It is that it will clear up capacity for the rails previously used. This freed capacity could be utilised by freight trains. Since freight by train is an efficient mode of transport and would replace freight by truck, it will have a net-positive effect on climate change.

The main arguments presented against the East Link Project was from Expert 1. The cost is extremely high and it is possible that the money could have a larger positive impact if it is invested in modernising existing rail, or used in some other infrastructure project which could yield a higher return of investment with reference to social and climate benefits. Expert 1 also mentioned concerns regarding the damage caused to landscapes, nature conservation and cultural art effects. These effects will be more severe because of the nature of HSR construction which requires straight tracks and thus makes it harder to avoid sensitive areas when planning according to Naturvårdsverket. There are also factors that reduce these effects, Trafikverket mentioned for example the fact that the East Link Project will be built mainly next to highways where these effects are already present. Both Expert 1, Expert 2 and Trafikverket agreed that the positive consequences of the HSR as regional growth, social benefits, and more sustainable travel and transport can be weighed against the negative. These are particularly the local affected flora and fauna and the environmental debt from the construction will take a long time to pay back, according to Expert 1 and Trafikverket. If HSR would be preferred over plane in the future depends according to Trafikverket a lot of unsure parameters like traffic forecasts, timetables and behavioural changes. However, transfer between the airports and the city centre takes so much time that on journeys up to around 500 km flights will have difficulties competing with HSR according to Expert 1. Another thought from Expert 1 was also that in the future there is a probability of functional and reliable electric aircrafts that could compete with the HSR, but a question is which routes it is most optimal to put them on.

3.2 Quantitative

Figure 1 shows the comparison of CO_2 emission after being visualized in JMP. It is clearly seen that, the per-passenger carbon footprint among these HSR lines are quite different with respect to portion of construction, maintenance and operation. For construction, the scenario is mainly related to

different infrastructures of HSR lines, especially the bridges and tunnels. Normally, HSRs in Asian countries consume more materials and energy than in European countries. For the operation emissions, the main factors that determine them are the number of passengers per year and the electricity mix of these countries [19]. Besides, the elevation of the top speed from 280 km/h to 350 km/h has been confirmed to increase the energy cost by approximately 60 %, and the operating speed is generally higher in China's HSR than in others, thereby leading to a slightly higher per-passenger carbon footprint. The analysis also concludes that, the total carbon footprint of HSR is about 4 to 6 times less than transport by airplane, but 7 to 11 times larger in terms of construction as shown in Table 2. It is notable that only one HSR has data on carbon emissions caused by maintenance, the rest have merged operation and maintenance emissions into only operations.

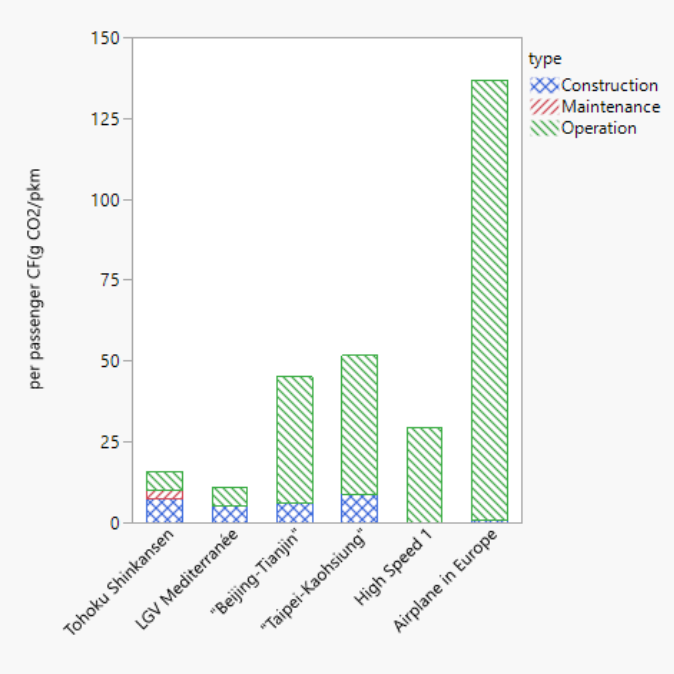

Figure 1. Comparison of the per-passenger carbon footprints of the different HSRs and airline.

Table 2. Carbon footprints in grams of CO_2 per passenger-kilometre of the different HSRs and European flight.

	Construction (g/pkm)	Operation (g/pkm)	Maintenance (g/pkm)
Tohuku-Shinkansen	7.4	5.9	5.9
High Speed 1	*	29.5	*
LGV Mediterranée	5.3	5.7	*
Taipei-Kaohsiung	8.9	42.9	*
Beijing-Tianjin	6.0	39.2	*
Airplane (European)	0.8	136.2	*

Strictly looking at CO2 emissions as a measurement for climate impact, it can be deduced that there is a benefit to higher ridership. A report on the Chinese Beijing-Shijiazhuang line shows that increasing ridership correlates to decreasing CO2 emissions per passenger. With data from this report, Figure 2 shows that an occupancy rate of 30 % leads to emissions of 178 g CO2 equivalents per passenger for each kilometre travelled. When the train has full occupancy, that number reduces to 54 g which is a decrease to less than a third of emissions at 30 % occupancy [18].

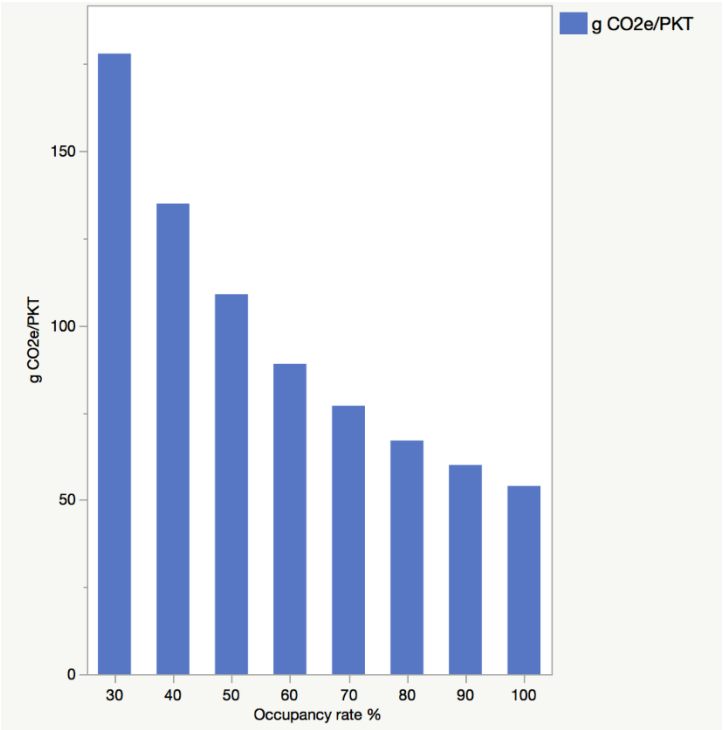

Figure 2. CO_2 emissions based on the occupancy rate.

Figure 3 describes how environmental balance is influenced by CO_2 emission and energy consumption, as well as the years of HSR line service required to compensate the environmental burdens associated with infrastructure, construction and maintenance. The graph consists of four different scenarios compared to the baseline which depicts initial condition. The conditions being modified are: transport, electrification, and renewable penetration conditions throughout the infrastructure lifetime (SA1), increasing the lifetime of infrastructure up to 100 years (SA2), only being used for passengers to commute (SA3) and more realistic demand for freight transport (SA4) [14].

4. Discussion

The environmental effect of HSR is a complex research topic since it greatly varies from case to case. In order to gather relevant qualitative data, it was deemed necessary to consult experts or people knowledgeable on the area. Given the expertise and prior experience of the people consulted in the survey, the credibility of the data may be considered high. However, the involvement of some experts in the ongoing East Link Project does not only mean they have knowledge about the project but could also result in a bias in favour of it. The data, therefore, needed to be further validated by the literature study in order to assert its quality. The responses from the experts consulted in the mail-survey, matched to a great extent with the previous data collected. None of the answers contradicted earlier findings and some arguments were supported by multiple sources, which strengthens the validity of the literature study. A limitation of the survey is the few respondents, which largely is on account of the limited time frame to find suitable experts, wait for responses, and have time to analyse the data.

The quantitative results mainly show the environmental impact of HSR in terms of greenhouse gas emissions. To make the results more representative, data were collected from different countries and regions in different literature. Analysing in JMP was useful when doing the data organisation and data visualisation. However, the results are solely based on research conducted by others. This means information that might have been previously analysed is being reused. This study was also dependent on existing research regarding the topic this project sought to investigate. Therefore, finding sufficient relevant data was sometimes difficult.

Both the qualitative and quantitative study indicate that one important factor for HSR to successfully compensate for its environmental impact is to get people to switch from other modes of transport to HSR. This is deemed to be possible due to several things that make HSR travel appeal to people. The increasing efficiency of HSR is one thing that can contribute to this shift. A fast and safe journey from one place to another without transfers or similar inconveniences is likely to attract more passengers.

HSR, as the main travel choice for people, has the potential to reduce climate impact compared with travel by airplane. The carbon footprint of HSR construction and operation is affected by many factors, such as the different infrastructure, the number of passengers per year, the renewable penetration in different regions. Considering these factors and the life cycle assessment, HSRs in areas with sparse population and complex terrain will do little to reduce CO_2 emissions. Since specific maintenance emissions are only given for one HSR it is assumed that the ones that do not specify maintenance emissions combine operation and maintenance emissions.

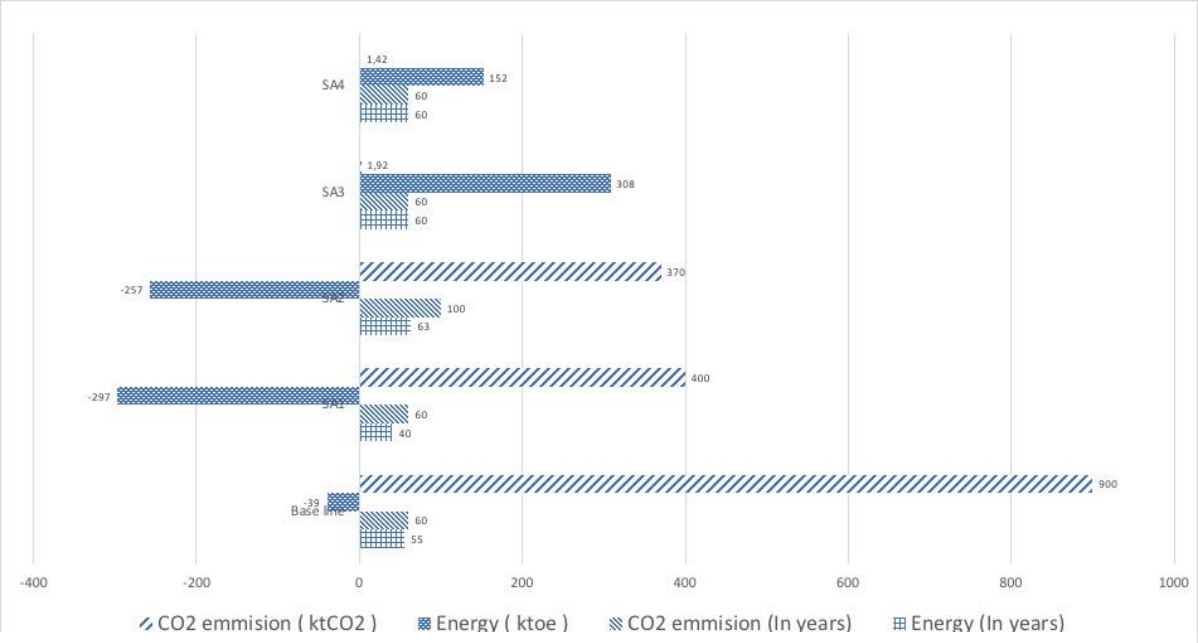

Figure 3. Years of service needed to offset environmental burdens linked to construction and maintenance of HSR.

The potential to reduce CO_2 emissions by HSR travel relies heavily on ridership. Fully occupied train rides will contribute with a very small amount per passenger. HSR has proved to be a viable option to aircraft. If a significant switch from air and road travel to HSR occurs, this could certainly bring benefits for HSR in this regard. However, for longer journeys, air travel is still much faster as airplanes reach much higher speeds than trains. Therefore, HSR is likely a more suitable option for medium distance routes. In order for HSR to be an environmentally viable mode of transport, the currently estimated volume of passengers per annum, is in some cases not sufficient to achieve an annual carbon footprint reduction linked with construction, maintenance and operation. The energy savings derived from HSR passenger transport compensates for the annual energy consumption burden associated with the infrastructure, provided the passenger volume is met.

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PART 3 – MATERIALS

Group 7.
An Investigation of Lithium-Ion Battery Recycling Processes Considering Sustainability

Akshay Mundayadan Chandroth, Richard Dang, Gustav Hindér, Doyel Joseph, John Magnusson, Husni Husen Mohammed

Group 7

dangr@student.chalmers.se
doyel@student.chalmers.se
hinderg@student.chalmers.se
husni@student.chalmers.se
johnmag@student.chalmers.se
makshay@student.chalmers.se

Abstract

As the world is moving away from extensive dependency on fossil fuels to a sustainable future, usage of electronic equipment and electrical vehicles have increased. To meet these demands, the yearly production of lithium-ion batteries is continuously growing. The production of lithium-ion batteries is linked with the consumption of rare resources and environmental pollution. Therefore, recycling of used li-ion batteries became important. In this research, different characteristics of lithium-ion batteries and different recycling methods were reviewed. Additionally, the authors identified challenges associated with the process of recycling li-ion batteries and the quality of recycled material. Based on the analysis, hydrometallurgy was found to be the most promising recycling method. However, all recycling methods are not economically feasible compared to production of lithium-ion batteries with virgin material. From quantitative analysis, it was found that the rate of extraction in the industry was found to be 23.4 % lower than the academic reports.

Keywords: Lithium-ion battery; recycling processes; · sustainability.

Introduction

The world is currently moving away from the exploitation of fossil fuels as an energy source and shifting more towards the utilisation of electrical energy. A phenomenal development which has assisted this shift is the evolution of lithium-ion (Li-on) batteries as an energy source since the early 90's. The benefits of Li-on batteries is having high efficiency, long life cycles and high-power supply when compared to other battery types [1]. Nevertheless, lithium-ion batteries were categorised as a premium device since its development due to the incrementation in installation charges with its advancements. However, the device still exists as an important choice for a variety of applications. One of the major drawbacks of lithium-ion batteries is its extensive dependency on rare earth materials to develop the battery core [2]. But these drawbacks did not have an adverse effect on the demand of batteries. As a result of this increased demand, researches were directed so as to improve the scope of supply of batteries resulting in a steady notable increase in the amount of battery waste [3], [4]. This enormous increase in the generated waste triggered the necessity of optimal recycling methods to strive for sustainability and meet future challenges and demands.

Several recycling methods for lithium-ion batteries were devised with time and the recovery potential and energy consumption standards of each method were found to be different. However, the vast opportunities and market value of lithium-ion batteries motivated the research community to scrutinize the methods to identify the recovery rates and energy consumption in order to create a better idea on methods [5]. Nevertheless, the quality of recovered material and the coexistence of the term sustainability proposed a challenge.

This major objective of the present investigation is to conduct a detailed study on the state-of-the-art trends in recycling methods of lithium-ion batteries and to identify the most efficient methods of recycling considering aspects like sustainability. Furthermore, the results from this investigation is intended to answer the quality of recovered material and its reliability in the battery development process compared to virgin materials.

There are numerous organisations and reputed investors working towards the improvisation of this sector. But certain challenges are still existing and are identified and listed.

1.1 Scope and limitation

Research strategies can either take a qualitative, quantitative, or mixed method approach based on the requirements [6]. This research is structured with a mixed method approach that will be used to answer the posed research queries. This methodology aids in better understanding of concepts and can resolve the queries considering its dynamic nature.

Due to the COVID-19 situation, there were limitations in conducting experiments and visiting industries in order to gather quantitative data. Instead, published secondary data was gathered from reliable literature for further processing. A comparative analysis method was utilised majorly to identify the differences and note it.

2. Methods

2.1 Literature Study

A literature study was performed to find articles based on selected keywords. The platforms used were Google Scholar, Web of Science, Scopus, Statista, and Chalmers library services. Also, a recycling company was contacted for inputs regarding the literature search. The main keywords searched were: lithium-ion, batteries, recycling, general, case, study, resource, comparison, and sustainability. The filtered words were: advanced and production, because the major objective of this project is to compare the general methods of recycling and not the production process. From the numerous articles found, 21 were selected and shortly summarized in order to gather arguments to support the queries.

The articles were divided into several subcategories for further analysis by categorising them based on current situation, environmental perspective, different methods of recycling, and comparison of recycled lithium with virgin lithium etc. A further detailed investigation was carried out through the literature, to collect validating points to form qualitative and quantitative results.

2.2 Qualitative Study

Qualitative data collection was a major challenge during the investigation procedure due to the contradicting information provided by each resource. The major dependable sources are literature and experts in the field. The arguments to support the framed research questions were available from the literature and a detailed analysis of the collected data was essential for formulating conclusions to structure the quantitative results. A semi structured questionnaire was prepared for each interview and a list of experts were chosen based on their field of research. The experts were chosen in such a way as to provide adequate information from each category such as different material extraction methods, the economic and environmental benefits etc. There were many limitations to get hold of interviews during the COVID pandemic situation. However, online platforms were helpful in overcoming this difficulty to a large extent.

For the qualitative data collection notable experts in this domain of research were chosen for interviews

- Christer Forsgren, Technical director at Stena Metall.
- Mark Foreman, Researcher at Chalmers, specialized in material recycling.
- Martina Petranikova, Researcher at Chalmers, specialized in hydrometallurgy.
- Rohan Singh, Director of strategy and product management at ZiptraX Cleantech, India.

The answers from the interviews were analysed to extract data. This entire process was manual and based on the group's deductive reasoning, which had a risk for biased results. In order to give validity to the data the group used transparent descriptive methods, where the group's reasoning was clearly described. The same data was also analysed by different members of the group in order to detect and deal with personal biases. When the data was extracted and compared between the group members it was categorized in order to draw conclusions from it.

2.3 Quantitative Study

In the present investigation, reliable literature and statistical data from resources were chosen as a source of reliable quantitative data. The quantitative data study was found to be essential to eradicate the confusion which persisted after the qualitative analysis. The collected literature was obtained from reliable platforms like google scholar, scopus and Chalmers library services. The collected statistical data was categorized and plotted in JMP software in order to compare and analyse the information to reach a credible conclusion on different methods of lithium-ion battery recycling.

In an experiment conducted by [7] , the researchers tried to optimize the recovery of lithium and cobalt through a hydrometallurgy process. Five important parameters (temperature, acid concentration, H2O2 volume, solid/liquid ratio and type of acid) were used as critical factors during the JMP analysis. The generated screening script was used to find which factors have the most significant impact on the recovery rates of each element. Also, a distribution analysis method in JMP was utilised for comparing and analysing the collected data about extraction rates of various elements.

3. Results

3.1 Literature study

Regarding the current situation in the area, there is literature and statistical data related to the ongoing recycling process. Nevertheless, certain statistical analysis related to

collection and recycling of lithium-ion batteries were collected at this state. It was found that a lot of batteries were either stored in households or at scrap yards, and even shipped away to other countries for recycling and reuse. These numbers weren't exact and have a phenomenal margin of error [2], [5], [8]. Hence, further detailed search for statistics has to be carried out.

The general recycling method is very complex [9] and it requires an immense knowledge to thoroughly understand the process. This project will highlight the methods for comparison and will gather information so as to understand the concept behind each recycling method. Each literature highlights different methods of recycling lithium batteries [2] and the information might be contradicting. Hence, it can be observed that several methods will be proved as useful in this project and the advantages and disadvantages of these methods were also available from the literature.

Utilisation of recycled nickel and cobalt compared to virgin materials can reduce the exploitation of natural resources by 51% [10].

It was noted that numerous technologies were available for extraction and recycling of elements from used lithium-ion batteries. Extraction techniques like pyrometallurgy (PM) and hydrometallurgy (HM) processes [1] were efficient enough to return the major portion of focus element. PM is based on exposing the batteries to extremely high temperatures in order to separate and extract the materials [11]. HM is instead based on the use of acid and other leaching agents to extract the materials [11]. Sometimes, the literature focused on a single method [12], while in other cases combinations of methods are in focus [13]. The choice of method is found to be connected with the required efficiency of extraction and element to be extracted.

Most of the literature found, related to recycling methods, are experimental, where these methods are practically carried out in order to scrutinize its effects on extraction of elements. By comparing both old [14] and new articles [15], the advancements in the field could be observed. Some of these experiments have very promising results, such as 99% Li extraction under optimal conditions [16].

A major, notable issue with these articles was that they only focus on the effectiveness of the methods and not on the economical or environmental aspects. The research community is focusing on developing much more efficient and sustainable processes, such as the study of LithoRec [17] in order to improvise the existing technology . From the present investigation, it was noted that their methods are much more sustainable but not as efficient as the prevailing methods. A latest trend in this field is bio metallurgy which is excitingly inclined towards the sustainable extraction of elements [9].

3.2 Qualitative Study

Current situation: A notable conclusion obtained from the interviews is that the efficiency of current methods of recycling are not sufficient enough to meet the increasing demand and for extracted materials to be incorporated into new batteries. The main hindrance was the cost of refining the material to a level where the quality is high enough. However, it can be downcycled into other processes which do not have the same quality requirements.

Forsgren indicated that lithium is currently not worth recycling due to the reduced price of the virgin product, comparatively. However, as Petranikova mentioned, it is uncertain if only virgin lithium production can satisfy the growing demand, which is the reason why a lot of research still focuses on lithium recycling. The cathode materials like cobalt, nickel and copper which can be found in most mobile phones, tablets and laptops were more valuable than anode materials. Profit can be achieved through recycling car batteries but there are numerous limitations hindering the process. Both Forsgren and Foreman pointed out that it is not efficient to recycle certain kinds of batteries like bus and cheap tool batteries due to the lower value and these batteries end up in landfills and incinerators. Also, another major threat is the release of toxic gases like Cl2 and SO3 during the leaching process [18]. This can lead to environmental pollution; however, the amount of hazardous waste is small in comparison to other areas.

Recycling methods: Regarding the environmental impact of pyrometallurgy (PM) and hydrometallurgy (HM), Forsgren said that HM is the more energy consuming process. However, if the energy comes from renewable resources HM can be considered more environmentally friendly compared to PM which requires fossil fuels. Also, Foreman mentioned that the CO2 emissions from HM were better, comparatively. Although the materials are still dissolved in acid and further treatment based on the area of application is essential. Petranikova pointed out that even though the solvents in HM can be toxic, they can be reused for several years which reduces their environmental impact.

The hydrometallurgy process was compared with other batteries recycling processes in order to identify its other important aspects. Foreman stated that the process offers good quality recycled material, and, in some cases, it can be the only process that can extract the material from its alloys. The HM ability to extract materials such as aluminium, manganese, and lithium was also mentioned by Petranikova who stated that HM has higher material recovery than PM. This benchmark quality is obtained through many sequential refining processes, as a result, hydrometallurgy has higher running and capital cost and is only suitable for expensive materials. However, it was concluded by Forsgren that PM is a superior process to extract elementary metals such as copper.

Challenges: During the interview, Foreman mentioned that one of the main challenges faced by many battery recycling companies is the segregation of dirty material from the used battery. Also, as Foreman mentioned, another important challenge is the economic feasibility of the recycling process. The discussions with Singh pointed out the issues like dumping of hazardous waste by avoiding the release of toxic substances into the atmosphere and issues regarding the availability of data on collection and segregation of Li-ion battery waste. The company struggles to minimize the cost of the recycling process to gain any profit from the recycled material. Foreman supported this by claiming that the end life of the battery has become less valuable as the new batteries are designed with cheaper materials. Another challenge that is highlighted by all interviewee is the problematic nature of the directive currently in place regarding battery recycling [19]. The directive states that 50% of battery weight must be recycled, but does not say anything about reclaiming the most valuable elements from a battery. This enables the companies to recycle only heavy metals and trade the slag containing valuable material. There is also a concern among the interviewees regarding future directive and how it shapes the battery recycling process.

Future Aspects: As mentioned by Forsgren, in the future, when car and bus batteries have reached their end capacity of around 70%, they will be used as energy storage devices for several more years, before being recycled. During this time, Petranikova states that the technologies will be developed sufficiently in order to deal with the increased demand, and potentially refine the materials enough, to create a circular economy loop of resources.

Furthermore, Forsgren mentioned that towards the future, new solutions for batteries will probably be found, lowering the need for recycling lithium-ion batteries in this regard.

3.3 Quantitative Study

The extraction rates of elements from 47 different hydrometallurgy experimental studies were obtained and analysed in JMP [20]–[22]. Multiple investigations covered the recovery of lithium and cobalt in an experimental process under optimal recovery conditions. A mean recovery rate of 96.5 % and 90.5 % for lithium and cobalt, respectively, was obtained.

From industrial reports related to the recovery rate of lithium, similar data was obtained and analysed [23][22]. Compared to the experimental process, the mean recovery rate of lithium (73.1%) is 23.4 percent units lower in industry. This implies that industry is not working under optimal conditions to maximise their recovery rate.

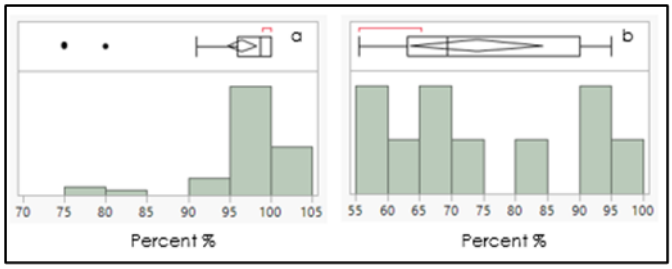

Figure 1. Histogram plot of recycling efficiency of lithium in a) experiment and b) industry.

Based on the JMP DOE screening of the data collected from the experiment conducted by Roshanfar, M., Golmohammadzadeh, R., & Rashchi, F [5] it was concluded that the significant factors for the recovery rate of cobalt are temperature of the process and H2O2 concentration. For recycling of lithium, the significant factors are temperature, H2O2 concentration and S/L (solid to liquid ratio). However, all factors have a crucial role in the recycling process.

4. Discussion

This chapter will discuss the results of the qualitative, quantitative studies and the credibility of the data gathered. Due to the limitations put on the data collection during the COVID-19 pandemic, a lot of secondary data was utilised by the authors and results can be contradicting when compared to real-time situations.

4.1 Qualitative Study

Cost of recycling and the quality of the recycled components is the major challenge faced by the industry. Hydrometallurgy is having a good recovery with a trade off of higher cost which narrows down the usage to limited recovery of precious metals.

From the interviews, an answer to the second research question was obtained. It is currently not economically feasible to refine the recycled material to a level where it has the same quality as virgin materials, even though it's physically possible. Since the interviewees covered experts both in the industry and within academia, the research group deemed this to be a credible result.

Regarding the recycling methods, pyrometallurgy and hydrometallurgy had different areas of usage. Even though hydrometallurgy seemed to be the more costly option, the group decided that it is still the most viable option due to the higher extraction rate and quality of materials which is essential in order to create a circular economy of lithium-ion batteries. Therefore, this method will be the main focus in the quantitative study, in order to assess how efficient the method is at this point of time.

Recycling methods. A never ending debate has always existed between hydrometallurgy and pyrometallurgy. It depends on the component to be recycled and the target elements to be extracted. Considering the sustainable aspects,

hydrometallurgy has an upper hand in a country like Sweden which produces required electrical energy from renewable resources. Hydrometallurgy is a much more energy consuming process compared to pyrometallurgy, but the CO2 emissions during the pyrometallurgical processes are higher compared to hydrometallurgy. If cost is the determining aspect for process selection, pyrometallurgy is a better option, due to its reduced expense compared to hydrometallurgy. However, considering the efficiency of the process, hydrometallurgy stands out to be the most efficient one.

4.2 Quantitative Study

During the research it was found that the industries do not publish enough data to get a clarified idea due to the secrecy they maintain on the specialized technologies in order to survive the competition.

The industry results and the experimental results were found to be contradicting. The main reason for these differences are the special conditions existing in industries compared to research organisations. An experiment has an optimal set of conditions compared to real-time practical problems in industries. This indicates the immediate requirement of improvisation of industrial conditions. However, this requires further research to identify the optimal relationship between recovery rates of elements and energy consumption. A major issue faced during this investigation is the credibility of the collected data, as mentioned by the interviewees. The recycling process of lithium-ion batteries are still in the early stages of development and the industries have the option to inflate the results and present them in order to attract the investors.

According to the result from the DOE there are three significant factors to increase the recovery efficiency in hydrometallurgy. For the industry to increase the efficiency with the following increase in profit, which currently is a problem according to the interviewees,, the optimized factors during the recycling process should be temperature, H2O2 concentration and S/L.

Even though the interview alleged, recycling of Li-ion batteries is not profitable, there exists data on industry reports regarding recycling of Li-ion batteries.The industry reports highlight the efficiencies of recycling methods, but does not take any consideration towards the economical aspects, which should be the main concern of industry reports to attain high profit margins. The fact that recycling is still being done despite being unprofitable could be a sign of the environmental awareness of producers, due to the toxicity risk of batteries in landfills.

4.3 Future aspects.

Today the method works because the amount of batteries is low. But when the current generation of batteries reaches its end of life expectancy, the current recycling strategies will not be enough.

The interviewees claim that the current recycling methods are not efficient enough, still there exists industries and new up-coming factories which mainly focus on recycling of lithium-ion batteries.

5. Conclusion

This major objective of the project is to investigate the current situation regarding the methods of recycling lithium-ion batteries. The focus was to find out whether the methods are efficient enough to meet the growing demand of batteries, and if the recycled material is having a certain benchmark quality to create a circular material flow, where recycled materials can re-enter battery production.

Two major methods of recycling batteries were found, pyrometallurgy and hydrometallurgy, each with their own advantages and disadvantages. Even though the methods could physically extract high grade material, it is not economically sustainable. Pyrometallurgy is currently the most suitable recycling method regarding the extraction of elementary metals from low value batteries. However, due to the possibility of extracting a high rate of lithium and cobalt, hydrometallurgy was deemed to be the most promising recycling method in creating circular material flows for production.

When comparing the reports from both academia and the industry, it was found that the extraction rate in the industry was 23.4 % lower than the academic reports. This shows a scope for improving the potential of the industries. From data analysis it was observed that the two most important factors in hydrometallurgy are temperature and acid concentration.

In this project, three main challenges in the field of recycling were found. The first one is the economic aspects of recycling. Since the processes themselves are very costly, it will be hard for companies to make a profit from recycling, which will deter investors. The second challenge is the collection of batteries from consumers. In the gathered batteries, a lot of other unwanted materials are included, which adds additional separation steps. The final issue is the antiquated directives regarding battery recycling, which is likely to be updated in the coming years. The uncertainty of legislation is currently halting the development of recycling plants, since recyclers don’t know what will be expected of them.

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Group 8.
Pet bottle deposit system: A mapping of behavior and motivational differences between the USA and Sweden

Ida Nykvist, Emma Valtersson, Johan Lené, Mariane Jakob, Viktor Bengtsson

Group 8

nyida@chalmers.se
emmava@chalmers.se
lenej@chalmers.se
marjakob@chalmers.se
vikbengt@chalmers.se

Abstract

The world is facing a growing concern about rapidly increasing plastic waste and how to recycle Polyethylene terephthalate (PET). The aim of the study is to determine what challenges the US face with using deposit systems and to investigate the behavior and motivational differences between Sweden and the USA. The project involved a literature-, a qualitative- and a quantitative study. The result shows a much higher recycling rate of PET bottles in Sweden. In the USA, usage of deposit systems is limited to ten states, where the PET bottle recycling rates are twice as high compared to non-deposit states. In conclusion, the USA has challenges with enforcing a new deposit system, due to political resistance and beverage industry opposition. Furthermore, behavior and motivational factors differ between Sweden and the USA. This may be due to Sweden having a low littering in general and thereby, each individual action becomes more visible.

Keywords: Deposit system, PET bottles, Sweden and USA

1. Introduction

In this section, the background of the project is presented. Furthermore, the project aim and research question are presented and the project limitations are highlighted.

1.1 Background

Today plastic recycling is one of the most important topics in the environmental sector of recycling. Manufacturing of plastic products has a huge environmental impact, the process contains sources that are limited and has a negative environmental impact from cradle to the grave [1]. A large amount of energy can be saved by successfully recycling the plastic that is manufactured. Recycling one-ton plastic results in 1000-2000 gallons of gasoline savings and 2000 pounds of oil [2].

Sweden is a pioneering country when it comes to recycling, the recycling rate of plastic is around 40% [3]. One of the key factors that contribute to the high recycling rate of plastic in Sweden, is the introduction of a deposit system for PET bottles and aluminum cans, established by AB Svenska Returpack 1984 [4]. In 2018, the recycling rate of PET bottles was 83,3% in Sweden [5].

Yearly, 2.4 million tons of polyethylene terephthalate plastic is thrown away in the United States of America (USA). From 2015 was 79 % of almost 6300 million tons of plastic waste sent to landfills or in the natural environment [6]. It takes almost 500 years to decompose a plastic bottle [7]. In similarity in the Swedish deposit system, the USA has “bottle bill laws”, where beverages such as beer and soft drinks require a refundable deposit [8]. The gap between Sweden and the USA in this sector is huge.

Bottle bills and deposit systems are mentioned in the introduction, which is representing the same thing. To avoid confusion, the term deposit system will be used throughout the report.

1.2 Project aim and research question

The project aim is to carry out a study comparing plastic recycling of PET bottles between the USA and Sweden. The target is to investigate the difference in behavior towards recycling in the USA and what the benefits are with having a deposit system, where 1 to 2 SEK return is given back after recycling, corresponding to the extra amount paid when purchasing bottles.

The research question that has been formulated for this study is:

- What are the challenges with deposit systems in the USA?
- How do the motivational and behavioral factors differ between Sweden and the USA, when using a deposit system?

1.3 Limitations

This study is carried out over one study period of eight weeks. The limitation was set to a comparison between two countries, the USA and Sweden. The process of how the deposit system works will not be included. The climate impact will not be compared.

2. Methods

Triangulation was performed by using quantitative and qualitative research, powered by literature studies to achieve a reliable research result [9], all of which are described further in this chapter.

2.1 Literature study

A literature study was carried out to gather general data to retrieve background knowledge about PET bottles recycling in the USA and Sweden. Different keywords were determined by the group connecting to the research question and the scope. Keywords of interest were; Deposit system, PET bottles, Plastic, Polyethylene terephthalate. Recycling, Sweden and USA. The keywords were combined and translated into various search-strings. Screening was made on different articles and scientific papers by relevance to the searched topic by using Google Scholar, Chalmers Library and Scopus. A filter was used in the databases, i.e. no literature older than 2000 was used and for some specific areas such as rules, laws and statistics, to find the most updated information available. Furthermore, only peer-reviewed literature was used. The literature was chosen based on the title of the text and by reading the summary. If the title was considered relevant, matching the research question, a deeper reading of the text was made and if the context was relevant, the information from the literature was extracted.

2.2 Qualitative study

To gain knowledge about human behavior towards the recycling of PET bottles, a qualitative study was conducted in the format of a questionnaire and interviews with experts from The National Association for PET Container Resources (NAPCOR). The purpose of the questionnaire was to confirm the literature study, support and add substance to our conclusions in the conference paper. The qualitative data was collected through a structured survey, in the form of a questionnaire, consisting of both predefined answers with multiple-choice questions and open questions, which enabled the participant to further explain their answers. The purpose of a structured survey is to gather comparative data so the result can statistically represent a larger population [10]. The questions are standardized and the participants answer the same questions in the same order [11]. The questionnaire was carried out anonymously, with voluntary participation, ensuring no judgment was made depending on who answered and the answers were confidential between recipients to ensure good research ethics [9].

There were two different questionnaires handed out which was created in Google Forms, one targeting Sweden and one targeting the USA. The questions in the questionnaire were formed after an extensive literature study with the literature used as a base. The focus groups selected for the study were mainly students with different nationalities in two different universities Chalmers University of Technology in Sweden and Northwood University in Michigan, USA.

The questionnaires were sent out via canvas for the students at Chalmers University of Technology and for students at Northwood University in the USA the questionnaires were sent out through a contact person at the university. The results from the two different focus groups were compared and visualized in diagrams using JMP and Excel.

To find possible experts to interview, questions were sent to three different associations found through google that clearly expressed that they are working with PET bottles recycling. One association answered and was willing to continue by answering questions by email. The purpose of the interviews was to gather information about the challenges of PET bottles recycling in the US, and also to ensure that data from the surveys were correct.

2.3 Quantitative study

To deepen the knowledge from the literature study a quantitative study was carried out. The study was conducted to find more information about PET bottles recycling rates, in Sweden and the USA and relations between states in the USA, which currently have some type of deposit law and those who do not. The study was carried out using secondary data from scientific papers, articles, newspapers and various studies in the field since the group was not able to gather primary data about recycling rates through sampling.

The purpose of a quantitative study is to collect numerical data, which is generalized between different populations to explain a certain phenomenon and be able to draw a larger conclusion. Quantitative methods are based on statistics, objective measurements and analysis through collected data from surveys [12]. The analysis was performed in three different steps: literature review, data collection and analysis of data. First, wide research of articles, containing data on how the frequency of PET bottle recycling has changed annually in the two different countries, was analysed. Various search platforms used in the researching process were: Scopus, Google scholar and Chalmers Library. The search words used

were Recycling rate, USA, Sweden and Bottle bill and deposit in different combinations.

Ultimately, to retrieve statistics about recycling rates of PET bottles, experts from Pantamera AB and NAPCOR were contacted. The data of interest was consciously limited to the time interval from 2005-2018 since older data is not relevant for this research and this time interval is within the data scope limit. Recycling rate data in Sweden were retrieved via email from Pantamera. Recycling rate data for the United States between the years 2010-2017 was extracted from "Post-consumer PET container recycling rate" reports retrieved from NAPCOR's website. Additional years between 2005-2009 were complemented and retrieved via email from the Director of Data Services from NAPCOR. When extracting PET bottles recycling rate data the information was manually added to excel and controlled by two group members, to ensure no data was missed in the transfer. After collection, the data was analysed and compared with additional sources, to validate the information, and later summarized in a graph which is presented in section Sweden vs USA PET bottle recycling rate.

3. Results

In this section the results from the literature study, quantitative study and qualitative study are presented.

3.1 Literature study

In this section, the results from the literature study are presented.

Recycling of PET bottles

PET is the world's most advantageous packaging material, especially for beverages, due to its advantageous material properties. A solution to how PET bottles should be recycled has for a long time been a challenge, partly because of a lack of knowledge about packaging polymer contamination. Over the past 20 years, recycling technology has made great improvement where ecological requirements and the increasing use of PET bottles have been major demanding factors for developing good methods for recycling PET bottles [13]. The global PET market is increasing with an annual growth rate of 6.9%. In 2000 the use of PET was 6,4 million tons compared to 2020 where it is projected to increase up to 23 million tons, generating large amounts of waste in ecosystems [14]. PET is not biodegradable, and will therefore remain in nature for several hundred years [15].

PET bottle deposit system in the USA

Figure 1 shows the relation of recycling and waste of PET bottles in the USA, and illustrates that a majority of the PET bottles is wasted [16]. In 2010, 33.3 Million tons of plastic was wasted in the USA. 75% ends up in landfills, 15% incinerated and 9.5% recycled [17]. Every year 50 000 million PET bottles are landfilled in the USA [15].

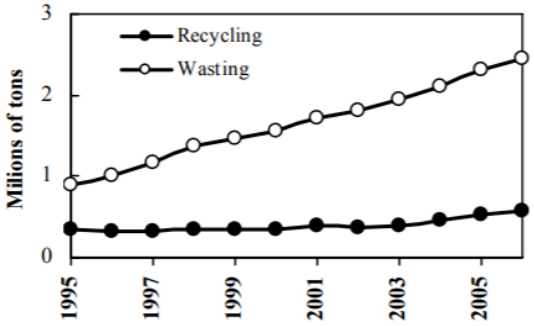

Figure 1. Relation between recycling and waste rates between 1995 and 2006 in the USA [16]

There are currently ten states in the USA which have instituted some form of a deposit system. One reason why the US falls behind in recycling is due to the lack of curbside recycling [8]. Furthermore, big companies such as Coca Cola and beverage associations, are reluctant in the use of botte bill systems, partly because of the costs. If the recycling rate is increased to 75 % by 2030, this would generate 1.5 million new jobs [18].

PET bottle deposit system in Sweden

The requirement for whom professionally makes consumable beverages in plastic bottles are required to ensure that the bottles are included in an approved deposit system, with the exception of beverages consisting of dairy, fruit, berries and vegetable products [19]. Pantamera is responsible for running Sweden's largest deposit system of aluminum cans and plastic bottles which has been used by the customer [20]. The collection of PET bottles increases if there is a specified deposit system because a deposit gives the customer a reason to return a bottle [21]. The advantages of Swedens' deposit system are that the waste is reduced in public places, also having this kind of system benefits the environment as all PET is collected in the same place [22].

Motivation factors of recycling PET bottles

The implementation of the Swedish deposit system for PET bottles in the United Kingdom is being investigated. One of the questions being studied was how people feel about the PET-deposit. The result from the survey is compiled in figure 2, this shows that the largest proportion of people are satisfied with a deposit between 1 SEK to 2 SEK [23].

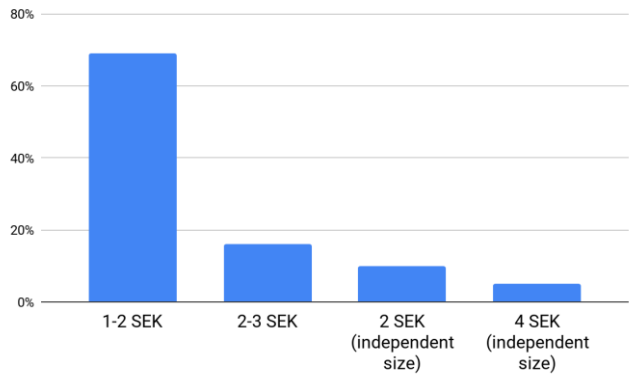

Figure 2. Opinion of reasonable deposit sum in the UK

Psychological factors affecting PET bottles recycling

The consideration that individuals want to recycle is influenced by several psychological factors, such as social norms and environmental values. The fact that it is not only the financial gain that determines the decision to use a deposit system [24]. There are non-monetary factors that motivate people to recycle and not necessarily have to be encouraged by politics or supported by the fact that it is a financial gain. Instead, the satisfaction experienced by following the social norms may be the factor that actually affects people's motivation for recycling [25].

3.2 Qualitative study

In this section the result from the qualitative study will be presented. In total, 17 answers from students in Sweden and twelve answers from students in the USA were received by the questionnaires. The results presented include the different perception of littering in the USA, Sweden and other countries. Furthermore, the likelihood of a PET bottle deposit system being used if it exists, as well as motivational factors for utilizing an existing deposit system in the USA, Sweden and other countries is visualised.

Littering of PET bottles

When the participants were asked if they think that it is a problem with littering where they originally come from the majority answered yes. When the answers were divided based on location, the majority in Sweden said no while USA and other countries said yes. Ultimately stating that a country with a well implemented deposit system, the perception of littering seems less, see figure 3.

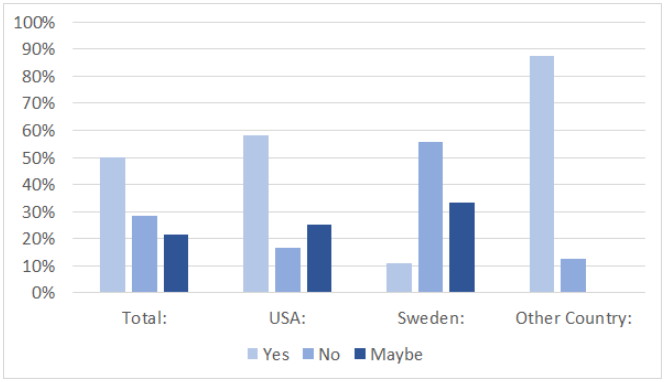

Figure 3. Littering by location from the surveys

Probability of using a PET bottle deposit system

Figure 4 shows the mean value of the likelihood for participants to use an existing deposit system on a scale between 1 to 10. The result shows, participants from Sweden re slightly more likely to use a deposit system than others. and the probability to utilize the deposit system is high.

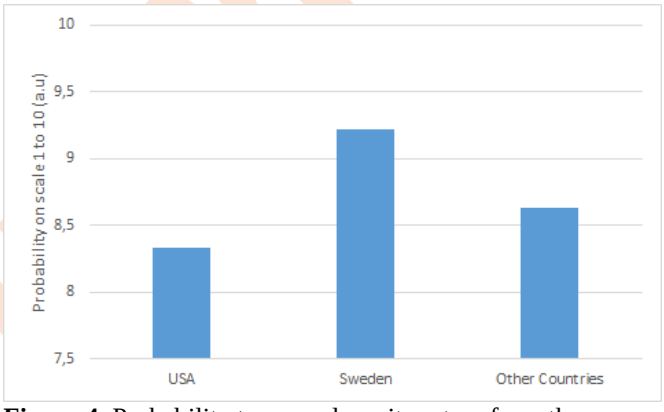

Figure 4. Probability to use a deposit system from the surveys

Motivation factors for using existing deposit system

When the participants of the survey were asked what would motivate them to use a deposit system the result showed that the environmental aspect was the most popular answer, see figure 5. This goes for all the participants regardless where they come from. The participants from Sweden were more keen to have additional motivational factors, such as the economical drive and less littering.

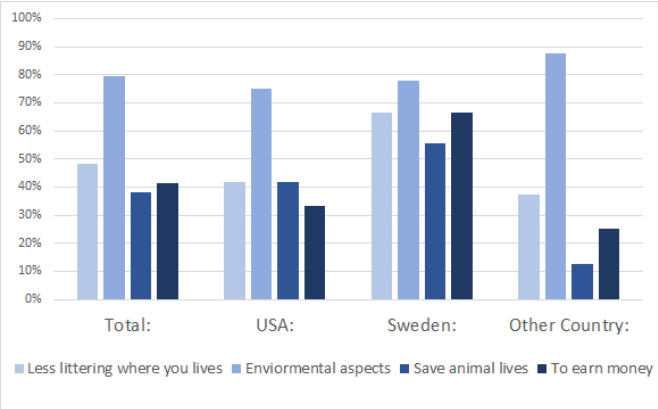

Figure 5. Results for the motivational factors from the surveys

Motivational factors in perception in littering

The survey examined how motivational factors changed when participants believed that there is a littering problem of PET bottles in their home country, see figure 6. The result shows the environmental aspect as the strongest motivational factor, regardless of origin. Other factors are evenly divided between the participants. In contrast, participants who don't believe there is a littering problem, see figure 7, the strongest motivational factors are less littering and environmental aspects.

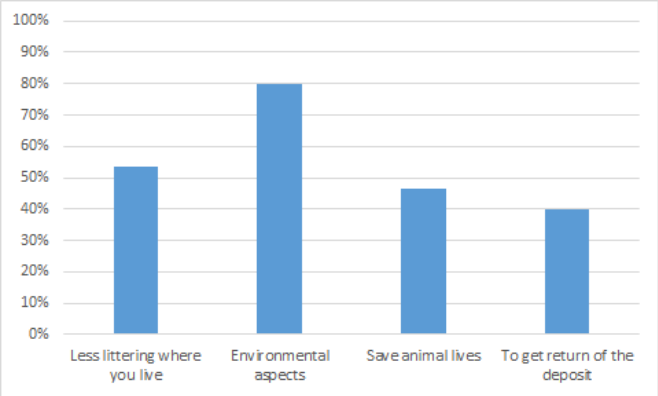

Figure 6. Motivational factors for people who believe that there is a littering problem in the home country

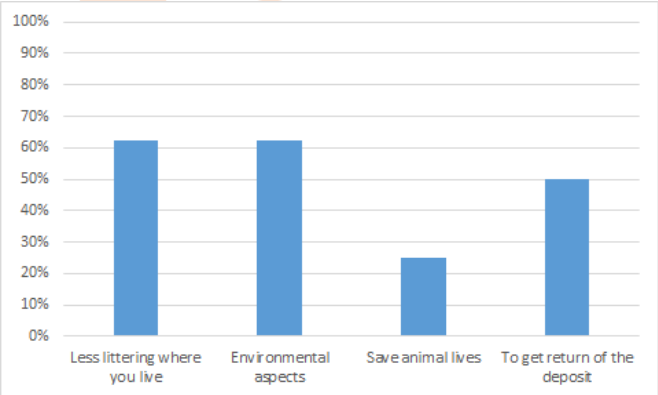

Figure 7. Motivational factors for people who believe that there is no problem with littering in the home country

NAPCOR interview

The interview questions focused on the challenges with depositing it in the USA. The benefits a deposit system brings and what efforts are made to increase recycling rates. The findings are summarised in table 1 below.

Table 1. List of findings from NAPCOR interview, divided by categories in the left column

Challenges	-Political restrictions to inforce new deposit systems -Beverage industry opposing deposit systems -Anti-plastic sentiment in the media, creating confusion about PET, not being separated from plastics in general - Unredeemed deposits - Each state has freedom to control how stringent the recycling programs should be
Benefits	-PET bottle recycling per capita higher when using deposit system - Twice the amount PET is recycled per person in states with deposit system - Great consumer confidence in deposit systems
Efforts	-Introducing new deposit systems legalization (most recent law instated into 2005) -Improve curbside/blue bin recycling infrastructure -Increase quantity and quality of recyclables collected

3.3 Quantitative study

Below, the results from the quantitative study are presented.

PET bottle recycling rate in USA

Today, ten states in the USA have some type of deposit system [26], see figure 8. These ten states contribute to 47% of the total recycling in the US, these states include 28% of the US population. When a deposit system exists, statistics show that 63.1% of all PET bottles are recycled, while in states where there is no type of deposit system, only 16.6% of all PET bottles are recycled [27].

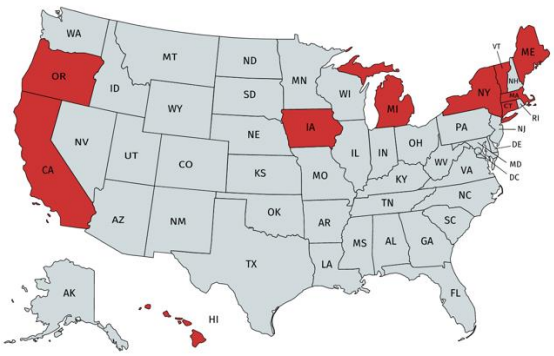

Figure 8. States with deposit laws

PET bottle recycling rate in Sweden

In Sweden, the goal is to have a recycling rate of 90%, and for today Sweden is just below this target [28]. The collection of PET bottles increases if a specified deposit system is used, this because the customers are motivated to return bottles [29]. The advantages of Swedens' deposit system are waste reduction in public places and benefits with PET plastic being collected in designated areas [22].

Sweden vs USA PET bottle recycling rate

Figure 9 shows the relation between USAs and Swedens' PET bottle recycling rate, between 2005 and 2018. The US has an average of 28% and Swedens' average is 82%[5][30]. In Sweden, the curve is quite flat in recent years. The USAs curve shows a slight increase until 2014, where the cure declines and the recycling rate.

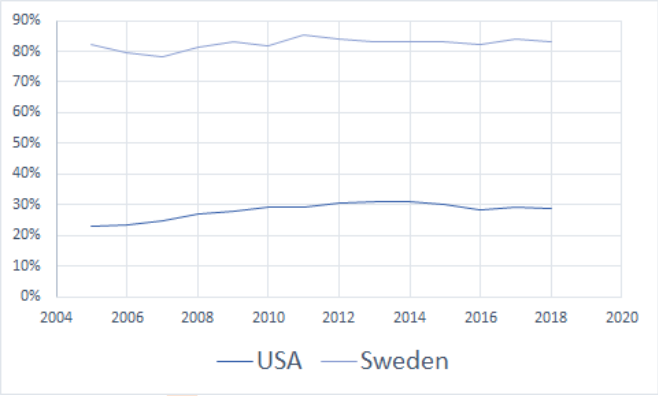

Figure 9. PET bottles recycling rate in USA and Sweden from 2005 to 2018

4. Discussion

One of the main ideas of today's deposit system is to achieve a higher individual incentive to recycle. One motivation to use a deposit system is the monetary advantage raised in the theory, the feeling of benefiting society and meeting the social norms that the society creates. The environmental benefits of a deposit system is the main factor that motivates people to actually use the deposit system according to our study and the knowledge of the positive impact of the environment generated by a deposit system, seems to be known to both the USA and Sweden. The awareness seems to be there, which means other factors contribute to the low rates of recycling in the USA. One drawback in the USA could be the non value adding time for an individual to spend on the activity, to find a station and transport the bottle for deposit. The accessibility of recycling stations needs to be improved, which might enhance motivation, and thereby increase recycling rate, in such cases. To increase awareness, an increased effort in marketing might be the key to success, by for example implementing advertising on each bottle, so the consumer is reminded daily of the benefits a deposit system brings or increases the deposit for each recycled bottle.

The results also show, people in Sweden tend to use a deposit system more than the USA. The reason why the deposit system is used to a greater extent in Sweden compared to the US may be because the attitude towards a deposit system differs. People in Sweden tend to be driven by the fact that, from an economic perspective, they can benefit from using a deposit system, which is not as highly valued by people in the United States. However, according to the results, an increased deposit might not lead to a higher motivation, since the largest proportions of people are satisfied with a deposit of 1 SEK to 2 SEK., which also was the lowest deposit offered. Instead, the fear of breaking the existing social norms might have a greater impact on peoples' motivation to use a deposit system, than the financial gain it entails. Another reason why using a deposit system in Sweden is substantially better than in the USA, is because Sweden has quite low littering in general and thereby, each individual action becomes more visible.

The result indicates that the low utilization of deposit systems in the USA does rather depend on the fact that several states lack an existing deposit system, which is noticeable affecting the countrys' overall performance. By implementing deposit systems in more states might lead to a higher recycling rate for the entire USA. The problem lies not in a lack of knowledge but rather a political reluctance and the beverage industry opposing deposit systems. The result shows, no new deposit law has been instituted since 2005, which indicates much convincing and encouragement at higher instances needs to be prioritized. Furthemore, different states have different laws and restrictions of how a deposit system should be used, which makes it difficult to generalize the data collected in the project.

Moreover, to meet the aim of the paper, the necessity of a questionnaire was inherent to gain knowledge about human behavior and mindset towards recycling of PET bottles. A questionnaire was a simple method to receive an overview on differences in behavior between the USA and Sweden.

However, the study had few answers. One limitation was the difficulty to find enough people to answer the questionnaire and to get in touch with the students at Northwood University in Michigan. From the results some assumptions could still be made, as clear differences in responses were shown. To increase reliability in the qualitative study, a wider survey with more answers would have been optimal, which would most likely have affected the results of the study. Fortunately, the interview with NAPCPOR confirmed most of the findings from the studies, validating the responses. The report is considered to have a high level of repeatability, in the literature study and the quantitative study due to the clearly presented method and systematic work structure. However, the qualitative study might set restrictions in repeatability, since the interview and questionnaire question is not attached in the document.

5. Conclusions

The aim of the study was to do a mapping of what the challenges the US faces with PET bottle recycling and what the main differences in motivation and behavior toward PET bottle deposit systems differ between the USA and Sweden. To conduct this study a triangulation was made, including a literature-, a qualitative- and a quantitative study.

Main findings from the research conclude that the USA faces challenges with low PET bottle recycling rates and implementation of new PET bottle deposit systems due to political resistance and intressents resentment.

Furthermore, behavioral differences between the USA and Sweden is that Sweden uses a PET bottle deposit system more, where Sweden has an overall positive attitude towards PET bottle systems. The motivational differences is that sweden in secondary are driven by the economic factor, while USA is more concerned about littering in secondary to the environmental aspect. Lastly, Sweden motivates PET bottle recycling by having a clean environment where littering is not acceptable, which the USA.

The paper was validated by using triangulation with complement of experts, comparing the results of the questionnaire. Additionally, by comparing sources of information increases the value of the paper.

Future research

With identified challenges and behavioral and motivational differences, recommendations for future research is further specific to investigate factors in motivation and behavior to compute tools and approaches used in Sweden, USA can apply, to increase the recycling rate of PET bottles.

Acknowledgements

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Group 9.
Exploratory study on collaborative consumption in Swedish clothing industry

Dilip Ganga, Filip Alpsten, Harshith Kumar, Juan González, Alberto Valdez, and Shanjith Raja

Group 9

gdilip@student.chalmers.se; filipal@student.chalmers.se; harshith@student.chalmers.se; juanf@chalmers.se; becerril@student.chalmers.se; shanjith@student.chalmers.se

Abstract

Production rates of clothes have exceeded the basic needs in the world for many years, where fast fashion is one of the drivers behind the increasing consumption. This comes with high costs of resources like energy and freshwater leading to pollution and carbon emissions. This research explores if collaborative consumption of clothes can reduce the environmental impact of the textile industry, while still allowing people to follow fashion trends, and how it can be implemented in Sweden. It has been found that collaborative clothing consumption has potential to reduce the environmental impact of produced clothes through possible extension and intensifying of their using phase. This, in combination with recycling, can play an important role in moving towards a circular fashion market. The current interest for such services among Swedish consumers is found to be relatively low. However, marketing aimed towards young, fashion interested people can be effective.

Keywords: Swedish clothing industry · Collaborative Consumption · Clothing Library.

1. Introduction

1.1 Background

Clothing has always been essential to humans; however, fiber production has overtaken necessity in the last few years. A trend that people buy more clothes, meanwhile caring less about them, has been shown; and this gap is getting bigger [1]. It is estimated that waste from the fashion industry will increase by 60 per cent from 2015 to 2030, leading to 148m tons globally [2]. Of all material used to produce clothing, 73% goes to landfill or incineration, 12% are losses in production, 2% is lost during collection and processing and only 12% goes to recycling into other applications and 1% are closed-loop recycling, see Figure 1 [3]. Clothes degrading in landfills or burned have negative environmental impacts by releasing greenhouse gas emissions and contributing to soil erosion and groundwater pollution [4]. This fashion consumption drives freshwater consumption, energy consumption and emissions having negative impacts on climate change. The impact of this in Sweden is described in Table 1. [5]

The linear economy of the clothes production in the industry has a high environmental impact through intensive use of water, non-renewable energy resources and chemical agents leading to considerable amount of CO2 emissions and waste accumulation. This type of model can be replaced by a circular economy where the service lifetimes of clothes and materials are maximized. This through improved quality of clothes, reuse of clothes and through recycling of the materials, thereby closing the loop of the system [1].

Table 1. Environmental impact - Swedish clothing consumption [5].

Impact Category	National-level impact	Impact per capita
Climate Change	3.27 million t CO_2 eq.	327 kg CO_2 eq.
Water scarcity	6.13 billion m^3 world eq.	613 m^3 world eq.
Energy resources	600 million MJ	6000 MJ

Note: eq. = equivalent

Maximising usage of clothes becomes an important aspect to reduce the environmental impact, comprehensive solutions and strategies should be accomplished to diminish environmental repercussions. Collaborative Consumption (CC), which encompasses gifting, lending, sharing, swapping, renting,

leasing, and second-hand uses, have positive environmental effects via gains in efficiency and encouraging sufficiency [6]. It is an alternative way of doing business that can potentially reduce the environmental impacts of fashion, by prolonging the practical service life of clothes [7].

1.2 Research questions

The aim of the paper is to answer the following question: How can a collaborative consumption clothing model diminish environmental impact in Sweden?

To further specify the research, the following sub-questions were formulated: a) What are the advantages, concerning environmental sustainability, of a CC clothing service system compared to conventional linear economy? b) What are the challenges of collaborative fashion consumption services in Sweden? c) What is the general opinion among Swedish people concerning CC clothing businesses as a way to diminish environmental impact.

1.3 Scope and Limitations

This paper is made in the framework of a Research Methodology course, the aim is to implement all the concepts and methodologies learned into a real case scenario. The data retrieved from the survey are found to be true and reliable. It is not to be viewed upon as a scientific paper. The study is focused only on the Swedish market. It is also only concerning environmental sustainability; social and economic sustainability aspects are excluded.

2. Methods

The research was conducted through an initial literature study and further quantitative and qualitative data collection and study. Triangulation between these methods was useful to get a comprehensive answer to the research questions.

2.1 Literature study

The main databases consulted to get scientific papers were Science Direct, SAGE, Scopus, Access Engineering, Emerald Insight and Semantic scholar. However, other electronics sources were useful to get thesis, LCA and textile industry reports. Relevant literature papers recommended by experts in this field were collected through the online Chalmers library platform and some data was retrieved through company webpages. The keywords and key phrases were clothing collaborative service, clothing waste management, clothing recycle, circular economy, and garment reuse.

2.1 Quantitative study

Primary data was collected by forming a survey with questions concerning people's attitude towards CC clothing services and about their current habits around clothing. The questions were formed by focusing on the data needed to understand the views of the customers and their awareness about the research topic. The survey was applied online and distributed among the author´s acquaintances. The results were based on primary data collected from the survey and secondary data collected from literature papers, used in the discussion section.

2.3 Qualitative study

A qualitative study was carried out to investigate how a circular economy can be achieved in the fashion industry. In this study, qualitative data was collected through remote interviews with experts in the field of circular economy and people involved in CC clothing services. The qualitative study was done in the form of a telephone interview with an employee of a charity organization in Gothenburg in charge, among other activities, to collect second-hand clothes and give it away to needy or homeless people. The aim was to get a general overview of that service and clothing disposal in Swedish society. The inductive approach was used in this study, where conclusions are drawn with particular facts and observations, which are used as a supportive frame.

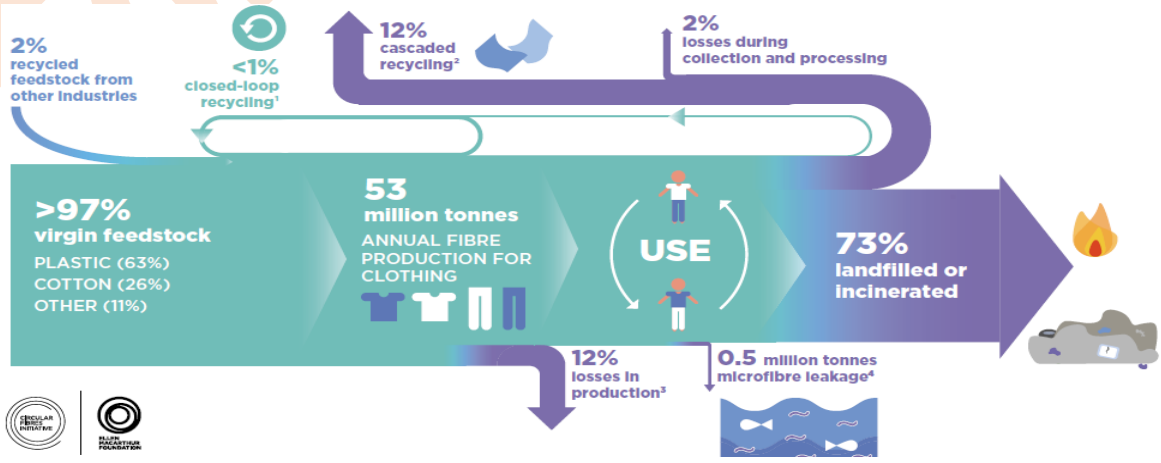

Figure 1. Global material flow for clothing in 2015 [3].

3. Results

Findings about the actual situation in Swedish fashion sector are presented with a circular offering perspective, as well as results from methods described in section 2.

3.1 Literature study

Fast fashion, which combines short, fast and cheap trendy clothing production, is one of the drivers behind the increasing clothing consumption and a throwaway fashion trend where large amounts of clothing are being disposed of before being worn out [8]. For instance, a study shows that 62% of Swedish people dispose of usable clothes (excluding socks or underwear) that they no longer want to use in the garbage and 21% of Swedes dispose of clothing because they are tired of them [9]. The Swedish market for collection and handling of used textiles is dominated by charity organisations, representing an estimated 90% of the market and the remainder is handled by private stakeholders [10]. Collection, sorting, reuse and recycling have different aspects to be improved in Nordic countries; main barriers related to low collections are: unclear regulations, definition of waste, and non-existing high grade recycling possibilities [11].

H&M states 'the fashion industry is running out of the natural resources it uses to make products and cannot continue to operate in the same way' and reaffirmed its belief that 'an industry-wide shift from a linear to a circular business model is the only solution'[12]. According to Camacho-Otero, Boks, Nilstad, acceptance of and participation in different types of circular offering is influenced by several factors illustrated in Table 2 [13]. Lack of consumer acceptance of circular offerings is one of the primary barriers for the transition to a circular economy [13]. Other major barriers were seen to revolve around 'consumer behaviour and education', 'disposal practices, collection and sorting infrastructure and processes' and 'recycling technologies' [14].

There are four principles of CC that play an important role to make the system work, these are: critical mass (network large enough to offer enough options to people), idling capacity (enough resources to share), belief in the commons and trust between them[15]. In order to bring this, it is said that by Mont [16], consumers behaviour is the most important key factor. The consumer's perspective of thinking must change from fashion-oriented to functional product-oriented, where importance is given to product services rather than style.

Furthermore, the challenges of the circular economy were also mentioned and addressed. Lack of market demand, lack of government legislation towards recycling and reuse, the reluctance of companies to involve in recycling and reuse of products, lack of up-gradation of tools (services and software) in the companies, and psychological perspective of customers thinking towards second hand-clothes [15,16].

Building on works by Stahel [17] and McDonough and Braungart [18] and Bocken et al. [19], two fundamental strategies toward cycling of resources are introduced. The first one is a slowdown of resource loops. Design of long-life goods extend product lifetime and the utilisation period of products is extended and/or intensified, resulting in a slowdown of the flow of resources. Second, closing resource loops, where recycling closes the loop between post-use and production.

Table 2. Factors and conditions influencing acceptance and adoption of circular offerings.

Category	Factor
Economic	Cost, gratification, offering, income, information, price, risk
Demographic	Age, gender, level of education, geographical location
Psychosocial	Attitude, behaviours, environmental values, materialism, subjective norms
Cultural	Desire for change, experience, experiment, fashion involvement, interaction, uniqueness, political position, identity, status
Socio-material	Daily life, ease of use, legal, location, technology

3.2 Qualitative study

Francisco Chávez, an employee for seven years of the charity organization Café Trappanér, was interviewed by telephone. The purpose was to get an overview of one of the most used methods for collection and handling of clothes. The questions were oriented to get an idea about society's behaviour regarding clothing disposal, opportunity areas of these organizations to be more efficient in clothing handling to diminish environmental impact. The main input of the interview was that Sweden is a very clothing consuming society. Fortunately, the society is very participative and all the time they have enough clothes to give away. The charity is open three days a week and every day about ten people go to ask for clothes, the most required items are underwear, jeans, t-shirts, and jackets. Unfortunately, most of the time they remain with a lot of clothes that they must trash or give to second-hand stores. He emphasises many of those garments are in very nice condition, meaning people get rid of clothes easily without making full use of them.

3.3 Quantitative study

The primary data for the quantitative study was based on the results gathered from the survey. Data such as gender, age, nationality, residence, clothing preferences, environmental awareness, and service criteria was collected. The survey was answered by people living in Sweden but also by people living outside Sweden. The three main nationalities are Swedish,

Mexican, and Indian. For customer acceptance purpose, the willingness to subscribe to a CC clothing service was analysed based on the nationality of the participants living in Sweden.

Figure 2 shows that almost two thirds of the Swedish participants are not willing to subscribe to the service. However, it is the opposite for the Indian participants and neutral for the Mexicans.

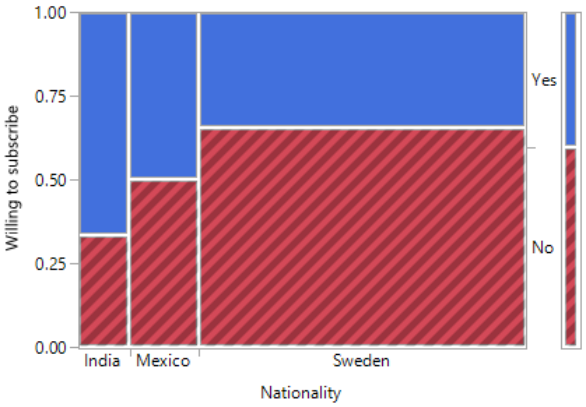

Figure 2. Graph of Nationality v/s Subscription willingness.

After performing a Chi-square analysis, a p-value of 0.2726 was obtained, so for our data set there is no significant connection in the decision of subscribing to the service with nationality. Therefore, the next analysis conducted was considering the age group of the participants. For this purpose, two age groups were considered, younger than 30 years old and older than 30 years old.

As shown in Figure 3, the participants younger than 30 years old are more willing to subscribe. In this case, the p-value obtained from the Chi-square analysis is 0.0028 so there is a clear correlation between the age group and the willingness to subscribe.

The next analysis performed was regarding the preferred transportation method, in case of having a physical store.
Figure 4 shows that the preferred transport method for both Mexicans and Indians living in Sweden is public transport but they do not choose to bike/walk. However, Swedish responses are more mixed.

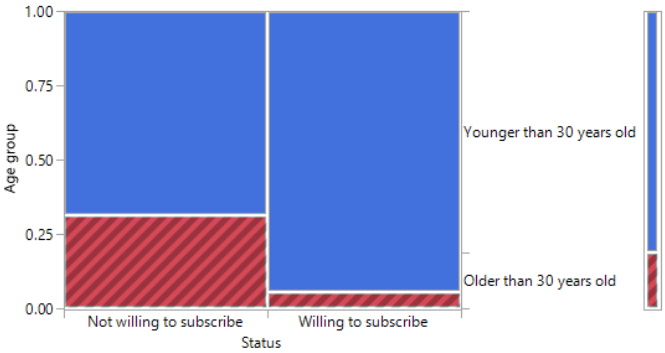

Figure 3. Graph of status v/s Age Group

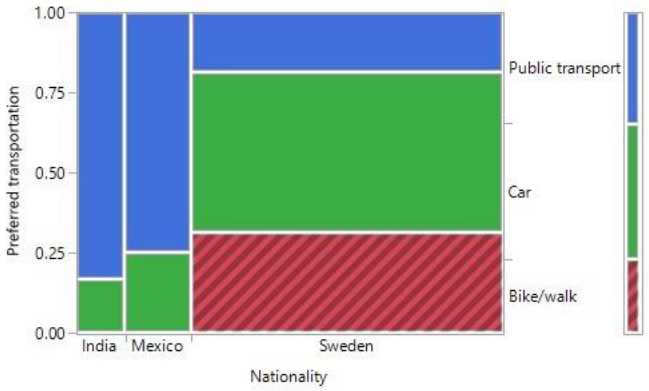

Figure 4. Graph of Nationality v/s Preferred transportation

The Chi-square analysis gave us a p-value of 0.0007 which indicates that nationality matters in the decision of preferred transportation method.

Depending on the preferred transportation method, the environmental impact varies. Figure 5 shows the final analysis performed which is about the reason for discarding clothes compared to the willingness to subscribe to the service.

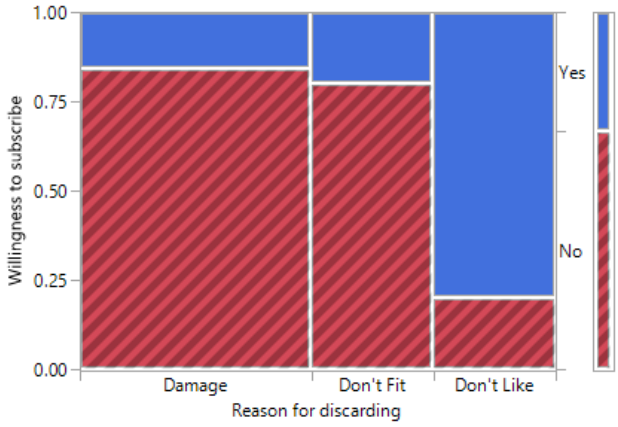

Figure 5. Graph of reason for discarding clothes v/s willingness to subscribe to a CC clothing service.

Most of the people that are willing to subscribe to the service are the ones that discard clothes because they no longer like them. The p-value for this analysis is 0.0015, indicating that this correlation is statistically significant.

4. Discussion

Due to short time and health issues nowadays, several limitations were faced. Data collection was based mostly in secondary than primary data collections. Surveys and interviews had to be carried out remotely or digitally, losing the reaction of people. The current data set is a small sample size which is mostly male population. In order to improve the analysis, a bigger and more varied sample is required. Similarly, it´s interesting to note that the people of other nationalities showed more willingness towards the clothing

library service than people in Sweden. As the research question is about implementing a circular economy in the Swedish clothing sector to reduce the environmental impact, we focus on reusing mostly as recycling is a big area where lots of development is needed. Swedish Environment Protection Agency proposed that by 2025, textile waste should be reduced by 60% [20]. To achieve this CC clothing services can be an important contributor to this reduction. The below mentioned points reveal the possibility of implementing the clothing library services more widely in Sweden.

- From this research can be seen that out of the 25% of Swedish people who have used clothing libraries, less than half of them are willing to subscribe to the clothing library again. From this it can be concluded that something in those customer`s expectations were not met by the service. It can be the design or quality of the clothes or something about how the service is designed. More research about it must be done to conclude the reasons behind it but to make a clothing library a profitable business these expectations must be met.

- Most Swedish people are not comfortable in exchanging clothes. 87% of them have voted less than or equal to 3 out of 5 for a comfortable rating. At the same time 61% of the people are donating their clothes currently. The interview with the charity organisation also reveals that the society is very participative in donating their clothes. If they are willing to donate clothes to libraries, they largely reduce the investment cost of these libraries.

Apart from this some major clothing and fashion retailers are already committed towards a sustainable future. Companies like H&M claimed that they have put moving towards circularity as their priority. In the interview with the charity organization, the interviewee quoted that the new business model and the more efficient usage of the production systems are key factors for achieving a circular economy. It was interesting to see that H&M have started to work on this by setting the foundation for the ground-breaking textile industries. One such example is, H&M supporting re:newcell to overcome challenges in becoming sustainable by producing recycled or sustainably sourced clothing materials to achieve their goal in closing the loop [14]. Swedish market allows the customers to return the used clothes back to retailers and the customer gets financial incentives in return. This will allow better circularity as well as attract the customers to make new purchases[21].

The preferred transportation method is another important aspect to consider. Using the car represents a high impact while walk/bike is the lowest impact. Figure 6 shows these three different scenarios [7].

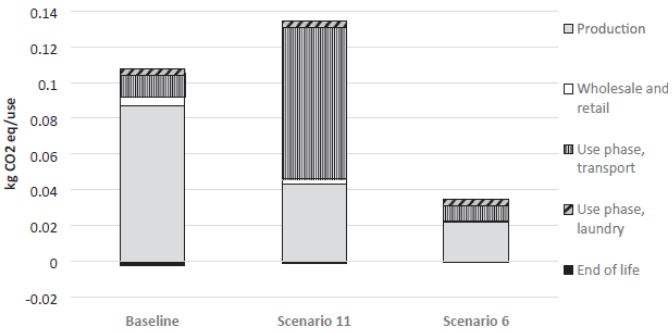

Figure 6. Global warming potential of the baseline with medium impact transport vs. the clothing library scenarios: scenario 11 (high impact transport, life×2, offline) as worst case scenario and scenario 6 (low impact transport, life×4, online) as best case scenario for one (1) use of the T-shirt. [7].

The previous scenarios also consider the service life compared to baseline (Quality of garments) and the type of setup being physical store (Offline) or online with a pickup point (Online).

To reduce the environmental impact instead of just offsetting it from the reduced production, a low impact transportation method is required. [7]. Since the preferred demographic is international people younger than 30 years old, it is recommended to establish the business near this demographic group (e.g. near international student accommodation).

5. Conclusions

The purpose of this study was to answer the following research question “How can a collaborative consumption clothing model diminish environmental impact in Sweden”

Previous studies have shown the advantage of the CC clothing service and their impact when moving towards sustainable culture. But when it comes to Sweden, there are some challenges that must be addressed to successfully implement this model. It is hard to infer the opinions of the Swedish people towards this business model from the data collected since it does not include all kinds of people.

This study can be used for:

- Devising marketing strategies to change the perspective of the people towards CC clothing service.
- Conducting further research in other areas where it involves other stakeholders apart from the end user.
- This can also be helpful in selecting regions to implement a profitable business model.

As mentioned in the discussion section, transportation method is an important factor. Therefore, the location is a key aspect. Following the recommendation of making it as

accessible as possible to the targeted demographic group, which is mainly represented by international people younger than 30 years old, can yield the best possible outcome.

Through this study, conclusions can be drawn by stating that the effective implementation of collaborative consumption model can be achieved through, change in consumer perspective towards fashion, proper government legislation for recycling and reuse and role of stakeholders.

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PART 4 – FOOD HABITS

Group 10.
Dairy versus vegan milk: influence of environmental impact on people's milk choice

Ahmed Fardan, Andrea Bongiovanni, Arvid Svanberg, Christian Kiprianoff, David Ancona, Sachin Subramanian

Group 10

fardan@student.chalmers.se
andbon@student.chalmers.se
arvidsv@student.chalmers.se
chrkip@student.chalmers.se
ancona@student.chalmers.se
msachin@student.chalmers.se

Abstract

Dairy milk industry has been under scrutiny due to its environmental impact and animal activists' movement. While vegan milk has been gaining attention due to the widely advertised lower environmental impact and consumers' health concerns. The purpose of this project is to assess whether environmental impact can influence consumers' milk choice. For this study, a survey of milk consumers in Sweden (n=300) was carried out to analyse the consumption habits and driving factors behind the milk choice. The study results were analysed using triangulation of quantitative, qualitative and literature studies. Majority of dairy milk consumers were hesitant to change their milk choice due to environmental reasons. Taste and health emerged as the most important factors behind milk choice followed by environmental reasons. It was concluded that improving the taste and consumers' awareness of the environmental impact can aid in the shift from dairy milk to environmentally-friendlier vegan milk.

Keywords: vegan milk, milk environmental impact, milk consumers' opinion

1. Introduction

The current diet and food production practices are degrading the environment. The food industry contributes to climate change by depletion of freshwater resources, deforestation, degradation of terrestrial and aquatic ecosystems [1]. The United Nations has developed 17 sustainable development goals (SDGs) to be achieved by 2030. Addressing food production and consumption can help in achieving several SDGs [2]. This has led to countries like Sweden to assess food consumption and choices which can reduce the environmental impact [3].

Dairy milk has been an indispensable part of human nutrition for a long time [4]. Dairy milk contains essential nutrients and is a crucial part of dietary recommendations globally [5]. Dairy milk is a good source of protein, fat, vitamin A, riboflavin, vitamin B12 and calcium [6]. In Sweden, the Swedish National Food Agency (Livsmedelsverket) recommends consuming 200-500 ml of dairy milk or vegan milk in the daily diet [7]. But dairy milk production is one of the largest contributors to environmental impact and accounts for 18.3% of the carbon footprint in the food industry [8]. The production of 1 litre of dairy milk has a carbon footprint of 1.29 kg CO2 eq [9] and a water footprint of 1352 litres [10]. This is much higher than that of a vegan milk option such as oat milk with a carbon footprint of 0.38 kg CO2 eq and water footprint of 5.3 litres [11]. Other vegan milk options such as soy, almond and pea also have a comparatively lower environmental impact than dairy milk [1]. This has been used as a marketing strategy by vegan milk companies [12].

An increasing share of consumers is switching from dairy to vegan milk. This shift can be seen by observing the market demand globally and in Sweden [4], [5], [13]. Despite the rapidly growing demand for vegan milk, dairy milk remains dominant in the global milk market with an estimated value of $442 billion [14]. Vegan milk's global market was estimated at $13 billion in 2018 and is expected to reach $36 billion in 2026 with an annual growth rate of over 13% [15]. The driving factors for vegan milk are health concerns, lactose intolerance and animal welfare [4], [5]. Vegan milk can offer an alternative to developing countries where the supply of dairy milk is insufficient [16]. The rise of vegetarianism and vegan diets are other propelling elements.

Few studies have been conducted to identify the motives behind consumers' milk choice. Two relevant studies were carried out in Austria [4] and USA [17], reported that cow

milk is considered as a staple food item and that taste is the main factor behind the choice. Vegan milk is purchased primarily for health reasons due to its lower fat content [17]. Consumers who consciously switch to vegan milk, do so due to the absence of lactose in it [4]. An estimated 65% to 70% of the world's adult population is estimated to have lactose intolerance and this can be a major driving force for vegan milk consumption [18]. Consumers of both dairy and vegan milk expressed health and taste as the motivation of their choice [17]. Vegan milk consumers expressed animal welfare and environmental impact as the principal reasons behind their milk choice [17], while dairy milk consumers do not consider either to be the main factor while choosing their milk [4].

1.1. Research question

Based on the above studies there are different drivers for the choice of dairy and vegan milk consumption. This project aims to understand whether the environmental impact can be a relevant factor in people's milk choice and their willingness to change it for environmental reasons. Hence, the research question addressed is: "*How is the environmental impact of dairy and vegan milk affecting people's choice of milk and its consumption?*".

1.2. Scope and Delimitations

The research project follows the set-up of PPU215 Research Methodology in Production Projects at Chalmers University of Technology and strictly adheres to the content, methodology and time frame laid out. The unfortunate circumstances due to COVID-19 pandemic is identified as a potential hindrance to the robustness of the project.

The project scope, that defines the data collection and analysis, is limited to Sweden in the last five years. The reason for the geographic and time limitation is due to the scarcity of recent research papers on this topic. This is also a justification for the need of this research.

The interested stakeholders identified were dairy and vegan milk companies. The study contains information on people's sustainability perception of milk and consumption habits which can be utilized for improving the marketing and sustainability approach of the milk companies.

2. Methods

2.1. Literature study

The literature study was initially performed to gather some background knowledge on the environmental impact of different types of milk. This was followed by gathering papers dealing with driving factors for milk consumption. The research was focused on obtaining appropriate peer-reviewed literature aligned with the research question. Databases such as Scopus, Google scholar, Statista and SCB were primarily used and accessed through the Chalmers library webpage. The keywords were selected through extensive discussions based on the scope and the research question. The main keywords identified were: (1) milk environmental impact, (2) milk consumer survey, (3) dairy versus vegan milk, (4) dairy milk consumption in Sweden, (5) vegan milk consumption in Sweden, (6) global milk market. The obtained literature was first screened through by reading the Abstract and Conclusion sections to check the paper's relevance for the research. Keyword 1 was used to evaluate the environmental impact of different milks. Keywords 2 and 3 were used to obtain scientific articles dealing with milk consumers' behaviour and motives behind milk choice. Keywords 4 to 6 were used to observe the trend of milk consumption globally and in Sweden.

2.2. Quantitative data collection

A survey for the acquisition of quantitative data was created to study the milk choice and its consumption of people currently living in Sweden or who have lived in Sweden in the last five years. It also aims to gauge people's perception of the environmental impact of their choice of milk and their willingness to change it for environmental reasons. A pilot survey was first drafted via 'Google Forms' and was sent out to a small group (n=30) to obtain feedback on the quality and relevance of the questions. Based on this feedback, the questions were reviewed and improved before finalizing the survey. The final survey (n=300), also in 'Google Forms' format, was then shared on social media platforms such as WhatsApp, LinkedIn and Facebook. It was designed in such a way that it could be completed in less than five minutes and thereby get more people to respond to the survey. The core questions asked in this consumer survey were:

- Which of the following types of milk do you c onsume - dairy, vegan or both?
- Which type of milk do you think is more environmentally friendly - dairy, vegan or both have the same impact?
- Would you change your choice of milk for environmental reasons?

The questions were formulated after internal group discussions based on both literature and the desired outcome of the study. Based on a research conducted, some key effects such as health, allergies, taste etc were considered in the survey [4]. The survey also included questions seeking the respondent's personal information such as age, profession, preferred choice of milk (dairy, vegan or both), etc. The purpose was to catch, if any, relations between these factors and their perceptions on the environmental impact of either dairy or vegan milk.

The responses (n=300) to the survey were exported from the Google Form and tabulated in MS Excel before importing them into JMP Pro 15. Relevant attributes were then plotted against each other using the 'Graph Builder' tool and these distributions were analysed in order to find key relations.

For secondary data, Chalmers was contacted seeking information on the consumption of milk at its campuses in Johanneberg and Lindholmen over the last five years. This data was acquired via email with the help of the Student Information Center and the Executive Head Chef at Chalmers Conference and Restaurants

2.3. Qualitative data collection

An open-ended question was asked in the survey about people's opinion on the environmental impact of dairy and vegan milk production. The purpose of this question was to compare this perception with different factors, like the type of milk they consume, and identify any relations. Responses to this question were categorized into one of five groups, depending on if they supported dairy milk consumption, vegan milk consumption, if their opinion was neutral or if they lacked information about the topic. Distributions of these groups were then plotted with relevant factors, using the 'Graph Builder' tool in JMP Pro 15 and key relations were analysed.

In order to obtain the milk manufacturers' perspective on the consequences of people's choice of milk, some dairy and vegan milk companies were approached. A structured interview format was drafted via email through a questionnaire. The companies were chosen based on their significant presence in the Swedish milk market over the last five years. These were Arla, Oatly and Alpro; who produce dairy, oat and almond milk respectively.

To aid in answering the research question, the companies were asked for their view of the Swedish milk market, consumption trends and their forecast about the evolution of this trend in the coming years. Further, some previously conducted research provided insight in framing the topics of interest into questions [4], [12]. The following questions were a core part of the interview questionnaire to gauge the company's view on these matters:

- What is your view of the Swedish milk market and how does it differ from the rest of Europe?
- Where is the market going and what do you attribute the change to? People drinking less milk overall or choosing other alternatives?

Oatly was the only company that responded to the questionnaire. This interview data was analysed and summarized based on the main points found in the answers. Both Arla and Alpro could not comply with the interview format and rejected the request.

3. Results

3.1. Quantitative results

From the survey (n=300), the data collected is plotted in Fig. 1. It shows that dairy is the most preferred choice of milk among individuals from all of the studied age groups. All age groups do consume vegan milk, but to a varying degree. The number of individuals who exclusively drink vegan milk appears to vary largely between the studied age groups.

Vegan milk had the highest popularity among people aged 20-29 and followed by people in age group 50-59 years. People who exclusively drink vegan milk are mostly aged between 20 and 39 years, accounting for approximately 70% of the total vegan milk drinkers. The proportion of dairy milk consumers is most prominent in the age group of 40-49 years, with almost three fourths drinking only dairy milk and nobody drinking only vegan milk.

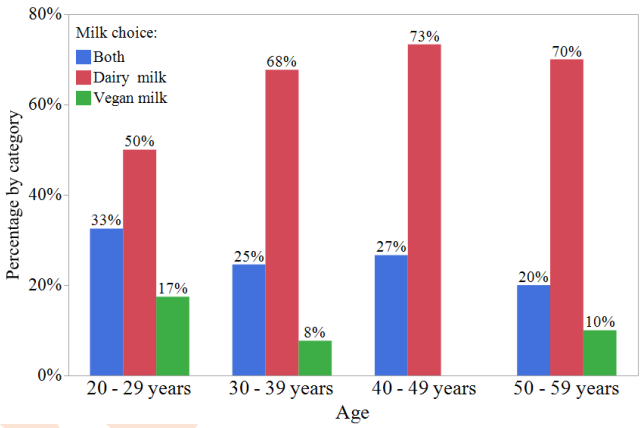

Figure 1. Milk choice distribution vs. Age

Dairy milk consumers are less inclined to consider other alternatives and were not willing to change milk choice for environmental reasons. Only 16% stated a willingness to change compared to 33% that answered 'No', as shown in Fig. 2. This is in stark contrast to consumers of vegan milk where the large majority are willing to change consumption habits based on environmental reasons. Half the dairy milk consumers and people who consume both dairy and vegan milk stated that they would maybe change their consumption habits.

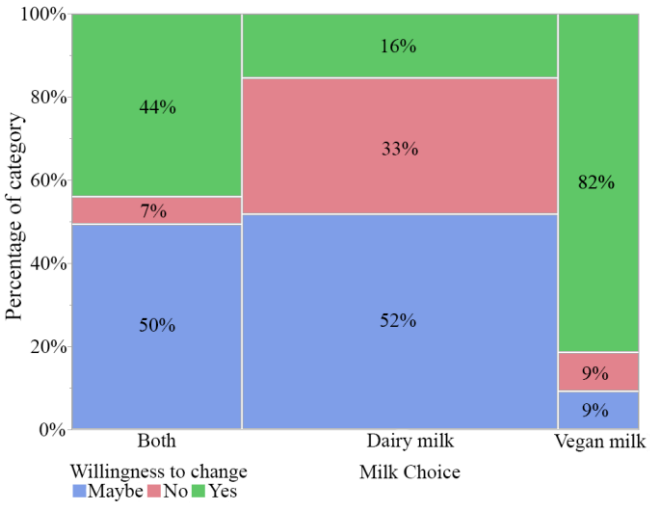

Figure 2. People's willingness to change milk choice for environmental reasons vs. Milk choice

Figure 3 shows the reasons behind people's choice of milk across all age categories. Taste emerged as the main reason, most prominently in 50-59 year olds. The second most important factor was the health benefits associated with consuming the respective type of milk. This was followed by environmental factors and allergies. It can be inferred here that although people base their choice of milk on environmental factors, it is not the primary or only factor that plays a role.

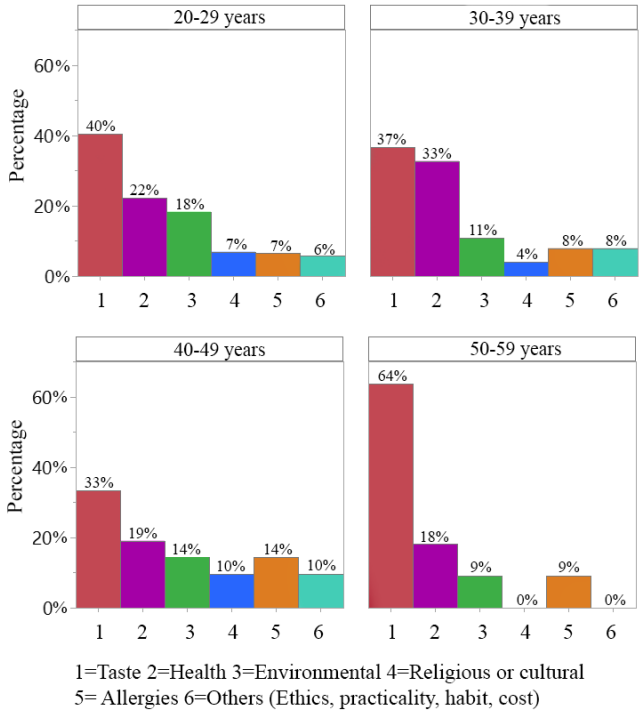

Figure 3. Reasons behind choice of milk vs. Age

The data obtained from Chalmers is presented in Fig. 4. Dairy milk purchase volume has been reasonably constant in the last five years, while vegan milk purchase volume has increased year on year. From communications with the Executive Head Chef of Chalmers, information was given that the purchased volume can be assumed to also be the consumed volume. The magnitude of difference between dairy and vegan milk consumption volume implies that dairy is still a popular choice among consumers at Chalmers, but recent years have seen a rise in the popularity of vegan milk.

Some quantitative data was provided by Oatly in addition to their answers to the interview questions. Following the overall trend of the vegan milk rise [15], Oatly has made increasing sales in recent years showing an increase in total production by 224% from 2016. Their oat base production has increased from 38 to 85 million litres between 2016 and 2018. The company has its largest presence in Sweden with 39% of their products being sold domestically [11].

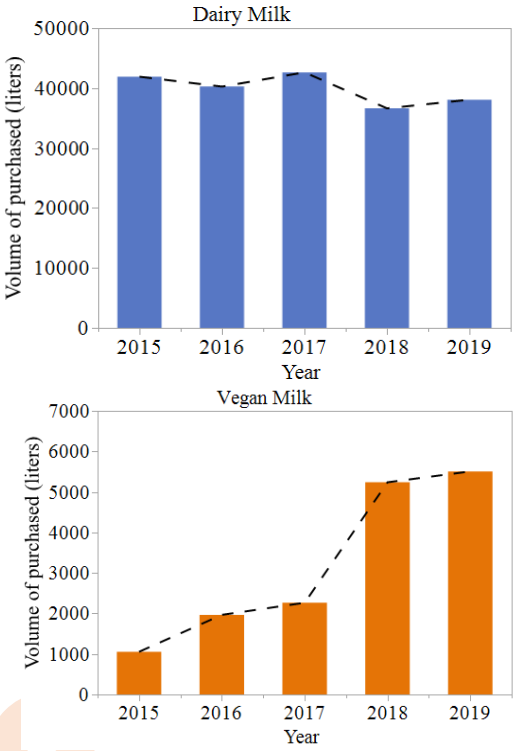

Figure 4. Milk purchased (in litres) at Chalmers. Courtesy of Chalmers Conference Centre

3.2. Qualitative results

Oatly's interview answers were studied and a few interesting patterns were observed. They claim a strong dairy norm is present in Sweden due to deeply rooted political and societal values. They believe government actions such as subsidies for dairy farmers and dairy milk in school are preventing the shift from dairy. Oatly considers these actions to be part of the norm, leading people to prefer and consume dairy milk.

The company sees an increasing trend of vegan milk consumption, but states that significant changes are needed in laws and society before equal market shares can be held for dairy and vegan milk. This shift from dairy to vegan milk is argued to be necessary from an environmental point of view, as they claim their oat milk is more environmentally friendly than dairy milk. Further, the company states that their product is also healthier, which is another reason they advocate the shift. Research is a word frequently used when claims like these are made, and references to both LCA's and other analyses were provided. Oatly has had previous collaborations with research-based entities such as RISE and CarbonCloud [11]. They market themselves as having an overall strong strive for sustainability in their entire production chain to reduce the climate impact of their products.

Oatly's perspective of the market is complemented with the milk consumers' opinions regarding the environmental impact of milk production obtained from the survey. Results in Fig. 5 show that the majority of vegan milk consumers and almost half of people that drink both dairy and vegan, agree with

Oatly's point of view, supporting the consumption of vegan milk. On the other hand, only a few dairy milk consumers support the same. Dairy milk consumers' opinions were distributed between a lack of information to formulate an opinion, people with neutral standpoint and people supporting dairy milk consumption.

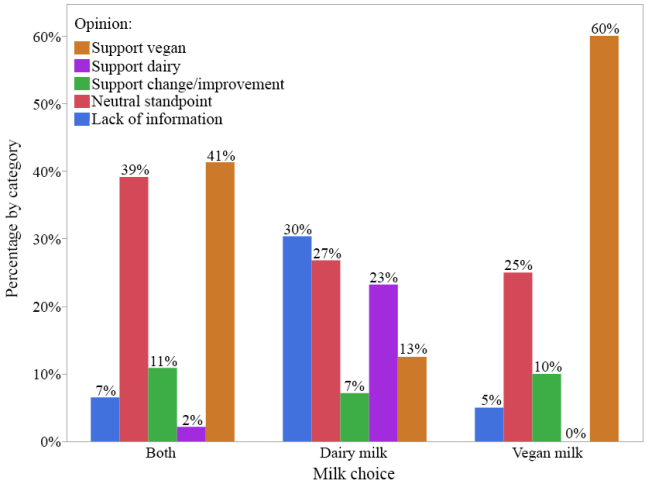

Figure 5. Opinion regarding the environmental impact of dairy and vegan milk production vs. Milk choice

4. Discussion

4.1 Analysis of results

From the different results, several discussion points were made by triangulation method: qualitative and quantitative results were analysed and compared with literature findings.

A notable pattern that has appeared in different observations is the growth trend that vegan milk alternatives have experienced the last few years. The vegan milk consumption data from Chalmers has shown an exponential increase in the last five years, while a similar pattern can be seen at the projected market value of vegan options worldwide in the next five years [15]. According to data from SCB, the dairy milk consumption trend in Sweden has decreased 3% on average yearly since 2016 [13], while on the other hand, Oatly's sales of oat milk have increased 50% yearly since 2016 [11]. Based on these comparisons, it is clear that vegan milk consumption has been on the rise in Sweden and will continue to do so in the foreseeable future.

An interesting observation made from the survey is that 14% of individuals in the age group of 40-49 years state that they care about the environment, but nobody in this group was seen to exclusively consume vegan milk. The reason for this inconsistency is uncertain and would need further research to determine the cause. From published literature, the main reason for consuming exclusively vegan milk is if the consumer is a strict follower of veganism and is against the consumption of animal products [4], [17]. Other possible reasons include allergy concerns, health benefits and health claims of the vegan milk [4].

From the results obtained from the survey's section regarding the willingness to change milk choice to reduce the environmental impact, it was observed that a third of dairy milk consumers would not change for this reason. The reason for this distribution can be explained with another question from the survey, regarding the reasons for milk choice. Environmental reasons came as a third option when choosing which milk to drink, behind 'Taste' and 'Health' aspects, which is similar to the consumer behaviour from the published literature [4], [17]. The milk consumers were not willing to change their milk choice, even if that may reduce the environmental impact. Another major driver for milk choice from literature is allergies, where 40% of the consumers' milk choice was due to allergies such as lactose intolerance [4]. While in this study, about 8% of the consumers in the survey reported that allergies are a driving factor behind their milk choice. This is a discrepancy and might be due to the higher percentage of survey takers belonging to the 20-29 age group.

Another point to consider is the strong dairy consumption habit present in Sweden, which according to the survey is not one of the main factors, but according to Oatly it still plays an important role. This strong norm is still a factor for people not wanting to change, and also can be for the ones that are not so sure and answered 'Maybe'. The possible reason for the consumers of age group 40-49 not consuming only vegan milk could be due to the habit of consuming dairy milk. A similar trend was observed in literature where vegan milk consumers mostly used dairy milk in their coffee due to its texture and taste. This can probably be an important factor to be addressed by vegan milk producers as Sweden has one of the largest coffee consumption per capita [20].

The survey also pointed out some interesting aspects regarding the people's opinion of milk production, for both dairy and vegan. As mentioned in results, there was a number of people lacking information in the three milk choice groups (dairy, vegan, or both), with the majority concentrated in being dairy milk consumers. This can mean that even if people are willing to change in favor of the environment, it was claimed by them there is a prominent lack of information on their side that affects their milk choice. However, awareness of the environmental effects was also not a major driver for milk choice as concluded by researchers in Uppsala, Sweden [21]. The field study included two choices of dairy milk, a regular milk and a climate-certified milk with lower environmental impact. There was a shift in consumers choosing climate-certified milk after becoming conscious of the environmental effects. However, this shift in choice was short-lived as consumers were not willing to pay a higher price for the climate-certified milk. This is a contradicting behaviour and a dilemma scenario experienced by the consumers.

A similar dilemma scenario was observed in the consumer survey conducted. The majority of respondents, at 56%, think that vegan milk is the most environmentally friendly option

yet a combined 67% of them say they will not or maybe change their milk choice for environmental reasons, with only 33% responding with a definitive yes. This could be largely related to a popular theory called 'NIMBY' which is an acronym for 'Not In My Backyard' [22]. It is a theory applicable when people want to advocate something positive but would not want to make any sacrifices for it to happen. In this case, people are aware of the fact that consuming vegan milk is better for the environment but are unwilling or hesitant to change their choice of milk because of it.

4.2 Limitations and possible improvements

In order to get a better representation of the overall age demographic of Sweden, it is essential that the respondents to the consumer survey are not majorly in the age category of 20-29 and just students. In this case, they accounted for 70% and 54% of the total respondents respectively, making the study slightly skewed in this regard, given that the geographical scope is Sweden. The quantitative data collected from Chalmers is also assumed to represent consumers mainly in the age group of 20-29 years.

Given the timeframe, no particular amount of survey respondents were aimed for. In literature, the number of respondents vary, up to n = 1001 for similar reports [4]. As a larger selection of the population will gauge the entire population more accurately, a larger selection should be considered which will also compensate for the age group bias discussed above. Considering that the geographical scope is Sweden, a bias in the age group could lead to misrepresentation. Further, given the scope and framing of the survey, the generalizability of the study results only extends to Sweden. This limits the implications of the study geographically but may see possible use to spark initiative to conduct similar studies with other geographical scopes. As done in this report, some of the findings are usable in other scope formulations to examine if different geographical scopes show similar factors behind their respective choice of milk. This report aligns with a set of previously conducted studies in other countries with similar aims to identify if environmental impact affects choice of milk and to further identify factors affecting said choice [4], [17]. This report contributes to bridge an apparent gap in literature and studies in this field within the geographical scope of Sweden.

Regarding credibility of survey data, General Data Protection Regulation (GDPR) impedes the registration of respondents' names and information. Since no information is logged, one might expect insincerity in the answers because there is no accountability on the participants. Other studies have used research institutes or university online platforms to help carry out their surveys and to reach out to respondents [4], [17]. These types of institutes might also provide a selection of the population that is representative for Sweden in its entirety. As this was not an option in the present case, it was decided to appeal to the sincerity of the network reached with the three social media platforms on which the survey was published, LinkedIn, WhatsApp and Facebook.

A few questions in the survey regarding people's opinion of the environmental factor related to consuming milk could be improved by better phrasing in order to avoid ambiguity in the respondent's mind. Additionally, the questions to which people could choose more than one option could have been made multiple-choice (choose only one) instead, with more efficient options, in order to save time analysing them. Further, as more feedback was received even after the final survey, perhaps another trial run should have been considered so these shortcomings could have been addressed. None of the reviewed articles similar to this project indicated any trial runs conducted for their respective surveys [4], [17]. A further possible improvement could be to review literature on survey methodology on a broader scale prior to formulating these questions.

Due to the COVID-19 related restrictions, another limitation faced was being unable to meet physically as a group for any meetings or conduct any face-to-face interviews with experts or stakeholders. For instance, two identified experts: Arla, as dairy milk producer, and Alpro, as almond milk producer, could not comply with the email remote interview format and declined participation due to layoffs.

A lot of useful information and qualitative data was extracted from the email interview with Oatly for this study. However, given the company's strong marketing profile, excerpts from the interview were carefully analysed with fair consideration given to possible bias towards promoting their products or implicated financial gains. As discussed in the interview analysis, many of Oatly's claims are strengthened by references and studies conducted by research institutes or companies [11].

Prior lack of knowledge in the field might have affected the framing of the project, underestimating the vastness of this field leading to an initially broader scope than the timeframe allowed. A more focused framing could have led to a more efficient progress of the project.

4.3 Recommendations for stakeholders

From the survey conducted, taste is the most prominent factor for people when choosing milk type. A suggestion to stakeholders would be to focus on the taste of their product in addition to the other identified key factors, health and environmental impact. To work towards the universal aim for lower climate impact, the lower impact alternatives should then improve their taste in order to be more appealing to the customer base. Although this cannot occur at the expense of losing health benefits as this is a multivariate problem with interacting effects. This report can contribute through this identification to a broader perspective on what companies

should focus on in their products to appeal more to its customers.

Further, a uniform way of measuring the climate impact of different types of milk could be a way to allow customers easier navigation regarding which type to choose. Taste is subjective, nutrients tables are already displayed by law, allergies and possible religious effects are also regulated and can be monitored from the containment/nutrient tables. However the environmental impact is not presented on most containers of milk. Oatly has presented their carbon footprint on their containers, but this is nothing that is legislated or uniformly tested by an unbiased agency. A suggestion would then be to find a uniform measure of climate impact across all types of milks which can be quantified for customers to understand, perhaps as a label on respective milk containers. An example could be to infer carbon footprint per nutrition content in the milk to acquire the means for fair comparison. The labelling could help people to understand the impact of their choice, thereby increasing the overall awareness. This concept of labelling to visualise environmental impact has been tried before with some variation to the above suggestion, but never gained foothold [21].

5. Conclusion

Vegan milk has been gaining increased attention due to different factors such as health concerns, veganism and perceived lower environmental impact. At the same time dairy milk has been under scrutiny due to ill treatment of animals and higher environmental impact. This has led to rise in varied milk choices and consumption patterns. This project studied if the environmental impact can influence people's milk choice and their willingness to change for environmental reasons.

From the triangulation of qualitative, quantitative and literature studies, it is seen that environmental impact doesn't primarily dictate the milk choice. The main driving factors were taste and health of the milk. Majority of the dairy milk consumers were hesitant to switch to vegan milk. It was also seen that there is a lack of information among consumers regarding the environmental impact of milk choices.

The transition from dairy to vegan milk can be facilitated by improving the taste and nutritional content of the vegan milk. The usage of carbon footprint labelling and sources of raw materials on packaging can improve consumer awareness. Stricter regulations from environmental agencies and governments can further aid in shift to more environmental-friendly vegan milk.

The future research directions would be to collect data from different sources, in order to suppress any possibility of skewed results. One ideal source would be supermarkets from where the data could be collected in the form of purchased milk. Another area of interest would be to explore the reasons behind the willingness to change the milk choice. This could provide a deeper insight regarding the factors to improve to aid the shift to more environmentally friendly options.

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Group 11.
Study of the Environmental Impacts of Organic and Non-Organic Beef Production

Dhanush Krishnan, Sanne Larsson, Vedanth Limbayyaswamimath, Britta Ottesjö, Sophia Wetterberg, Linnea Widroth

Group **11**

gopalad@student.chalmers.se
lsanne@student.chalmers.se
vedanth@student.chalmers.se
brittao@student.chalmers.se
sophiaw@student.chalmers.se
linwid@student.chalmers.se

Abstract

The study aimed to identify the environmental impacts and improvement potentials of organic and non-organic beef production within the scope of cradle to gate, by determining the causative factors of the impacts. The study was done through a triangulation of literature, qualitative, and quantitative studies. The study identified 13 different environmental impacts that were categorized under global warming, land, water, and other. The study identified large information gaps when investigating the environmental impacts, due to knowledge gaps and inconsistent measurement methods used among researchers. Organic beef production system's negative environmental impacts are significantly lower than the non-organic. The non-organic system contributes to soil erosion, acidification, eutrophication, and reduced water quality to a higher extent. Still, they are often regarded as the same system. The paper concludes that it is important to differentiate systems and consider all the identified environmental impacts when calculating the environmental impact of beef production.

Keywords: Environmental Impact · Organic Beef Production · Non-Organic Beef Production.

1. Introduction

Beef consumption is a widely discussed topic in recent years [1]. From a Life Cycle Assessment (LCA) perspective, livestock production accounts for 14,5 % of the human-induced greenhouse gas (GHG) emissions per year, of which beef production is responsible for 41 % [2].

Studies on the environmental impacts of beef production are generally carried out using an LCA analysis [3] and the negative impacts are generally measured in GHG emissions [4]. The primary GHG emissions studied in beef production are methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) [2]. Therefore, the environmental impacts, especially GHG emissions from beef production and how they should be reduced, is a debated topic in today's society due to the rapid change in global warming [1].

The general idea in society is that all the environmental impacts of beef production are negative. The most commonly discussed solution to reduce the negative environmental impacts is by limiting the amount of meat people eat [5]. Some people advocate stopping eating meat at all in order to reduce emissions [5].

Some researchers and experts are questioning how the impacts are measured, as the focus often lies in the negative impacts. Some studies present gaps in the usage of LCA analyzes which solely evaluates the GHG emissions when studying the environmental impacts of the production [6]. The environmental perspective is limited when only GHG emissions are measured [6]. Parameters like the use of pesticides, soil health, and biodiversity are needed to diversify the perspective [6]. Studies on other environmental impacts of beef production systems present varying results on different impacts but are still not able to take the full environmental cycle into consideration [7-9]. There are clear gaps in the current research methods of measuring the impacts according to experts in the field.

The research today does not include a diverse picture of all the environmental impacts and how they are connected to different production systems. Most studies generalize all types of beef production systems under one category. This even if there is a large variety in regulations and ways in which the beef is produced within each system. The impacts on the environment usually look different for different production systems going from small scale to highly intense beef production, regardless of industry [3].

During the initial literature study on the subject of environmental impacts of beef production, only a few articles were found presenting results that did not generalize beef production systems as one. This generalization is contributing to the gap of research methods to find the root causes of

environmental impact to create a more sustainable beef production. The results, from the studies measuring the impacts of each production type, vary between different studies [3], [10]. There is no clear picture of how organic and non-organic production systems are impacting the environment.

It was proposed to divide the general beef production system into organic and non-organic to further diversify the study into the environmental impacts of beef production. This is the most natural division because when looking at beef production systems, regulations, and certifications naturally make the same distinction. The difference in the rules and regulations between organic and non-organic production creates the biggest difference in production execution. The organic production system can be defined as either an EU certificated organic system, or through other countries' certification guidelines. Non-organic production can then be defined as all other production types that are not certified organic. The definition of the different production systems in this paper will align to the EU standards [11].

The initial study and the identified gaps shed light on several interesting points of view regarding beef production systems. Whether there is a difference in the environmental impacts between different beef production systems like organic and non-organic will be further investigated. What the impact for each system is, and if one system accounts for higher impacts than the other will be examined. What can be done within each system to reduce the negative impacts and are different systems beneficial in different aspects?

The problem with measuring the environmental impacts of beef production systems is that a differentiation between different types of systems is often not made. The system is more complex and involves other factors apart from GHG emissions. To investigate this difference, all the environmental impacts of the different production systems need to be determined, not only the GHG emissions. The research questions (RQ) is defined as:

RQ(1) What are the current environmental impacts of organic and non-organic beef production systems?

RQ(2) What environmental improvement potentials can be identified within those systems.

2. Methodology

The methodology used was a triangulation of three techniques; a literature study, a qualitative study, and a quantitative study. The literature study was done initially, further complemented by a qualitative study diving deeper into the research question. The qualitative study included further literature searches and expert interviews. Later supplemented with a quantitative analysis of the gathered data.

The databases used throughout all the studies were; Chalmers University of Technology online database collection and Google Scholar. The following databases were redirected from the previously mentioned; Science Direct, Springer, Oxford Academic, Statista, Taylor and Francis, and Wiley online library.

For the credibility of the sources, peer-reviewed, well-cited, and sources by well-known organizations in the research field were used. The following keywords were primarily used in all three studies; beef production, LCA, and environmental impact.

2.1 Literature study

The literature study aimed to determine previous research done in the field of beef production and its environmental impacts and improvement potentials within each system. The study further aimed to identify limitations and gaps in the research field. This was done through meticulously reviewing articles on the environmental impacts of beef production systems. Additional keywords were used to broaden the scope; biodiversity, habitat conservation, holistic management, future, current situation, suckler, GHG emissions, graze fed, and land use.

The selected articles older than 2015, which contained authentic statistics that could not be found in more recent articles were further scrutinized to ensure they held relevant information. Numerical statistics were corroborated by recognized authorities such as the Food and Agriculture Organization of the United Nations. Furthermore, the literature under investigation was studied for its relevance on the cradle to gate perspective and sustainable beef production practices. The articles were chosen based on how well their content was linked to the research question, describing impacts, gaps, and improvement potentials.

2.2 Qualitative Study

For the qualitative study, additional literature study was made focusing on the different environmental impacts of organic and non-organic beef production to reach data saturation [12]. That means that even though new articles were found, no additional environmental impacts were identified. To narrow down the scope for the qualitative study the following keywords were used respectively; organic and non-organic beef production, GHG emissions. The qualitative study was carried out with semi-structured interviews made with experts based in Sweden. Interviewee one was a professor with 35 years of experience in the field of conventional and organic farming. Interviewee two was an industrial expert with 20 years of expertise in organic beef production, currently working with developing sustainable beef production. The semi-structured interviews provided a deeper understanding of the research area, to identify impact categories and improvement potentials. The questions, as well as general information about the interviews, were sent to the interviewees before the interviews.

The interviews were transcribed, and keywords were extracted. A thematic analysis was done where similar keywords were grouped and compared to the literature findings to validate and complement the previously collected information regarding different environmental impacts of beef production [13]. After identifying the different environmental impacts from both the literature study and the interviews, the common effects of the different impacts on the environment were identified and grouped under main categories.

2.3 Quantitative Study

The list of identified environmental impacts, discovered from the literature and qualitative studies, was used as the base for the quantitative study. The quantitative study's aim was to compare and find out to what extent, each environmental factor of the organic and non-organic beef production impacted the environment. The articles from earlier studies were reviewed to determine which articles contained numerical data on one or more of the environmental impacts of both the beef production systems. There were only five articles that fulfilled the requirements and selected as data.
An Excel sheet was created where the numerical data, with respective units, was noted for each relevant article under the columns of organic or non-organic beef production. To provide an informative visual comparison of the result, the graphical functions in Excel was used. The graphs were analyzed to find trends of the environmental impact parameters concerning organic and non-organic beef production and to compare them. Qualitative data collected from interviews with experts in the field of beef production were used to analyze the impact parameters of which numerical data could not be found.

3. Results

In this section the results are presented in two subsections. The first part presents the identified impact areas. The second part presents the results describing each impact area connected to the improvement potentials by presenting problematic areas for the two different beef production systems. The causative factors of the impacts for each system are additionally presented in the result section.

3.1 Environmental impact areas

From the literature analysis and the qualitative study, several environmental impacts of beef production systems were identified [2], [3], [14],[1,2]. The defined environmental impacts were divided into the following main categories; global warming, land, water, and other. Table 1 presents the different impacts under each main category. A description for each impact and how the impact is related to beef production, is further included in Table 1.

Table 1. The identified environmental impacts and relation description to beef production.

Impacts	Description
Global warming	
Energy consumption	Energy used for beef production [2].
Enteric fermentation	Emissions from cows burping and manure, measured in CH_4 [2].
GHG emission	CH_4, N_2O, and CO_2 [2][1].
Soil carbon sequestration	Animals contributing to carbon storage [9][2.]
Land	
Acidification	Rest products from beef production and agrochemicals [3][1,2].
Agrochemicals	Chemical fertilizers and pesticides[1,2].
Biodiversity	Diversity in the soil and landscape [9][1,2].
Eutrophication	Rest products from beef production and agrochemicals [3][1,2].
Feed production	Type of feed production and area of land used for feed production/grazing [3][1,2].
Manure Management	How manure is used and stored[2].
Water	
Water cycle	Impact on the water cycle[1,2].
Water use	Amount of rainfall and groundwater usage [3][2].
Other	
Human environmental impact	Animal welfare, growth hormones and antibiotics used in production[1,2].

3.2 Impact differences between systems and problematic areas

The environmental impacts presented in the previous section, 3.1, affects each beef production system differently. Numerous problematic areas regarding environmental impacts for each beef production system were identified in the literature and in the qualitative study. The results from the literature, qualitative, and quantitative studies are compiled under the identified environmental impacts in the coming subsections.

Global warming. The subcategories of environmental impacts identified under the main category global warming are; GHG emissions, enteric fermentation, soil carbon sequestration, and energy consumption. One article indicated that the GHG emissions, measured as global warming potential (GWP), were lower for the non-organic production system. The reason for this being that animals in the non-organic production have shorter life cycles and higher weight gain [3]. Articles containing data specifically on the GHG emissions, that are not re-calculated to GWP, are presented in Figure 1. GHG emissions are generally calculated in kg CO2-

[1] Information retrieved from interviewee one, professor
[2] Information retrieved from interviewee two, industrial expert

eq per kg of live weight [15]. Results from four different articles are presented as a cumulative effect of the individual gasses CO_2, N_2O, and CH_4, emitted during the various farming operations [10], [16-18]. The numeric results do not present any clear indication that one of the two production systems have a lower impact regarding GHG emission, see Figure 1.

The majority of the GHG emissions of beef production are represented by enteric fermentation [14]. There are no clear trends that can be seen in the analysis of the data from different studies about the amount of enteric fermentation animals from each system creates. This is because different sources provide contradicting results for organic and non-organic production [17], [18].

There is evidence that well-managed grazing and feedlot finishing systems could contribute to soil carbon sequestration, thus countering the effects of GHG emissions from beef production [9], [19]. Carbon can be stored in the soil through grazing animals, grazing is used more extensively in organic production[2].

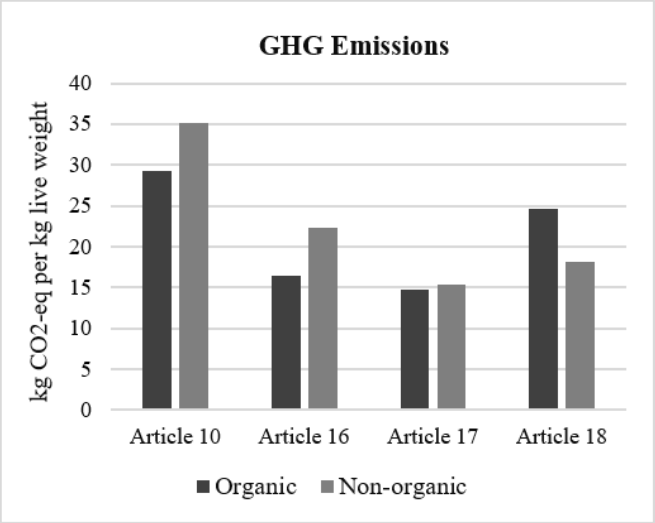

Figure 1. Data from different articles on the measured GHG emissions generated from organic and non-organic beef production.

An analysis of the energy consumption studied in different articles, shows that non-organic production generally utilizes more energy than organic production, see Table 2 [10], [17]. A reason for this is that a more intense production is often found in non-organic production systems, where the animals are kept indoors or in managed pastures. Non-organic production requires more energy in the form of producing and delivering feed and managing the animals. The animals are kept outdoors and grazing during large parts of the year in organic production, which means that less feed needs to be harvested. This leads to the reduction of total energy consumption throughout the life cycle[1,2].

Land. The subcategories of environmental impacts identified under the main category land are; feed production/grazing, agrochemicals, manure management, biodiversity, eutrophication, and acidification.

The land on which the animals graze, and where their food is produced, should be located on marginal land according to researchers[1]. On the marginal land, vegetables, and crops that humans can eat directly cannot be grown with an economical benefit [8][1]. The animals in non-organic beef production are nourished with food that the humans can digest, in comparison with the organic production where they are nourished with feed that humans cannot eat, e.g. grass. By growing grass on both pastures and cropland, the soil health and the carbon in the soil can be restored[2]. A research professor believes that the type of feed used in beef production is one of the highest environmental impact parameters of beef production[1]. When using non-marginal land to grow feed, the animals are using land that could be used to grow human food. Feed grown using the non-organic methods contributes to eutrophication and acidification by the extended use of agrochemicals[1]. Agrochemicals in beef production comprise pesticides, and chemical fertilizers[1].

In organic production, the use of agrochemicals is limited or forbidden for the farm to be organically certified [11]. Organic beef production uses manure as a fertilizer to bring back nutrients to the soil in crop production. Growing feed and crops without using manure require the use of chemical fertilizers. In most non-organic beef production systems, the chemical fertilizers are used instead because it is easier to use and apply to the soil[2]. When the manure is not used as a fertilizer for crop or feed production, it is stored in silos and pollutes the environment greatly, see Table 2[2]. Chemical fertilizers, unlike manure, degrade the soil because the chemical fertilizers do not contribute with organic matter which builds up the carbon content, see Table 2[2]. By handling the cultivation of the grass in the right way, including clover, and manure, the need for agrochemicals is eliminated. Clover and grass can absorb nitrogen from the atmosphere[1].

Chemical fertilizers and other agrochemicals can be connected to both biodiversity, eutrophication, and acidification. The use of agrochemicals reduces biodiversity[1,2]. The biodiversity is decreasing in non-organic production where the feed is produced by using agrochemicals, as well as in production systems where the animals are not grazing[1,2]. According to experts, grazing animals contributes to building biodiversity in the soil and landscape[2]. In organic production, the animals are either grazing or nourished with feed that has been organically produced. Resulting in more biodiversity in organic production than non-organic[1,2].

[1] Information retrieved from interviewee one, professor
[2] Information retrieved from interviewee two, industrial expert

Regarding the eutrophication, the quantitative data do not present any clear indication that either one of the two production systems has a lower environmental impact, the results are contradictory [10], [16]. Feed production is part of the production that is contributing to eutrophication. Producing feed with chemical fertilizer that will end up in lakes and thereby the water cycle (groundwater), leads to eutrophication. The systems not using chemical fertilizers instead use natural fertilizers like manure that have less impact on the eutrophication[1,2].

Regarding acidification, the data do not present any clear indication that neither of the two production systems has a lower environmental impact, the results are contradictory [10], [16]. Beef production's environmental acidification impact is caused by excess use of fertilizer and by high-density beef production systems. Here the animals cause soil erosion and degradation by trampling the soil to a high extent[1]. The erosion further reduces the biodiversity in the soil[1]. Acidification and eutrophication from beef production can be caused by improperly stored manure but can be reduced through leaching of manure management [14]. Dung beetles [20] and dairy-based calves [17] can further have a role in having a better environmental impact from beef production.

Water. The subcategories of environmental impacts identified under the main category water are; water use and water cycle. Irrigating pasture in farmlands requires large quantities of water in order to grow feed in dry areas and hydrate the animals [3]. Beef production systems can impact the water use and water cycle by using rainfall efficiently as drinking water for the animals, irrigation of pastures and feed production, and thereby decrease the use of groundwater [8][2].

The use of agrochemicals in beef production further impacts the quality of the water, as the non-organic production uses agrochemicals which pollute the water by runoffs. Runoffs cause excess nitrogen, pesticides, and herbicides to get into the water cycle causing eutrophication and acidification[2]. Traces of these pesticides can be found in drinking water as they infiltrate in the water cycle[2]. By using permanent pasture, it is possible to keep the water in the ground and thereby prevent runoffs[2].

The non-organic beef production generally has a negative impact on the water and mineral cycle, because of the intense cycling of nutrients in the landscape, thus reducing biodiversity. Grazing methods can improve the water cycle as grazing animals keep the water in the landscape[2].

Other. Agrochemicals can further be related to animal welfare according to experts[1,2]. Extended use of fertilizers and pesticides in feed production decreases the feed quality[1].

Experts mentioned that the large use of antibiotics and growth hormones in beef production can lead to antibiotic resistance [21][1]. Growth hormones and excess antibiotics are primarily used in non-organic production, especially focused on the high intense production feedlots[1]. Giving animals low-quality feed or deviating from animals' normal diets, feeding them with grains, maize, and soy, makes the animals more likely to get sick and thus require medicine, e.g. antibiotics[1,2].

In organic production, growth hormones are forbidden to use in order to increase the growth rate [11]. Antibiotics in organic production are only allowed if necessary for an individual animal by medical causes and must then be strictly supervised by a veterinarian [11]. Healthy animals are not necessarily directly connected to the environmental impacts, but healthier animals give higher production yields[2].

A comparison between data, indicating the level of negative impact, extracted from studies that contained sufficient information on each environmental impact of organic and non-organic beef production, is presented in Table 2. Therefore, the data comparison for GHG emissions, enteric fermentation, acidification, eutrophication, and feed production are not included in Table 2.

Table 2. Comparison between data on the level of negative environmental impact of organic and non-organic beef production

Area	Organic	Non-Organic	Source
Energy consumption	Lower	Higher	[10], [17]
Agrochemicals	Lower	Higher	[1,2]
Biodiversity	Lower	Higher	[1,2]
Manure Management	Lower	Higher	[14][2]
Water cycle	Lower	Higher	[1,2]
Water use	Lower	Higher	[3][2]
Human environmental impact	Lower	Higher	[1,2]

4. Discussion

The results shed light on different problematic areas in beef production. Several of these areas are quite baffling to explain. After identifying various flaws in the different beef production systems, these can be converted into improvement areas. In the coming section, the results are discussed followed by the methodologies that were used and their limitations.

4.1 Findings

An important confirmation was to differentiate the organic and non-organic production systems when measuring the environmental impact of beef production. Beef production systems can differ depending on the regulations in a specific country and how individual farmers prefer to work. The biggest difference in beef production regulations and individual preferences worldwide was the difference between organic and non-organic beef production systems. The organic production has stricter regulations than the non-organic,

[1] Information retrieved from interviewee one, professor
[2] Information retrieved from interviewee two, industrial expert

regarding herd size, feed, use of agrochemicals, and antibiotics/growth hormones.

The results vary between different analyzed studies. A reason for the varying results can be that studies are using different measuring methods when calculating the environmental impacts. The results can differ over time. Some studies measure different units, making it difficult to compare the results with other studies.

Experts expressed concern regarding the current lack of knowledge in natural cycles to get a true, full view of the environmental impacts as all parameters of the different natural cycles, e.g. the carbon cycle, are not calculated for.

Global warming. The findings of GHG emission levels could not indicate a clear trend of whether the emissions from non-organic beef production were higher or lower than organic beef production. One factor that makes the GHG emissions hard to compare between the organic and non-organic production systems is the life-length of the animals. Since the animals in organic production generally live for a longer time, they automatically impact the environment during a longer period of time. The resources needed per kilo produced meat will, therefore, be higher for organic than non-organic. For this reason, the GHG emissions should be higher for organic production compared to non-organic production. Since there is no clear trend in the results for the GHG emissions, the results are even contradictory, other factors than GHG emissions are affecting the result. The validity of the result can be discussed, but a conclusion concerns the importance of examining the entire picture and considering it when analyzing other studies' results. For example, there is a correlation between results and the geographical location and to specific limitations of each study. This can be one of the reasons why it is hard to find a trend in the results since there can be large differences, even in regulations, within each type of system.

An improvement potential identified in order to lower the GHG emissions of beef production is to use well-managed grazing and feedlot finishing systems. Using well-managed grazing and feedlot finishing systems contributes to soil carbon sequestration which counter the effects of GHG emissions. Well-managed grazing systems are often found in organic production. If the soil carbon sequestration is measured and deducted from the cumulative GHG emission in further studies, organic production could possibly have a lower GHG emissions than non-organic production, even though the animals live longer. Organic production could even have a positive environmental impact because of the carbon storage.

The result from other studies does not show any trend in the data regarding enteric fermentation. But both systems have a clear negative environmental impact, which leads to inconclusiveness regarding the difference between the systems. This area of impact could be further investigated to deepen the understanding of how different factors affect how beef animals contribute to the environment in a negative way.

The non-organic beef production generally utilizes more energy than organic production since the production is more intense and more energy is needed for feed production. One improvement potential to lower the total energy consumption for non-organic production is therefore to increase the grazing and thereby reduce the need to grow feed.

Land. The type of feed used in beef production has shown to have a large impact on the environment. Organic production utilizes the land on the farms in pastures to a higher extent than non-organic production. Organic beef production uses land resources efficiently through pasture restoration by grazing. Thereby increasing soil carbon sequestration and biodiversity of the land, providing a higher land quality.

An interesting area to discuss regarding feed production is whether farming land should be used for growing food to animals or humans. Here, the quality of the land is an important factor for decision making. When it comes to organic systems, they tend to use marginal land in a better way both regarding growing animal feed and for the animals to graze compared to non-organic. This has a lower impact on the environment since other crops could not be grown on these marginal lands.

Non-organic beef production uses agrochemicals in the feed production because it is easier to manage for intense production systems. The drawback with the fertilizers is that they can cause acidification in the soil and end up in the water cycle causing eutrophication. Using natural fertilizers like manure instead of chemical fertilizers will have less, or a positive, impact on biodiversity and reduced negative impact on acidification and eutrophication. Crop and feed production in organic beef production must strictly comply with organic regulations. Manure is used as natural fertilizers to grow the animal feed which builds up the carbon content and brings back nutrients to the soil thus improving the nutrients cycling.

Several things can be done in an intensive beef production system to improve the growth of the grass in addition to chemical fertilizers. By including clover in the grass growing process, the need for fertilizers decreases. Clover improves the growing process since it binds nitrogen from the air to the plants, thus reducing the negative environmental impact of the production.

Water. The main factor impacting the water quality is agrochemicals that are used in non-organic production. Through runoffs, the agrochemicals are carried to lakes and groundwater, and thus polluting the water.

Water pollution can additionally occur if manure is managed incorrectly, e.g. in silos in non-organic production, the manure can then contribute to acidification and eutrophication.

To reduce the negative impact on water quality from beef production, rainwater can be used efficiently to diminish the

use of groundwater. Another improvement potential is to utilize grazing methods, and correct storage of manure or preferably use the manure as natural fertilizers. The most important improvement that can be done to reduce the negative impacts is to decrease the usage of agrochemicals, to reduce acidification and eutrophication.

Due to the pesticides infiltrating the water cycle, traces of these can end up in human drinking water, not only polluting the environment but also directly harming humans. This points to the importance of reducing the use of agrochemicals in all types of non-organic production.

Other. When looking at how beef production can impact the human environment, an improvement potential that could be investigated is the quality of meat, and if the quality depends on the different production systems. This is not regarded in this study, but there is a strong belief that the use of antibiotics and growth hormones is affecting the meat quality.

Due to the human demand of beef, the use of antibiotics and growth hormones is increasing during the production phases and thus intensifying the production. Growth hormones and antibiotics are used in large quantities in non-organic production. This use of antibiotics can affect the antibiotic resistance for humans since residues of antibiotics stay in the meat that is digested by humans. This is therefore something that could be further investigated.

The limited use of antibiotics in organic production is due to regulations that forbid or limit the use, and that organic herds often are healthier than herds from high-intensity non-organic production. The healthier herd is a result of that the animals eat healthier diets of grass, leading to the belief that organic meat can be of higher quality and poses as less risk in creating antibiotic-resistant bacteria.

There are more regulations regarding animal welfare in organic beef production, leading to smaller-scale production with smaller herd sizes that causes less erosion in the land. Regulations forbid organic cows to be fed with other than organic feed. Organic feed is produced without agrochemicals polluting soil and water. Organic production thus contributes to less negative environmental impact than non-organic or high intense production.

General findings. A commonly used method to measure the environmental impact of beef production is LCA from a cradle to gate perspective. Several of the found LCA studies do not include most of the parameters that have been identified in this study. For example, agrochemicals are not included, but from the result of this study, agrochemicals is identified as one of the most important factors to consider and to reduce. From the study, it was clear that the type of feed and the extensive use of the agrochemicals triumphed over the other notions of impact parameters. It can further be said that only looking at GHG emissions does not show the whole environmental impact picture for the production system, and how each production can impact the environment in both positive and negative ways.

4.2 Methodology improvement and limitations

This study was restricted to a cradle to gate perspective, to solely focus on the environmental impacts from the life of the animal, thus the fam production's emissions. Where the cradle is from the calf stage and the gate was defined to be the slaughterhouse.

Narrowing down our research topic to the specifics of organic and non-organic production and by using expert interviews enabled the possibility to reach the point of data saturation even with the limited number of literature available.

The qualitative study was conducted to identify additional environmental impacts. The two interviews were 30 minutes and 45 minutes respectively. Hence, the amount of results differed between the interviews. It can be discussed if even more environmental impacts could have been identified if both of the interviews were 45 minutes long. However, this is unlikely since the majority of subjects were commonly discussed in each interview. The two experts interviewed may be biased in their views. To minimize the risk of a biased view and to increase validity even further, more interviews could have been conducted. This would bring the project closer to reaching a higher grade of data saturation.

Well-trusted sites were used to ensure the validity of literature findings, however, one can discuss whether literature is reliable even though it is well-cited and thoroughly reviewed. To ensure the validity of all the environmental impacts presented in this paper, a complementary literature study could have been made. The goal of the complementary literature study would then be to find more information about the additional environmental impacts identified from the interviews.

The quantitative data analysis on the environmental impacts of the beef production systems would have been preferred to conduct based on more data, but due to lack of reliable and consistent data, this could not be fully achieved. If the measurement units would have been uniform throughout all studies on all impacts, a comparison between the different impacts could have been performed to a larger extent. To state the validity of the quantitative result, a more in-depth analysis for each country needs to be conducted, since the gathered studies are carried out in different countries thus affected by domestic specific rules and regulations regarding both organic and non-organic production. The data is considered to be recent enough to represent today's beef production systems.

5. Conclusion

There is a large information gap when it comes to determining the environmental impacts of beef production. The gap presented mentions that only looking at GHG emissions does not show the whole picture, which is

confirmed in the research. The study identified 13 different environmental impacts; which was categorized under global warming (energy consumption, enteric fermentation, GHG emission, soil carbon sequestration), land (acidification, agrochemicals, biodiversity, eutrophication, feed production, manure management), water (water cycle, water use), and other (human environmental impact).

The environmental impacts of beef production systems are often generalized as the impacts of one type of production system. Because non-organic production contributes to a very high negative environmental impact, most studies, therefore, present beef production systems to have a substantial negative environmental impact. The organic beef production system has a lower total negative environmental impact than what most people think. Organic production can even have positive environmental impacts as it contributes to higher biodiversity and soil carbon sequestration. Grazing and manure management are methods commonly used in organic production favoring the environment.

In the non-organic production system, the animals are fed with unnatural feed. This feed is often grown on non-marginal land with the use of agrochemicals that contributes to more enteric fermentation, soil erosion, acidification, and eutrophication. The study found that these parameters, in combination with the animals living in a crowded environment, often results in the animals getting sick and needing antibiotics. Overuse of antibiotics in production can lead to antibiotics resistance. Although the organic production system would not be suitable for big-scale production, this system is to be preferred over the non-organic in future production.

There is a need to divide beef production systems into organic and non-organic when doing an environmental impact analysis. When looking at impacts it can be seen that different impacts are affecting the different systems in different ways, and to a different extent. It is important to consider all the environmental impacts when calculating the total environmental impact of beef production and to develop consistent methods for assessing environmental impact.

Further research on the improvement potentials of the environmental impacts identified within this paper and their environmental benefits are suggested.

The research can be further extended to study the impact of agrochemicals, antibiotics, and growth hormones higher up in the food chain.

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Group 12.

The CO_2 emissions caused by packaging materials from home food delivery

Arpita Annepanavar, Erik Lilja, Matilda Bergman, Mohan Rajashekarappa, Shareyas Bhandesh and William Bäckström

Group **12**

arpitas@student.chalmers.se
bhandesh@student.chalmers.se
lilerik@student.chalmers.se
mariberg@chalmers.se
mohan@student.chalmers.se
willbac@student.chalmers.se

Abstract

Ordering food online is increasing along with changing lifestyles. To maintain food quality when delivering food a variety of disposable materials are required. Increased demand for packages impacts the environment negatively. However, the choice of material could be adjusted to minimize harm. This exploratory study is aimed to identify the two main packaging materials within home food delivery and further evaluate their impact on the environment in terms of carbon dioxide (CO_2) emissions. The study was conducted through a triangulation method. Paper and plastic were the most frequently used packaging materials. Furthermore, paper had the highest recycling rate and plastic was costly and difficult to recycle. Contrasting findings were identified and both plastic and paper were considered to release the least CO_2 emissions through life cycle analysis. In conclusion it was found that the recycling process was crucial when deciding the impacts of the materials with regard to CO_2 emissions.

Keywords: Home food delivery · CO_2 emissions · Packaging materials

1. Introduction

Home food delivery exists over the entire world, from the developing countries to Western Europe. The trend is in an early developmental stage and during the last few years home food delivery has increased steadily because it has become more common in people's everyday life. Problems associated with the delivery service are single-use materials, choice of packaging material and the amount of resulting waste. Changes of materials, recycling and reduction of materials could be used to alleviate the problem [1].

From earlier studies it was found that the most commonly used packaging materials within the food industry are; plastic, paper, glass and metal [2]. To be able to manufacture these packages, raw materials need to be acquired and in the end of life phase, the packages need to be recycled. The effects on the environment throughout the life cycle of materials are observed to be global warming potential, acidification, ozone depletion, human toxicity, and photochemical ozone creation [3]. It is also found that global warming potential is a very secure way to identify the packaging materials impact on the environment as carbon dioxide (CO_2) emissions are directly related to climate change [3][4]. This is based on CO_2 emissions being released during combustion of fossil-based fuel in the production phase of bags that made a major contribution to global warming potential [3]. Moreover, it is shown that certain materials have a high CO_2 emission when produced and a large impact on oceans and landfills in the end of life [4]. In addition, it is found that recycling in the end of life significantly affects the CO_2 emissions [5].

Studies have been conducted regarding different materials' impact on the environment through CO_2 emissions. However, it is observed that information regarding the impact of the growing packaging industry within home food deliveries is still lacking.

1.1 Project aim and research question

This exploratory study was aimed to investigate the impact of the growing production of packaging materials resulting from home food delivery. Therefore the following research questions were addressed: “Which are the two main packaging materials for home food delivery?” And “How are the two main packaging materials from home food delivery impacting in terms of CO_2 emissions?”. The study intends to act as a foundation of a concept for a more sustainable solution within the food industry with regard to packaging for home food delivery.

1.2 Limitations

The two main determinant factors of the project were the time limitation and the ongoing pandemic in the world, Covid-19. Therefore, it was initially chosen to only study the effects of the materials through carbon dioxide emissions and focusing on the two main packaging materials used for home food delivery. Furthermore, the project decided to only evaluate two main packaging materials without considering mixed material packaging and different categories of materials. Lastly, the project's data collection was severely limited, for example by difficulties in obtaining interviews with experts within the packaging industry, materials engineering and environmental studies.

2. Method

This section presents the methods used within the study aiming to answer the research questions. The process contained a triangulation method with three approaches: literature study, qualitative study and quantitative study. The literature study was a continuous process compared to the qualitative and quantitative studies, which is illustrated in Figure 1.

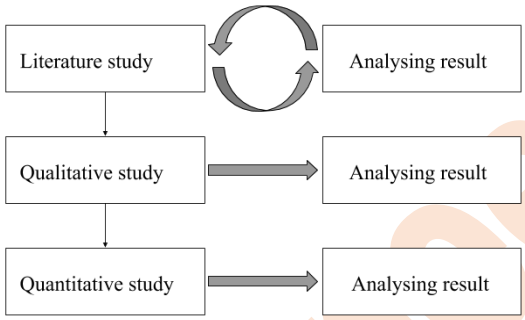

Figure 1: Illustration of the triangulation method.

2.1 Literature study

The literature study started with gathering information aiming to reach broader knowledge and identifying previous studies within packaging materials for home food delivery and the materials impact through CO_2 emissions.

The data was collected using databases like Google Scholar, ScienceDirect and Chalmers library. Keywords were decided through discussions to streamline the search process after the research questions were framed, see Table 1.

Table 1. Keywords

Keywords	
Packaging materials	Take-away food
Home food delivery	CO_2 emissions

The credibility of the sources was ensured by using platforms that handle published articles and books, excluding grey literature. Research about the environment and CO_2 emissions is an ongoing topic which requires including the most recent literature to ensure reliability. Litterature older than 15 years was therefore excluded. Initially using the keywords in Table 1, 36 published articles and books were gathered. It was further found that only 10 of the articles and books were relevant for answering the research questions.

The first source described properties of different packaging materials used within the food industry such as glass, metal, paper and plastic. The importance of having eco-friendly packaging materials is discussed by highlighting the environmental impact of different packaging materials [2]. The second source also provided information regarding different packaging materials however focusing on waste alternatives impacting on CO_2 emissions [6]. The third source presented carbon footprint, recycling rates and end of life results from paper and plastic food packages [7].

The fifth source investigated the climate impact of the packaging materials, plastic and paper, using Life Cycle Assessment (LCA). Further the major impacts and resource consumptions such as global warming potential which represents CO_2 emissions from the production chain for both plastic and paper were found [3].

The sixth source was a comparative study of environmental impact of plastic and paper as packaging materials [8]. The seventh source presented life cycle based environmental analysis of packaging. In addition the contribution of packaging material in terms of energy consumption and CO_2 emissions were investigated for plastic-based packaging solutions [9]. The eighth source stated the amount of embodied energy per unit and the amount of recycled material in circulation. The book also explained the difficulties with recycling plastics and how this affects CO_2 emissions [10]. The ninth source included analysis of consumers' response to environmental-friendly packaging [11]. Lastly the tenth and eleventh sources discussed how and when the materials, paper and plastic will lead to more CO_2 emissions [13][14].

2.2 Qualitative study

The qualitative data was collected by forming one set of interview questions for the experts, see Table 2. The questions were developed by focusing on understandable formulations and collecting useful data about different materials' impact with regard to CO_2 emissions. In addition, the questions were formulated to ensure contributing to answering the research questions.

Table 2. Questions for the experts

Questions asked through the survey
Is the waste from food packaging a problem for Global warming? • How does it affect Global warming? • What challenges could you see for the future?
Compared to each other which are more or less environmentally friendly and motivate the following packaging materials with pros and cons: Plastic and Paper?
What materials are more beneficial to recycle?

The selected experts were professors within the field of sustainability and climate studies, see Table 3. Foremost they were selected because of their deep knowledge and valuable information complementing the literature study. The experts were interviewed through the online platform Zoom.

The qualitative data was further analysed starting with listening and interpreting the data from the interviews separately within the project group. The subjective observations were validated through a common discussion and the major key findings were identified. Moreover, the interviews were transcribed in order to categorise the data through coding and to help understand the context. To transform the data into information, coding was performed manually in two different approaches, bottom up (highlighting key messages obtained from the data) and top down (identifying data answering the research questions).

Lastly the interviews were thoroughly studied, and correlations were drawn between the information from the interviews and from the literature in order to identify patterns. Quality criteria was ensured by comparing the data received during the interview from the experts with the findings from the literature study.

Table 3. Information about the experts

Expert number	**Background**	**Area of expertise**
Expert 1	Professor	Climate research focus on sustainability in production
Expert 2	Professor	Climate research focus on research circular economy

2.3 Quantitative study

A questionnaire was carefully designed to collect quantitative data acting as a complementary study to the already performed studies answering the research questions, see Table 4. The questionnaire was developed to ensure having questions formulated in an understandable way and only having one response per person. The consumers were surveyed online through the service Google forms. The survey was handed out through different social media platforms such as Facebook, LinkedIn, and WhatsApp, aiming to reach out to a sample size of 120. The specified sample size was chosen because it was perceived to be sufficient to be able to draw conclusions from the analyses performed through the statistical analysis tool JMP. The total number used for the analysis was 124. Google form helped to determine gender and age of the respondents to ensure covering different ages and gender.

Table 4. Questions asked through the survey

Questions asked through the survey
What material have you got when you have ordered food for home delivery? *Alternatives: Plastic, Paper, Glass, Aluminium, Wood and Other*
Do you recycle the package when it is used? *Alternatives: Yes, No or I do not know*
How often do you order food for home delivery? • Every week • Every other week • More seldom • Never order food for home delivery.
Which packaging material do you prefer? *Alternatives: Plastic, Paper, Glass, Aluminium, Wood or Other*

After procuring the collected data, it was transferred into a Google spreadsheet which made it easy to further perform an analysis. The analysis process contained performing different correlations between the collected data by using tools within JMP like Fit Y by X, Graph builder and Distribution [12]. These analysing tools were selected because of their ability to visualize the given data both within the analyses process and to convey the result in a presentable manner. The analysis process further contained identifying new information. The conclusions from the analysis were validated with corresponding literature study and the interviews with the experts that were previously conducted.

3. Results

In this section the results of the findings will be presented in three parts, the literature results, the qualitative results, and the quantitative results.

3.1 Literature results

Among different packaging materials used within the food packaging industry, plastic is found to be the most used

material with 40% consumption [2]. It was also found that cardboard and paper were the most recycled packaging materials and that reusing paper resulted in less effect on CO_2 emissions [6][7][10]. Plastic had a lower recycling fraction because of difficulties and cost inherited which led to higher probability of being sent to landfills than paper and contributed to enlarged CO_2 emissions [7][10][13][14].

Moreover, it was found that consumers are aware of the environmental impact of plastic as food packaging material and seeing cardboard and paper packaging as more environmental-friendly [11]. It was further revealed through the LCA method that plastic is a more environmental-friendly material compared to paper bags. This is because the fertilizers used during plantation of trees, raw material preparation and production phase have 2.48 times higher global warming potential than plastic [3][8][13]. Plastic packaging also proved to be eco-friendlier than glass and tin with regard to life cycle energy and CO_2 emissions [9][13].

The perception of being sustainable using paper bags as food packaging materials was found to be complex because it sometimes included mixed materials, making it difficult to recycle hence contributing to more CO_2 emissions [13]. Despite paper being easier to recycle, the process requires four times more fresh water than for recycling plastic. This resulted in three times more carbon emission compared to plastic [13]. The study conveyed that the disposal method for plastic resulted in a major cause of CO_2 emissions [13].

3.2 Qualitative results

Through interviews with Expert 1, who is researching sustainability in production and Expert 2, who researches circular economy, the CO_2 emissions from plastic and paper packaging were discussed. Expert 1 explained that most of the CO_2 emissions from plastic and paper come from the production stage where energy is consumed. Plastics made with petrochemical products such as oil contribute more to the CO_2 emissions. The recycling process of paper has a shorter carbon cycle in comparison with plastic because oil is not a renewable resource.

According to Expert 2, 50% of energy is saved today in the production process when recycling plastic. However, it is difficult and expensive to recycle plastic because of the cleaning process and the separation of different types. It was also revealed that regulations hinder using recycled plastic for food containers. The process of combustion is crucial for deciding the impact of CO_2 emissions because plastic waste releases a large amount of CO_2 emissions during combustion. In addition, both experts described that recycling paper had advantages both from energy and economical aspects. Therefore, a large amount of cardboard and paper is recycled.

3.3 Quantitative results

The survey revealed that plastic and paper were the most received packaging materials for home food delivery, which is illustrated in Figure 2. It was further observed that a large number of consumers ordered home food delivery more seldom, see Figure 3. The low frequency of ordering home food delivery could initiate that the contribution does not have an enlarged impact on CO_2 emissions.

Furthermore, it was discovered that conducting the survey through Google forms had a quality error, all questions were mandatory. This resulted in a positive response to "Never order food for home delivery" also to having a response to "Received packaging material", see illustration in Figure 3. Consequently, these responses on "Received packaging materials" were considered outliers because it was contrasting.

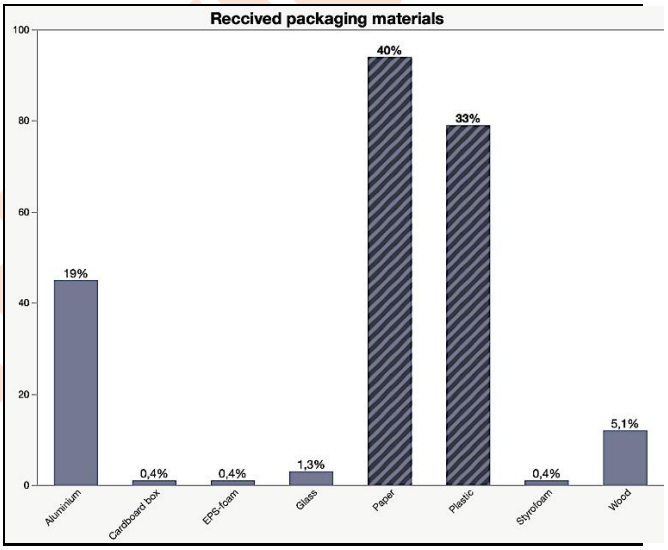

Figure 2: Illustration of received packaging materials from home food delivery.

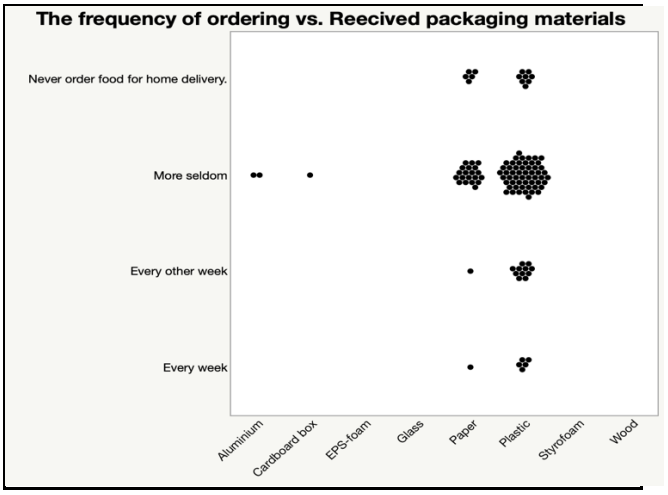

Figure 3: Illustration of the frequency of orders in correlation with received packaging materials.

Moreover, consumers thought plastic was the material that caused the highest CO_2 emissions and that most of the respondents recycled, see Figure 4. It could also be seen that even if the consumers did not recycle, they were aware of the materials impact on CO_2 emissions. In addition, 55% of the respondents preferred paper as packaging material, see Figure 5. Together Figure 4 and Figure 5 indicated consumers' awareness of materials impact on CO_2 emission, leading to a more sustainable choice of packaging material for home food delivery.

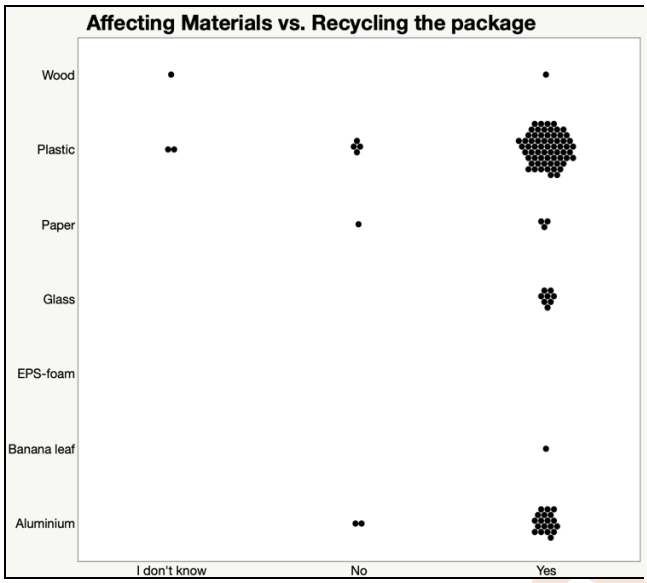

Figure 4: Illustration of the correlation between affecting materials and recycling the package

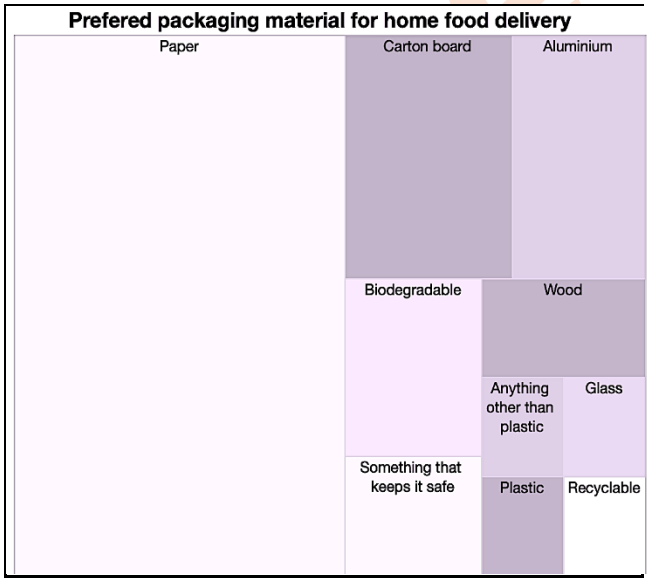

Figure 5: Illustration of the preferred packaging material for home food delivery

The survey led to more findings which could be used to ascertain for instance the recycling and frequency of order distributed over age and gender. Furthermore, the collected data could be used to identify the preferable type of food for different age and gender. However, analysing the distribution over age and gender did not contribute to answering the research questions. Therefore, these were not considered and only findings from the total number was interesting. The gender and age distribution were merely used to ensure a variety among the respondents.

4. Discussion

The strategy used for the literature search was continuously performed during the project which helped to obtain relevant information and ensure a quality search. However, there was complexity in the qualitative data collection because the interview questions were formulated with a broader aspect of global warming. More relevant data could have been collected if the interview questions were framed after narrowing to one of the causes of global warming, CO_2 emissions.

Furthermore, the survey that was conducted reached the sample size that was aimed for to ensure quality of the analysis. The respondents from the survey contributed to answer the research question regarding the main packaging material within home food delivery. However, the survey was not aimed to answer the research questions about the CO2 emissions impact caused by the two min packaging materials used within home food delivery. In addition, they could have contributed with information regarding their recycling habits and what material they recycled. In order to use these answers, it would have required a deeper analysis method than the time allowed.

The second research question regarding how the two main packaging materials within home food delivery impact in terms of CO_2 emissions was difficult to answer. This was because some of the literature sources revealed that paper released less CO_2 emissions than plastic and some identified that plastic released less CO_2 emissions in comparison with paper. The experts highlighted that the recycling process of plastic was crucial for deciding which of the two packaging materials that had the least impact with regard to CO_2 emissions. The contrasting results could therefore be based on how the plastics' recycling process was considered within the different studies.

Both literature results came from credible sources that focused on CO_2 emissions. For example, the sources that argued for plastic being more eco-friendly studied shopping bags and the sources that argued for paper being more eco-friendly studied food containers which were relevant for our study.

In addition, the survey revealed that the respondents thought that plastic was more harmful than paper. The result from the respondents showed that the awareness of the impact regarding different materials recycling processes in

terms of CO_2 emissions is lacking. This knowledge gap could be overcome to make sustainable choices and increase the general awareness. Further studies need to be done in order to investigate the contrasting answers and identify appropriate solutions to close the knowledge gap.

5. Conclusion

The study aimed to answer the research questions through a literature, qualitative and quantitative perspective. Through the study it was found that plastic and paper were the two main packaging materials used within home food delivery.

Furthermore, both paper and plastic were evaluated in terms of the effect of CO_2 emissions. Paper was recycled and reused in a larger amount than plastic which contributed to less CO_2 emissions because the energy intensive step of production was excluded. However, paper was also identified as being more harmful considering its life cycle analysis compared to plastic. This was primarily because of high energy and resource consumption during the production phase. It was also revealed that consumers preferred recycling and that they thought paper was eco-friendlier than plastic.

The CO_2 emissions from plastic are dependent on the chosen disposal method. The recycling process of plastic is costly but will contribute to less CO_2 emissions compared to emissions caused by combustion or accumulation in landfills.

The contrasting answers showed that the recycling process of plastic was crucial when deciding the impacts of the materials with regard to CO_2 emissions.

Throughout the study it was revealed that there are contrasting answers regarding packaging materials' effect of CO_2 emission because of how the recycling process is considered. The general awareness of the effect of different packaging materials observed in the survey indicates that information is lacking. Future research regarding CO_2 emission caused by packaging materials from home food delivery is therefore considered as valuable. This future research could clarify the impact of CO_2 emission caused by the different packaging materials. It could furthermore contribute to a more sustainable choice of packaging materials within home food delivery.

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PPU215 Research Methodology in Production Projects

This course aims to develop MSc students' professional and scientific skills by working in groups on a research project to answer an open-ended research question. All projects started with a contemporary engineering problems. The groups defined a research question which formed the basis for their research project. The project work included planning, time management, teamwork, various forms of communication and ethical considerations in engineering (professional development). The groups answered their research question using a triangulated approach combining literature studies, quantitative and qualitative methods (scientific skills). At the end of the course, all groups presented their research project with a conference paper and oral presentation at the *'PPU215 Conference: Engineering Solutions for the Environment'*. This book is the conference proceedings for the Spring 2020 edition of the course.

Organisation

Division of Production Systems

Department of Industrial and Material Science

Chalmers University of Technology

Visiting address: Hörsalsvägen 7A, M-building (5th floor), SE-412 96 Göteborg