The Possibilities of Intermodal Transport to reduce Carbon Emissions in Logistics by Heineken

Msc. Thesis

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by

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Preface

In presenting my Master's thesis in Engineering and Policy Analysis, I find myself at the conclusion of a rewarding journey. Titled "The Possibilities of Intermodal Transport to reduce Carbon Emissions in Logistics by Heineken," this thesis is a practical exploration closely tied to my internship at Heineken within the Global Procurement office for the Logistics department.

The central theme of this thesis centers on the practical application of sustainable practices in the logistics sector, specifically examining the potential of intermodal transport to cut carbon emissions in Heineken's supply chain. This research aims to provide practical insights that contribute to Heineken's ongoing commitment to sustainable business operations.

I extend my appreciation to Carlos, my manager at Heineken, for his consistent support and willingness to share information crucial to this thesis. I would also like to thank Arjen for his support at a higher organisational level and ongoing interest in the progress of this study.

A special acknowledgement is reserved for Mr. Verbraeck, my first supervisor, whose knowledge on intermodal transport, derived from his project with the University of Maryland, and the data shared from the intermodal course, have significantly influenced the direction and outcomes of this study. The frequent feedback meetings were a source of guidance that helped me along the way. I also want to express my gratitude to Mr. Ludema, my second supervisor, for his time and effort. His expertise in supply chain and logistics and sharp questions have played a pivotal role in elevating the quality of this thesis, pushing it to the next level.

The past nine months spent at Heineken have been an enlightening experience. Balancing academic demands with the complexities of a global corporation has been challenging yet instructive. Observing the operations of such a large company on a global scale has provided valuable insights into sustainable business practices.

This project has kindled a greater interest in contributing to global sustainability. As I conclude this thesis, I look forward to seeing how the insights gained during this research can contribute to practical advancements in sustainable logistics. I am optimistic about my role in fostering sustainability and hope to carry this passion beyond the scope of this academic endeavour.

Thank you to everyone who has been part of this insightful experience.

T.J.M. Senden
Amsterdam, December 2023

Abstract

Globally efforts are being made to combat climate change, including the Paris Agreement and the European Commission's 2030 climate target plan. The Heineken Company introduced its own 2030 sustainability goals, including achieving net zero emissions in its production line by 2030 and operating in a carbon-neutral value chain by 2040. To reduce the emissions caused by logistic operations, Heineken launched the Net-Zero Logistics program, which focuses on reporting emissions and implementing carbon reduction measures, including increasing its use of intermodal transport.

Intermodal transport, is the use of different types of transport modes during the transport process. Intermodal transport is typically focused on surface transport including, roads, railways and waterways. Literature suggests, intermodal transport could help to improve carbon reduction and achieve Heineken's net-zero logistics goals. Therefore, Heineken is eager to learn where there are more opportunities to use intermodal transport, how much it would cost and what the exact reductions would be. This report focuses on answering these questions and answering the research question:

What is the impact of intermodal transport on Heineken's emissions, costs and lead-time compared to the current mode of transport?

The main objective of this study is to find out where Heineken's potential for reducing transport emissions through the use of intermodal transport lies. This includes looking at the cost and lead time of the alternative. To this end, a model and methodology has been developed that allows a comparison to be made between road and intermodal transport based on the availability of data.

The emissions calculations in the model use a globally agreed framework to comply with reporting guidelines. The first step is to calculate emissions for road transport. These emissions are calculated using provided emission factors per country, modality and payload. These emission factors are multiplied by the total distance of the transport route in kilometres. The distance can be easily determined using Google Maps. The emissions from intermodal transport are then calculated. How this is done depends heavily on the data available. Three methods have therefore been developed. Each method describes how available data can be used to calculate both emissions and costs. The first method is based on the availability of data on intermodal transport options. If this data is available, the intermodal option with the closest transshipment hubs can be chosen as input. With this method it is known that intermodal transport is already taking place between the two hubs. An online intermodal distance tool can be used to determine the distance between these two hubs. For the first and last mile by truck, Google Maps can again be used. These distances are then multiplied by the emission factors. This method is used for the European region. If intermodal transport data is not available, but locations of intermodal hubs are, these can be used. Again, the nearest hubs for the lane can be selected and used to determine the intermodal distance. This method is used for the US region. Finally, if these intermodal hubs are not known from a database, they can be found by using open source data such as openrailwaymap.org for rail options combined with information from the Internet. Again, the closest intermodal hubs are selected and used to determine distance and calculate emissions. This method is used for the African region with Ethiopia as the reference country.

Costs are determined using two methods. For the Europe region, an internal intermodal pre-tender is used to collect transport costs. These bids for intermodal options can be used for evaluation against historical trucking costs. The other method is to use average historical transport rates per kilometre for both truck and intermodal. This method is used for the U.S. and African region.

The lead-time is determined based on either info from an intermodal database if available such as in Europe or based on average transport speeds multiplied with the travelled distance with an added average dwell-time.

Finally, the comparisons between emissions, time and costs of road and intermodal transport is calculated.

Experiments have been conducted with Heineken's existing transport routes with differing characteristics. The characteristics that were differed are region, high or low lane distance and high or low transshipment hub distance. This resulted in 34 experiments based on the availability of transport lanes and intermodal options matching these requirements. From these experiments can be concluded that opportunities for both emission and cost reduction through intermodal transport are possible on distances above 600 km. In addition, for shorter distances, intermodal transport can also reduce emissions and make savings if the first and last mile distance are below 30% of the total intermodal distance. Beyond these restrictions, there are other specific cases where intermodal can still lead to savings. The use of intermodal transport does require an extended transport time to be taken into account. When looking at the intermodal modalities is is found that the biggest emissions savings can be found using short-sea and the biggest cost savings can be made using rail. Barge transport in most cases is not that competitive. A scenario combining renewable electric trucks and intermodal transport offer an even more environmentally friendly alternative to trucking. The limited range for these trucks make them less desirable for long distances and therefore not use full for direct trucking but are very effective when used for the first and last mile of the intermodal transport. The scenario for increased carbon prices showed no direct significant impact on transport costs and therefore on the decision-making.

In future research, the method and template can be be used to analyse more routes within Heineken global or in local operating companies. Additionally from a bigger study with more transport lanes, conclusions could be drawn from data analysis of the outputs. In addition, the input values of cost and lead time can be further specified in co-operation with the carriers.

For Heineken it is recommended to focus on longer lanes as these show bigger reduction potentials. Also big options for reductions are possible in the U.S. which are not yet exploited yet. It is also advisable to check intermodal costs with carriers for the USA and possibly Ethiopia to get a more accurate indication. It should be noted, however, that for Ethiopia there are only a few suitable interchangeable transport lines due to the scarcity of intermodal options. To further explore intermodal options an integrated tool can be obtained to analyse transport lanes with real-time transport data from carriers.

Contents

List of Figures

List of Tables

Acronyms

CCWG Clean cargo working group.

CO2-eq Carbon dioxide equivalent.

EWI EcoTranIT World Initiative.

GHG Green House Gases.

GLEC Global Logistics Emissions Council.

GWP Global warming potential.

IANA Intermodal Association North America.

LSP Logistics service provider.

OpCo Operating company.

WTW Well-To-Wheel.

1

Introduction

1.1. Background

Due to ongoing climate change in the world, in 2015 the Paris Agreement is adopted. The Paris agreement is a legally binding international treaty on climate change, which was adopted by 196 parties at the United Nations Climate Change Conference in 2015 (UNFCCC, 2015). The agreement aims to limit global warming to well below 2 degrees Celsius above pre-industrial levels (1850-1900), with an aim to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. The Paris Agreement represents a crucial global effort to address the urgent threat of climate change and to promote sustainable development worldwide. As a response to the Paris Agreement's objectives, the European Commission announced the 2030 climate target plan in September 2020. It contained a set of policies and measures designed to reduce greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels (European Commission, 2020).The plan reflects the European Union's commitment to taking urgent action on climate change. It includes a range of measures across various sectors, such as energy, transport, buildings, and industry, aimed at accelerating the transition to a low-carbon and sustainable economy.

In 2021, The Heineken Company introduced the 'Brew a Better World' strategy (The Heineken Company, 2022) presenting their 2030 sustainability goals. The strategy is a response on both the Paris Agreement and the climate target plan of the European Commission. The 'Brew a Better World' strategy of Heineken focuses on three pillars, namely, on the path to: (1)net-zero impact, (2) an inclusive fair and equitable world, and (3) moderation and no harmful use. With the global goal of net-zero impact, the company aims to reach net-zero emissions in 2030 within its whole production line. By Net-zero, a term established at the Paris agreement and recognised by GLEC (Global Logistics Emissions Council), is meant that all Green House Gases (GHG) emissions are brought to zero as far as possible and the remaining amount (Max. 10%) is offset. GHG that are taken into account are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs). CO_2-eq is used as universal unit of measurement to indicate the global warming potential (GWP) of each of the six greenhouse gases, expressed in terms of the GWP of one unit of carbon dioxide. It is used to evaluate releasing (or avoiding releasing) different greenhouse gases against a common basis (Ranganathan et al., 2004). In 2022, Heineken's baseline year for their climate goals, the company had a total carbon footprint of 17.578 ktonnes CO_2-eq (The Heineken Company, 2023). Moreover, the Heineken company set the goal to operate in a fully net-zero value chain in 2040 with an intermediate target of 30 % absolute reduction by 2030 (The Heineken Company, 2022). These goals are in line with the set goals of the Paris Agreement and European climate target plan. As part of both the production line and the value chain, Heineken's global logistics department is also determined to meet these targets. Heineken's emissions related to logistics will be 11%, totalling 1.9 kt CO_2-eq in 2022 (The Heineken Company, 2023) which will be taken as the baseline for future reductions. To reduce these emissions, Heineken has launched the Net Zero Logistics programme. This programme focuses on achieving the targets set in the Brew a Better World strategy within the logistics of all operating companies worldwide. To achieve this, the programme focuses firstly on reporting the logistics carbon footprint and secondly on possible carbon reduction measures. Possible measures described are: logistics efficiency, fuel and fleet management, low emission technologies and intermodal transport. Based on the last, Heineken set out an internship assignment to explore where within the company's logistics chain more use could be made of intermodal transport in order to reduce carbon emissions. This study is based on the set assignment by Heineken and therefore focused on CO2-eq reductions by intermodal transport in the logistics supply chain of Heineken.

Intermodal transport refers to the movement of goods using multiple modes of transportation, such as trucks, trains, ships, and/or airplanes, within a single journey. The key characteristic of intermodal transport is the use of different modes of transportation in a coordinated manner to optimise efficiency, cost-effectiveness, GHG-emissions and/or overall logistics performance. Although intermodal transport is not a 100% net-zero option, it is seen as a serious tool for reducing emissions across the globe. Due to a lack of charging infrastructure, absence of renewable sources for the electricity generation and a limited range, intermodal transport is a more suitable measure for some regions of the world than other more environmentally friendly transport methods, such as electric trucks.

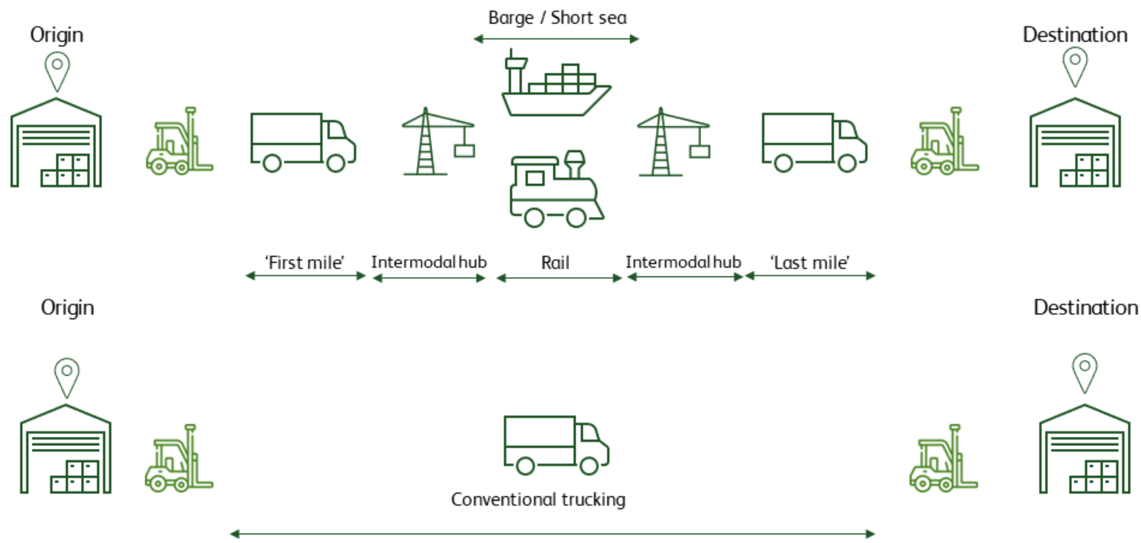


Figure 1.1: Conventional versus intermodal routing

Figure 1.1 illustrates the difference between conventional truck transport and an intermodal alternative. Both have a point of origin and a point of destination, but naturally the route in between differs. Conventional trucking goes straight from origin to destination, sometimes with a rest period in between depending on the distance. In the intermodal alternative, most of the journey is by rail, barge or short sea shipping. The part of the journey before and after this is called the first and last mile. Although this first and last mile is (usually) still carried by a conventional truck, the majority of the journey is carried by the lower-emission intermodal transport mode. An important consideration here is the possible additional lead-time of the intermodal alternative from transshipment at the intermodal hubs and the waiting time there for the next mode of transport, compared to the conventional mode of transport.

1.2. Heineken's logistics

Within the value chain of Heineken there are logistic operations in multiple stages. Starting with the inbound transport of either raw materials for the production process or packaging materials. Furthermore, there is inter brewery / external warehouse transport, this is transport of finished goods to other warehouses and/or breweries owned by the company. Primary distribution then is the transport of finished goods to customers (distributor, wholesalers, retailers etc.), whereas secondary distribution is the transport of finished goods to the hospitality industry. Secondary distribution is mostly outsourced to other companies (such as Sligro in the Netherlands) with a few exceptions in countries. A visual overview of Heineken's logistical operations is shown in figure 3.2

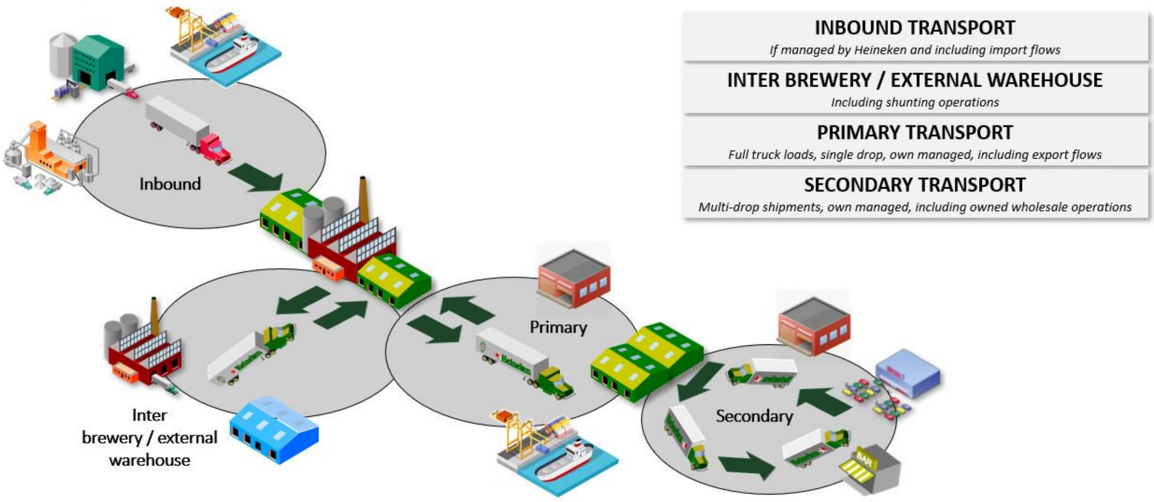


Figure 1.2: Heineken's Logistical operations

The transportation of the goods within Heineken is primarily coordinated at a national level, relying on subcontractors known as Local Service Providers (LSPs) for the majority of the transport operations, although there are a few exceptions. These LSPs manage the end-to-end transport process, from the delivery of the container, collection at the point of origin, the entire transport by one or more modalities, to delivery at the final destination. The reason for Heineken's national focus in logistics is that, in the past, Heineken has bought national breweries in order to expand its operations and distribute its own brands in the country through the acquired distribution network. Each of Heineken's Operating Companies (OpCos) is responsible for independently organising transport within their respective countries, separate from the global office in the Netherlands. Recurring transport from origin to destination is referred to as a transport lanes. The shipments transported through these lanes encompass a wide range of contents, including inbound raw materials and packaging, empty (returnable) packaging, bulk beer, and finished products. The frequency, distance and volume of these lanes vary individually. Logistics service buyers at the national and global office handle these cases and initiate a tendering process where LSPs can bid for the offered lane. This approach allows for competitive pricing and selection of suitable LSPs. For larger lanes, covering several countries or involving higher volumes and/or frequencies, the global office takes over. In Europe, for example, the global office is responsible for a total of 1300 lanes. While some of these lanes (being it short segments) have already adopted intermodal transport to a limited extent, it's worth noting that out of these 1300 lanes in Europe, 1000 still rely exclusively on road transport [1].

1.3. Problem statement

Heineken currently already uses intermodal transport on a small scale, but is looking for places to expand its use, with emission reduction as the main motive. Specifically, Heineken wants to understand which current national and international transport routes are suitable for carbon reduction through intermodal transport. In addition, it is interesting to understand how the costs and lead-time of intermodal transport compare to regular truck transport, which is the current most common used mode of transport. The ultimate goal of this study is to explore and give Heineken's logistics procurement team more insight into which characteristics of transport lanes are suitable for intermodal transport to reduce emissions, and at what cost. It also provides insight into which routes would benefit from future intermodal options, in order to discuss with logistical service providers whether these could be introduced.

[1]Retrieved from internal communications

1.4. Scientific and curriculum relevance

The topic is scientifically relevant because the world is currently looking for different ways to become more sustainable. One of these ways, as mentioned earlier, could be intermodal transport. The potential for reducing emissions through intermodal transport has already been studied. However, these studies are outdated or have been carried out in other specific regions. Therefore, this study can be a new scientific addition to the current state of intermodal transport. It can be combined with the question of whether this is a possible option for a large corporate such as Heineken and/or what complications there might be in implementing it.

The research topic is interesting for the curriculum of the Faculty of Technology, Policy and Management at TU Delft, and in particular for the Engineering and Policy Analysis Master, for the following reasons. The road to a net-zero future can be seen as a grand challenge. It is a challenge that will take multiple years and involves numerous stakeholders both from within and outside of the Heineken company. This study will help inform decision-makers on the path to overcome this grand challenge. Furthermore, a combination of analytical methods will be used to answer the knowledge gap such as modelling, data processing, interviewing and bench marking. And at last, the topic includes observing the logistical networks across the world as a system, while looking from a multi-actor perspective including the multiple motives within Heineken and the views of logistical service providers facilitating the transport.

1.5. Thesis objective

The objective of this thesis is to have multiple deliverables. The first deliverable will be a methodology to calculate possible emission reductions through intermodal transport per transport lane. This methodology will defer based on the availability of data in the region. The methodology will be suitable to fill in currently used transport lanes. The methodology will focus on providing an intermodal alternative for the route accompanied with the differences in emissions, costs and lead time. With this methodology it will become easier within Heineken or other actors to identify possible lanes for intermodal transport and use this information in talks with LSP's (Logistical service providers). This methodology will be incorporated into a model for internal use.

Another deliverable will be the identification of characteristics of transport lanes that are suitable for emission reductions through the use of intermodal transport. These characteristics will be predictor variables, such as transport distance, distance to intermodal hub and modality that indicate a suitable line for emission reduction. The idea is also to use possible identified lanes in the process directly when allocating lanes for the coming year (2024).

1.6. Report outline

This report consists of 9 chapters. In the first chapter the problem is introduced combined with background information, the relevance and the thesis objective. Chapter 2 elaborates on the thesis' methodology and describes the research questions, methods and approach to tackle the research problem. Hereafter, in chapter 3 a detailed literature review is discussed providing extra information and understanding on the state of the art of intermodal transport. The model that is created is described in chapter 4 after which it is verified and validated in chapter 5. The experiments conducted with the model are described in chapter 6. The results of the experiments are given in chapter 7 and discussed in chapter 8. Finally, in chapter 9 conclusions are drawn.

2 Methodology

This research aims to investigate the suitability of intermodal transport for reducing carbon emissions and costs in Heineken's logistics operations. Through a literature review, the knowledge gaps and challenges of intermodal transport are identified, leading to the formulation of the main- and sub-research question. Based on the sub-research questions, research methods and accompanying research tool are chosen. Then a research flow diagram will be presented that displays the outline of the research. At last, the scoping of the research is discussed to explain what is in- and excluded form the study. The outcome of the study will guide Heineken in determining the regions where intermodal transport can be pushed for, and can also contribute to the understanding of intermodal transport possibilities in the literature.

2.1. Main research question

A research objective can be formulated from background information on intermodal transport and the assignment of Heineken to explore where Heineken could environmentally benefit from intermodal transport, taking into account carbon emissions, costs and lead-time. This objective leads to the following research question:

> What is the impact of intermodal transport on Heineken's emissions, costs and lead-time compared to the current mode of transport?

The outcome of the research question will be used by Heineken to determine in which regions it should push for the use of intermodal transport in order to achieve its net zero logistics goals. This knowledge can then be taken into account when tendering and negotiating with potential logistics service providers. As infrastructures and schedules are constantly evolving, the findings will also be suitable for scientific purposes to better understand the overall possibilities of intermodal transport and to add another user case to the literature.

2.2. Sub research questions

Based on the main research question and the aforementioned knowledge gaps sub-research questions have been formulated to structure and focus the research. The resulting sub-research questions are:

1. What transport lanes of Heineken and their accompanying characteristics are interesting to further explore in order to determine where intermodal possibilities lay for Heineken?
2. How to calculate the current carbon emissions of Heineken's transport lanes?
3. What are the potential carbon emission savings by intermodal transport?
4. What is the difference in costs and lead-time of intermodal transport compared to conventional truck transport?

2.3. Research approach

The research approach adopted for this study is a combination of a case study and a quantitative approach. This approach allows for the use data gathering and calculation techniques to quantify the impact of intermodal transport on carbon emissions, costs and lead-time. At the same time, it enables a detailed examination of Heineken's logistics operations through a case study analysis to identify the potential for intermodal transport to reduce emissions.

2.3.1. Case study approach

The case study approach involves an in-depth examination of a particular case or phenomenon. In this study, the case is Heineken's logistics operations, specifically its transport lanes. Due to the nature of the assignment coming from Heineken and investigating existing transport alternatives, the case study approach is logically used. This approach will be used explore in which regions intermodal transport may be possible. And then develop a method to identify the carbon emissions on transport lanes and the potential for intermodal transport to reduce emissions.

2.3.2. Quantitative approach

The quantitative approach involves the collection and analysis of numerical data (Burke Johnson & Onwuegbuzie, 2004). In this study, quantitative data will be collected from Heineken's logistics database to determine route lengths and costs associated with different transport lanes. Hereafter, conform the GLEC framework the emissions of these lanes will be determined. The next step will be to take the existing origins and destinations of the lanes and obtain possible intermodal transport routes from the Ecorys, intermodal-course or openstreetmap database. Quantitative data about carbon emissions factors can be collected from the CCWG and EWI databases. The numbers of both conventional and intermodal alternatives will then be compared and analysed to identify patterns, relationships between the lane characteristics and outcomes. This approach provides a rigorous and objective method for assessing the impact of intermodal transport on carbon emissions, costs and lead-time.

In summary, the combination of a case study and quantitative approach provides a robust and comprehensive method for assessing the impact of intermodal transport on carbon emissions, costs and lead-time. The sub research questions will be used to guide the analysis and ensure that all aspects of the research problem are addressed.

2.4. Research methods

In order to answer the main-research questions: "What is the impact of intermodal transport on Heineken's emissions, costs and lead-time compared to the current mode of transport?" a set of sub research questions are compiled in the previous chapter. These questions are:

1. What transport lanes of Heineken and their accompanying characteristics are interesting to further explore in order to determine where intermodal possibilities lay for Heineken?
2. How to calculate the current carbon emissions of Heineken's transport lanes?
3. What are the potential carbon emission savings by intermodal transport?
4. What is the difference in costs and lead-time of intermodal transport compared to conventional truck transport?

To answer these sub-questions and subsequently the main research question, research methods will be selected. First, in order to narrow down the scope of the research, an exploratory literature review combined with interviews with local Heineken employees is conducted. This method is used to identify interesting characteristics of the current transport lanes in the top emitting countries where Heineken operates. Based on these characteristics the further research is scoped down to areas where the use of intermodal transport looks promising. For this, the presence of infrastructures, intermodal data, possible transshipment hubs, types of train propulsion and national energy mix will be considered.

Then, to answer the question of the current carbon emissions of transport lanes, a calculation method and model will be created to connect the transport lanes to real-world travel distances. This distances can then be used to determine carbon emissions per lane based on GLEC approved emission factors. At the base of the method is data on the transport lanes of Heineken. This input-data from Heineken will include information about origins, destinations and transport modalities, as ratio data with exact numbers of volumes and frequencies. For truck, rail and barge emissions, data is used from the EcoTransIT World Initiative (EWI) calculation tool accredited by the smart freight centre. EWI identifies the environmental impacts of freight transportation per nation in terms of direct energy consumption and emissions during the operation of vehicles during the transport of products (EWI, 2022). For short-sea emissions, data is used from the Clean Cargo Working Group (CCWG). Clean Cargo is a collaborative initiative between ocean container carriers, freight forwarders, and cargo owners that facilitates accurate greenhouse gas emissions inventory calculations for Clean Cargo members (CCWG, 2023). This data can then be used to determine the approximate emissions by mode and vehicle type for each country. The deliverable of this question will be numbers on carbon emissions for the chosen transport lanes which can later be used for bench-marking.

The next step is to determine the numbers on the emissions of the intermodal transport alternative in order to compare with conventional trucking. For this question, the bench-marking method will be used. The emissions of current trucking routes, determined in the previous question, will be used as benchmark or the so-called control group. The emissions of the intermodal transport routes can then be compared to see if carbon reductions are possible and if so, how big they are. For this step another set of data is required, intermodal transport data to be precisely. However, this data is not available on all regions of the world. To present a complete method, three different sub-methods will be described based on data availability.

For Europe, this data can be retrieved from Ecorys. This data set will include information about existing intermodal transport lanes including the origins, destinations and transport modalities. Ecorys is willing to provide intermodal data for this study as they are a research focused consultancy and are curious to see if their data will be useful to interested companies. For the USA data is available only on possible intermodal hubs, however there is no exact data available for actual exploited intermodal lanes with origins or destinations. Then, for Africa, the locations of the infrastructure can be identified using openrailwaymap.org. openrailwaymap shows the locations of railways around the world, based on the open source openstreetmap database. This data, combined with an internet search for transhipment terminals and dry ports, can give an indication of where rail transport can be used.

The following step will be to determine the trip distance of the intermodal lanes which must be retrieved as this is not included in any data. The websites used for this step will be 'Brouter.de' for rail and barge transport and 'sea-distances.org' for short-sea transport. This intermodal data with distances, combined with the emission factors from the EWI and CCWG, gives a figure for the emissions of the intermodal part of the alternative. From the available data, the closest intermodal hub to the origin and the closest connected hub to the destination of the transport lane is selected. For the 'first mile' and 'last mile' of the trip the same calculation method will be used as the step before. For the transshipment between different modes a constant value determined by GLEC will be used. The combined emissions of the first mile, transshipment, the intermodal part and the last mile result in the total emissions of the intermodal alternative. By comparing the conventional trucking emission and intermodal alternative emissions, this step will result in an analysis of the emission reductions per lane, thus showing where Heineken could benefit from using intermodal transport. Here it is interesting to see which characteristics of a lane make it suitable for reductions through intermodal transport.

The final step in determining the difference in cost and lead time of shifting to intermodal transport is again based on data availability. In Europe, for example, a pre-tender round is used. The known lanes for the coming year are open for all LSPs to bid on as usual. However, in this pre-tender round they can only offer intermodal transport options. These bids will then be bench marked against the data Heineken has on existing routes and modes of transport. This approach provides an accurate forecast of the cost differences.

If this data is not available, estimates are made based on distance and transport rates. These transport rates are obtained from the intermodal course website (Intermodal Association North America et al., n.d.). These estimates can give an indication of what the difference in cost will be.

The same approach is taken for lead times. For truck lead time, the maximum regulated driving distance per day is taken and based on that the lead time is determined. For intermodal, the same method is used for the first and last mile done by truck. For the lead time of the intermodal leg, the average transit speed per modality per region is taken and used to calculate the time based on the distance. For the transshipment time, the average dwell time of the terminals in the region per transshipment is used. These figures together give an indication of the lead times for intermodal transport.

Again, the results for cost and lead time are examined to better understand what characteristics a lane must have to be interesting for an intermodal option.

2.5. Data processing tools

This research uses a combination of different data processing tools and websites to carry out the research methods mentioned above. These tools have been selected to ensure efficiency and to meet the desired outcomes of this study. The tools used are Microsoft Excel, routescanner.com, openrailwaymap.org, brouter.de and sea-distances.org.

Microsoft Excel: At the heart of this research is Microsoft Excel, a widely used programme within Heineken. Excel serves as the backbone of this research, facilitating data organisation and calculation. However, its real strength lies in the creation of a robust calculation template that can be used by the company even after this study has been completed. This continuity of use beyond the research period is the main reason for using Excel, especially considering that e.g. Python, although a powerful and perhaps more suitable tool, is not known and therefore not adopted within the company.

Routescanner.com: This website provides an optimisation tool for intermodal routes. This website also calculates emissions compared to truck routes. This tool can be used to validate our model by comparing the emissions and transport time of truck and intermodal.

Openrailwaymap.org: This open platform database shows where rail infrastructure exists around the world. The tool is used to determine where rail transport is an option in Africa.

brouter.de: This web application is a routing tool for modes other than road. Using the 'river' and 'rail' options, you can determine the distances for barge and rail to be used in the calculations.

sea-distances.org: This web application provides distances between sea ports and can be used to determine short sea shipping distances to be used in the calculations.

Taken together, these tools provide collaborative support for this research. Excel, with its user-friendly interface, is used to create the model template. Python extends the data processing capabilities to provide distance data. Finally, SPSS provides advanced statistical analysis, identifying correlations and predicting variables related to emissions, costs and lead times.

2.6. Scoping the research

Scoping the research is essential to define the boundaries, focus, and limitations of the study. It helps establish the parameters within which the research will be conducted, ensuring a clear and manageable investigation. In this section, the scoping of the research for investigating the suitability of intermodal transport for reducing carbon emissions in Heineken's logistics operations will be discussed. Scoping is necessary to provide clarity and structure to the research project. By defining the scope, specific objectives, research questions, and methodologies can be established that will guide the study. It helps to manage the available resources effectively and ensure that the research remains feasible and focused. Scoping also focuses the research on the most relevant aspects of the research problem and provide meaningful insights within the available time-frame.

2.6.1. Scope of transport lanes and intermodal data

In this research, the choice has been made to focus solely on the current transport lanes used by Heineken. This decision allows for a detailed analysis of Heineken's existing logistics operations and facilitates the identification of the most carbon-intensive transport lanes. By narrowing the scope to these specific lanes, the research can provide targeted recommendations for reducing carbon emissions through intermodal transport alternatives. Besides, additional emissions within these lanes due to special equipment such as reefers won't be included in the research.

Furthermore, the data for intermodal transport will be obtained from Ecorys, a trusted source in the field. It is important to note that due to data availability and limitations, there may be additional intermodal transport options that are not included in the analysis. However, by utilising the data provided by Ecorys, a comprehensive assessment can still be conducted, considering the available intermodal routes and their potential emission reductions. For regions in the USA and Africa, where data such as that from Ecorys is not available, less precise data is used, incidentally. For the US, this is data on the location of hubs, between which it is assumed that intermodal options are not certain. Furthermore, for Africa, an approximation is made of where any transport is possible, based on existing railways. Whether freight transport is actually possible here is also uncertain.

In addition, the research scope also includes transport lane lengths, with a minimum threshold of 300 kilometres. This criterion ensures that only transport lanes suitable for intermodal transport, which is more competitive for longer distances, are considered. By excluding shorter transport lanes, the study focuses on scenarios where intermodal options can provide significant carbon emission reductions and cost savings. This targeted approach allows for a more precise analysis of the most promising intermodal opportunities. The minimum length criterion is based on the article of Meers et al. (2014), highlighting the increasing competitiveness and efficiency of intermodal transport over longer distances. By concentrating on suitable transport lanes, the research aims to provide valuable insights into the benefits and considerations of intermodal transport for Heineken's logistics operations, specifically in terms of carbon emission reduction and cost optimisation.

2.6.2. Scoping by emission-intensive countries

To further scope down the research, a focus will be placed on the most emitting countries in terms of CO2-eq emissions. For the purpose of this study, these countries are defined as those emitting more than 50 kilotons of CO2-eq. To account for Europe's interconnected infrastructure and transportation systems, Europe will be considered as a single country in this context.

The choice to concentrate on the most emitting countries enables a targeted analysis of regions where significant carbon emissions reductions can be achieved. By focusing on these regions, the research can provide valuable insights into the specific opportunities, and potential benefits of implementing intermodal transport solutions within these high-emission areas.

2.6.3. Scope refinement through research question 1

To further refine the scope, the research will address the first sub-research question focused on identifying transport lanes and regions which differing characteristics. By answering this question, the study will identify varying regions and transport lanes. The characteristics are determined based on examined literature. This information will enable a more wide exploration of intermodal transport possibilities and potential emission reductions within these specific regions.

By scoping the research in this way, the study can provide Heineken with broadly applicable but useful insights that will enable the company to make informed decisions about the implementation of intermodal transport solutions. Additionally, the scoping ensures that the research remains manageable within the available time and resources, while still addressing the core objectives and research questions of the study.

2.7. Scenario exploration

In addition to the main research questions and methods outlined in the previous sections, this research project also aims to conduct scenario exploration to further understand the potential outcomes and implications of implementing specific scenarios in Heineken's intermodal logistics operations. The scenarios that will be explored include the use of renewable electric trucks and an increased price of carbon.

2.7.1. Utilisation of renewable electric trucks

One scenario to be explored is the use of electric trucks in parts of the intermodal alternative. This scenario examines the impact of switching from conventional fuel-based trucks to electric trucks. With substitution in the first and last mile part of the transport lane, intermodal transport is expected to become even more effective. These trucks can be charged with so-called 'green' renewable electricity, so that the emissions from these trips are zero.

2.7.2. Application of the increased price of carbon

Another scenario to be explored is the application of an increased price of carbon. These carbon prices are expected to rise over the years and encourage more sustainable decision-making. This exploration aims to estimate the potential cost implications and incentives associated with incorporating an increased price of carbon into Heineken's logistics decision-making. The analysis will assess how pricing carbon emissions could impact the cost of conventional trucking and therefore potentially also increase attractiveness of intermodal transport.

The scenario exploration will involve conducting additional research, data collection, and analysis specific to each scenario. It will utilise quantitative methods, such as modelling and cost-benefit analysis, to evaluate the potential outcomes and trade-offs associated with each scenario. The findings from the scenario exploration will provide insights into the potential (future) benefits, challenges, and implications of implementing these scenarios in Heineken's logistics operations, offering a broader perspective on the effectiveness and feasibility of intermodal transport.

2.8. Research flow diagram

In this section, the research flow diagram will be presented, which outlines the overall process of the research project. The diagram includes the main research question, as well as the sub-questions, input/output data, and methods used. This visual representation provides a clear overview of the different stages of the research, allowing for a better understanding of the project as a whole. It also helps to ensure that all aspects of the research are carefully planned and executed in a logical and efficient manner. The research flow diagram for this study is presented in 2.1 below.

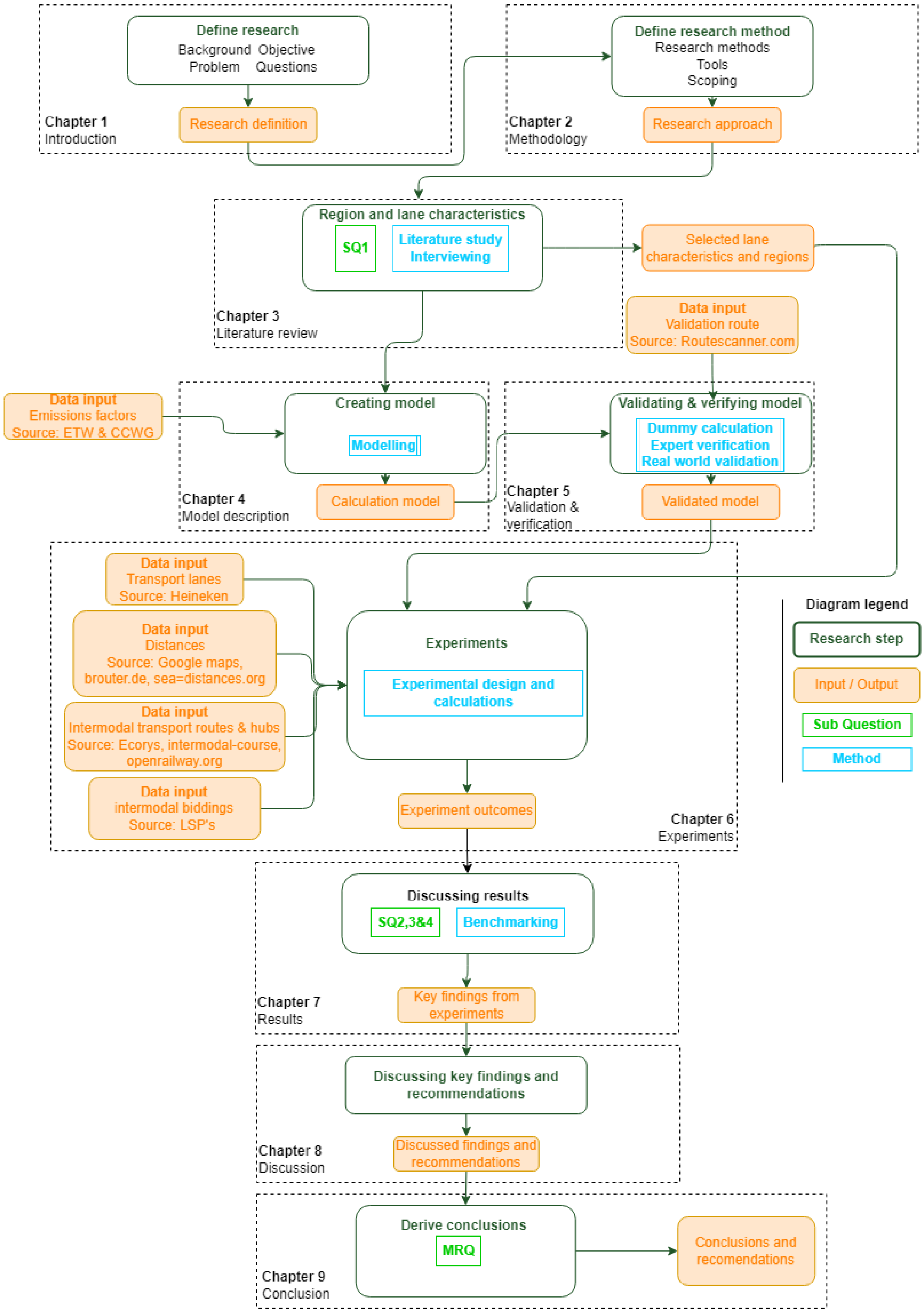


Figure 2.1: Research flow diagram

3
Literature review

In this chapter the relevant literature will be examined. This is done to better understand the problem of implementing intermodal transport. There will be looked at which researches have been done on the topic and if there are examples of implementations. After the literature review on intermodal transport, a section on Heineken's current way of logistics will be presented. Hereafter, knowledge gaps will become known and research questions can be formulated. In section 3.1 the search methodology of the literature review is described. Hereafter, in section 3.2 the findings of the literature review on intermodal transport is presented. Then, in section 3.3, the current state of Heineken and its logistics is described.

3.1. Search query

A framework will be followed to find the right literature and come up with the current state of art and knowledge gaps still to be filled. The main scientific database that is used is Scopus because of its certainty of peer-reviewed journals and articles. Also, Scopus is specialised in applied public policy which corresponds with the topic. Furthermore, various search terms are used to find relevant scientific literature as noted below:

- (intermodal OR multimodal OR synchromodal OR co-modal)
- (intermodal OR multimodal OR synchromodal OR co-modal) AND (transport OR logistics OR transportation OR shipping)
- (intermodal OR multimodal OR synchromodal OR co-modal) AND (Heineken OR subsid* OR models OR calculation*)

As different synonyms for intermodal such as multimodal, synchromodal and co-modal are used these are also all included in the search terms. In addition to the query, the snowball method was used to find relevant articles based on the articles from the earlier search results. For all outcomes, the selection of the best papers was based on a preference for papers with high citations over papers with few or no citations. Furthermore, some grey literature will be examined such as Heineken reports, (inter)national regulations and other theses in order to make up the whole picture.

3.2. State of the art intermodal transport

To order the findings from the literature review, multiple questions are formulated. The questions include: What is intermodal transport? Why use intermodal transport? When is intermodal transport interesting? and How to compare transport emissions? For the full literature review, see **??**

3.2.1. What is intermodal transport?

As Ishfaq (2013) states, on many occasions road transportation has been the most used mode of freight transportation, as it offers better performance, better transit times, and the tariffs are competitive compared to other modes. The same applies to Heineken, where road transport is the preferred mode. Nevertheless, the increase in freight transported by this method has also led to system overloads, as well as numerous accidents during transit, damage to goods, waiting costs and most important damage to the environment (Vannieuwenhuyse et al., 2003).

All of these mentioned negative side-effects can be countered by using intermodal transport. But what is intermodal transport? Intermodal transport, is the use of different types of transport modes that are involved in the transport process of commodities and/or passengers (Li et al., 2013). Intermodal transport is typically focused on surface transport including, roads, railways and waterways as shown in figure 3.1. In addition, there is also some work done to make air transport an alternative option in intermodal transport. However, this option is not considered further in this research due to its large negative environmental impact.

(a) Barge (b) Truck

(c) Rail (d) Short-sea

Figure 3.1: The modes of intermodal transport

Figure 1.1, in the introduction, illustrates the difference between conventional truck transport and an intermodal alternative. Both have the same point of origin and destination, but naturally the route in between differs. Conventional trucking goes straight from origin to destination, sometimes with a rest period in between, depending on the distance. In the intermodal alternative, most of the journey is done by rail, barge or short sea shipping. The part of the journey here-before and after this is called the 'first-' and 'last mile'. Although this first and last mile is still carried by a conventional truck, the majority of the journey is carried by a lower-emission intermodal transport mode. An important possible downside here is the possible additional lead time of the intermodal alternative from transshipment at the intermodal hubs and the waiting time there for the next mode of transport.

Furthermore, in the literature there are some disagreements on the correct term for intermodal transport. Harris, Wang, and Wang (2015) conclude that intermodal transportation is often used as a synonym for terms such as multimodal, co-modal and synchromodal transportation. However, there are subtle differences between these terms. Multi-modal is considered to be a type of transportation that uses at least two different types of transport, intermodal can be seen as a particular type of multi-modal transportation that uses the same loading unit, while co-modal adds the various modes' efficient use of resource utilisation, and synchro-modal lays stress on real-time transportation. However, for the remainder of this thesis, the term intermodal will be used for all of the above concepts.

3.2.2. Why use intermodal transport?

Looking at the use of intermodal transport for freight transport is interesting because of multiple reasons. First of all, road–rail intermodality has high potential for alleviating the congestion of the road mode by moving large volumes of freight (Bierwirth et al., 2012), reducing greenhouse gas emissions (Bauer et al., 2010) and boosting performance significantly through economy of scale improvements (Meisel et al., 2013). A 2011 proposal by the European commission also sees that intermodal transport can help reduce emissions (European Commission, 2011). To do so, they made investments in the international train network and transshipment ports. Regulations were also simplified to accommodate intermodal transport.

When looking at the different kinds of intermodal transport, the sea–rail option can be recommended for the movement of bulk goods, especially when the freight unit cannot be standardised, due to the system's flexibility for transportation and low costs (Beresford et al., 2011). Zhang et al. (2022) looked into rail-water transport and made a data envelopment analysis (DEA) model in order to evaluate carbon emission efficiency of intermodal transport. The focus of the research is specific on rail-short-sea transport related to 14 ports in China. Although the study is conducted in china, it shows that reductions can be made in many ports in terms of carbon emissions through intermodal transport.

The effectiveness of road–barge option is highly sensitive to any changes in the amount of freight to be transported and the capacity of each mode's vehicles and intermodal terminals (Özpeynirci et al., 2014; Vannieuwenhuyse et al., 2003). Kaack et al. (2018) also mention in their paper little is yet known about possible carbon reduction using inland water transport because of the lack of data and research.

For road-rail usage, the research of Craig et al. (2013) shows results that indicate an average reduction of 67g of CO2 per ton-mile, however it can vary between 29 and 220g of CO2 per ton-mile depending on the specific origin-destination lane.

As mentioned before, at the moment, road transport is the main mode of transport used by Heineken. As the literature suggests, intermodal transport could help to improve carbon reduction and achieve their net zero logistics goals. However, less is known within Heineken about where opportunities are to expand their use of intermodal transport, how much it would cost and what the exact reductions would be resulting in the knowledge gaps of this research.

3.2.3. When is intermodal transport interesting?

However, cost remains the biggest driver of choice for businesses. So Meers et al. (2014) looked into the influence of different factors on the break-even distance for intermodal transport. For instance, the characteristics of national infrastructures; regional market conditions and volumes. First they did a literature review which found that break-even distances widely vary because of the aforementioned factors but also the definition of the measurement method and the specific case on which they applied their method. The article also presents their own quantification of break-even distances for both rail transport as inland water transport. It follows that rail transport break-even distances are around 300 km if the post-haulage distance is lower than 20 km and 464 km for higher post-haulage distances. Break-even distances for inland water transport are much lower with only 85 km for post-haulage distances of 20 km. However, when looking at the possibilities of intermodal transport via inland waterways or short sea, Kaack et al. (2018) describe that too little is known yet about possible carbon reduction. The most difficult data to obtain are on inland waterways and short sea transport because of its region-dependency so described.

Zgonc et al. (2019) also looked at the break-even point for intermodal transport. The results confirm the importance of distance for the mode choice and show there is not only one but in fact many break-even distances between the two options. One of the mentioned determining characteristics is the weight/volume ratio. However for Heineken this isn't a problem because the shape of finished product goods allows for full container shipments. This leaves shipment numbers and distance as determining factors. For the intermodal transport network, the average total costs fall at a decreasing rate as the quantity of loads rises, indicating economies of scale; in the road transport network they are constant. Despite the relatively short drayage (The first and last part of transportation by truck) distance compared to rail haul, drayage accounts for 25–40% of origin-to-destination expenses and thus greatly affects intermodal transport's competitiveness. The break-even distances between intermodal rail-road and unimodal road transport in two-sided drayage areas are estimated to lie in the interval from 104 km to 1143 km, with average break-even distances estimated to be at 578, 605 or 640 km.

3.2.4. How to compare transport emissions?

In order to compare intermodal transport options with current road transport, emissions should be measured as accurately and comparably as possible. After the Paris agreement, over 140 calculation methods and tools have come forward on the basis of individual initiatives to calculate and report the environmental impact of logistics operations. However, these methods are lacking in various ways by either focusing on a specific region, not specialising in transport in particular, only providing high-level guidelines or not being entirely comprehensive. In an effort to deal with the challenges of current Green House Gas accounting practices, the GLEC framework has been developed to create a universal framework for calculating logistics emissions by integrating existing methods and tools. It covers all important ingredients for evolving methods by focusing specifically on transport, covering all transport modes, having full regional applicability and incorporating the entire transport chain. After a research of Stevens (2018) Heineken embraced this accounting framework in order to report and calculate their (future) emissions.

The Global Logistics Emissions Council (GLEC) (Smart Freight Centre and partners, 2021) is a voluntary membership of more than 100 companies, industry associations and green freight programs, backed by experts, governments, and other stakeholders with a wide range of levels of engagement. GLEC's mission is to establish and implement global, harmonised guidelines for calculating and reporting logistics emissions and enhancing efficiency across global logistics supply chains with education. The Framework is accredited as being aligned with the Greenhouse Gas Protocol. The GLEC Framework describes how to calculate and report emissions in a detailed way. It looks at mode of transport, transshipment emissions, type of energy carrier and country/region-specific characteristics such as efficiencies or energy mix. In this way, overall emissions can be calculated as accurately as possible.

On the quest to further optimise and combine (intermodal) transport networks, Ecorys introduced a intermodal links dashboard and route planner (Ecorys, 2013). The online planner focuses on combining container schedule data of different carriers and operators to optimise container routes either for lowest emissions, earliest arrival time or shortest lead time. The intermodal links planner is covering short-sea, rail and barge. Giving the exact distances and time of transport. The data behind the engine can be used to calculate and compare with road transport and its related carbon emissions. Ecorys' planner can also be used to get in touch with the proposed Logistical Service Providers. Another website providing the same features is Routescanner (2022). The websites differ in their affiliated logistics partners.

When comparing the modes of transport, it is important to also include the additional costs and emissions associated with a mode of transport. Instead of the conventional way with truck transport where there is only loading and unloading. With intermodal transport, 1 or 2 transshipment's have to be made in between (Ricci, 2003) and thus be accounted for. The costs and emissions for the loading and unloading do not have to be included in the comparison because they are done in both alternatives.

3.3. Current state Heineken

3.3.1. Background on The Heineken Company

Heineken, a renowned Dutch brewing company founded in 1864, is a global leader in the beer industry. Known for its flagship beer brand, Heineken Lager, the company operates through multiple subsidiaries and divisions. Within the Netherlands, there are three entities: Heineken Netherlands, Heineken Netherlands Supply, and Heineken Global.

Heineken Netherlands is responsible for managing activities in the Netherlands, focusing on marketing and distributing a range of beer brands to meet local consumer preferences. Heineken Netherlands Supply handles logistics and production, ensuring efficient distribution nationally and for export. It plays a crucial role in maintaining the supply chain.

Heineken has a vast global presence, operating in over 190 countries. It offers a diverse portfolio of beer brands, including Heineken, Amstel, Desperados, Tiger, and Strongbow. Heineken's global division coordinates international strategies, ensuring consistent brand positioning, quality control, and market expansion across regions. In 2022 Heineken sold 256.9 million hecto liters of product world wide of which 15% in the Africa, Middle-eastern & Eastern Europe, 34% in North and South America, 19% in Asia-Pacific and 32% in Europe (The Heineken Company, 2022). Heineken owns 265 Breweries in 93 countries, producing most of the beer for their domestic markets. However, some exemptions are made, for instance the US market which doesn't produce Heineken themselves but imports it from the Netherlands for historic and marketing reasons.

3.3.2. Logistic operations

Within the value chain of Heineken there are logistic operations in multiple stages. Starting with the inbound transport of either raw materials for the production process or packaging materials. Furthermore, there is inter brewery / external warehouse transport, this is transport of finished goods to other warehouses and/or breweries owned by the company. Primary distribution then is the transport of finished goods to customers (distributor, wholesalers, retailers etc.), whereas secondary distribution is the transport of finished goods to the hospitality industry. Secondary distribution is mostly outsourced to other companies (such as Sligro in the Netherlands) with a few exceptions in countries. A visual overview of Heineken's logistical operations is shown in figure 3.2

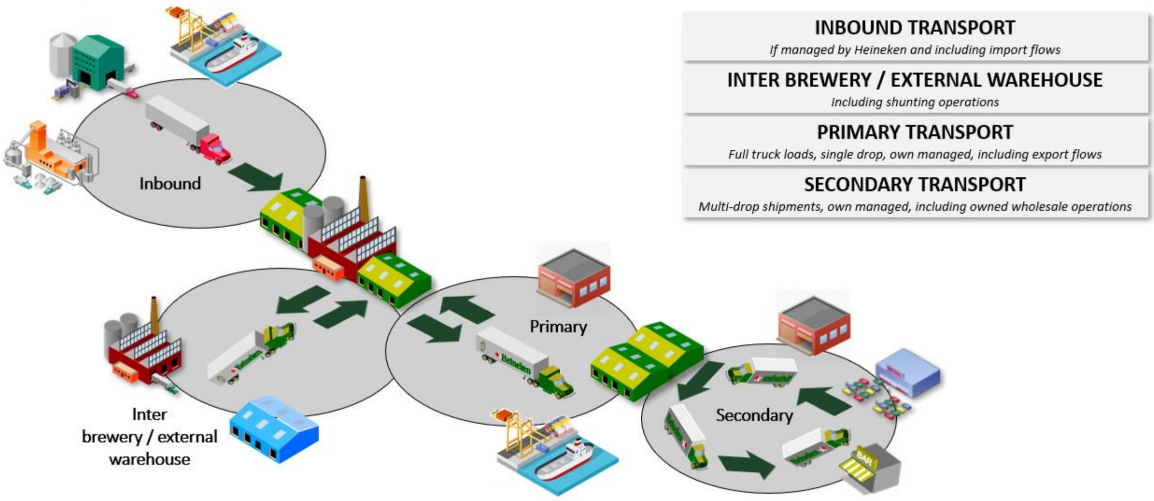


Figure 3.2: Heineken's Logistical operations

The transportation of the goods within Heineken is primarily coordinated at a national level, relying on subcontractors known as Local Service Providers (LSPs) for the majority of the transport operations, although there are a few exceptions. These LSPs manage the end-to-end transport process, from the delivery of the container, collection at the point of origin, the entire transport by one or more modalities, to delivery at the final destination. The reason for Heineken's national focus in logistics is that, in the past, Heineken has bought national breweries in order to expand its operations and distribute its own brands in the country through the acquired distribution network. Each of Heineken's Operating Companies (OpCos) is responsible for independently organising transport within their respective countries, separate from the global office in the Netherlands. Recurring transport from origin to destination is referred to as a transport lanes. The shipments transported through these lanes encompass a wide range of contents, including inbound raw materials and packaging, empty (returnable) packaging, bulk beer, and finished products. The frequency, distance and volume of these lanes vary individually. Logistics service buyers at the national and global office handle these cases and initiate a tendering process where LSPs can bid for the offered lane. This approach allows for competitive pricing and selection of suitable LSPs. For larger lanes, covering several countries or involving higher volumes and/or frequencies, the global office takes over. In Europe, for example, the global office is responsible for a total of 1300 lanes. While some of these lanes (being it short segments) have already adopted intermodal transport to a limited extent, it's worth noting that out of these 1300 lanes in Europe, 1000 still rely exclusively on road transport [1].

[1]Retrieved from internal communications

Another consideration in the switch to intermodal transport is the impact of container free-time. Free-time refers to the allowed period for container loading, unloading, and return without additional charges. Heineken, like other companies, try to operate within these time constraints to reduce costs.

Intermodal transport often involves longer transit times compared to conventional truck transport due to factors like transfers, terminal handling, and coordination. This extended duration is influenced by the need to coordinate multiple modes of transportation.

However, the increased time involved in intermodal transport should not pose a problem for Heineken's receiving OpCo or customers. With advance planning and adjustments, the longer transit times can be accommodated. By incorporating expected delays into operational plans, Heineken and stakeholders can effectively manage the intermodal process and ensure timely deliveries.

Proactive logistics and supply chain planning, coupled with communication and collaboration, allow Heineken to minimise disruptions and maintain smooth operations. Aligning expectations and making necessary adjustments with OpCos and customers enables them to adapt to extended transport duration.

3.3.3. Ways of transport

As mentioned above, Heineken's shipments include a variety of contents such as (raw) materials, empty packaging, bulk beer and finished products. These consignments are transported using a variety of transport equipment, including Low Duty Vehicle, Rigid Truck, Semi-Trailer, Double Trailer or in the case of intermodal transport and/or sea-transport, a container. This equipment can vary in size and have specific characteristics such as: loading method, fuel type and maximum payload. Depending on the chosen mode of transport and the contents of the shipment, one of these means of transport will be chosen in agreement with the LSP. However the finished product and flavour of beer can be influenced by sun and/or temperature, transport is only occasionally adjusted to this. A so-called reefer, a refrigerated container, can be used to maintain the temperature. However, this is only done in extreme cases such as in southern Europe and Mexico during some periods in the summer months, or in cold environments such as Kazakhstan or middle Canada in the winter to prevent the beer from freezing. In addition, facilities that ship finished products are always enclosed to keep out the sun.

4

Model Description

This chapter describes how the calculation model will be set up. It is structured into multiple sections with the support of an example calculation. The example case used is first illustrated in section 4.1 to support the remainder of the chapter. The first calculation step is to examine the method used to calculate current emissions from road transport. This is done in section 4.2. Then in section 4.3 the emissions from intermodal transport are calculated. How this is done depends heavily on the data available. Therefore three methods have been developed. Each method describes how the data can be used for calculations. In section 4.4 it is explained how the comparison between emissions, time and costs of road and intermodal transport is calculated. Finally, section 4.5 shows an input data flowchart to support on which input data sources are needed for the model based on the availability of data.

4.1. Example case

In this section, we present an example case a transport line for Heineken randomly generated by an AI tool. The transport line originates from the Heineken brewery in Zoeterwoude, Netherlands, and the destination is the Heineken brewery in Madrid, Spain. The transport line is responsible for delivering Heineken beer from the brewery in Zoeterwoude, with the postcode 2382, to the brewery in Madrid, with postcode 28053, where it is then distributed to various locations throughout Spain. The transport line makes 100 trips per year, and we will use this fictional case to demonstrate how to calculate the carbon emissions associated with the transport line. The information of the fictional transport lane is summarised in table 4.1

Table 4.1: Example calculation case

Variable	**Input**
Origin Country	Netherlands
Origin postal code	2382
Origin City	Zoeterwoude
Destination Country	Spain
Destination postal code	28053
Destination City	Madrid
Frequency	100 trips

4.2. Trucking emissions

This section presents the method used to calculate current emissions from road freight transport. This figure will later be used as a bench-marking reference. Firstly, the necessary input data are described and then the calculation formulas are presented.

4.2.1. Input data

To do the calculations, input data is needed first. For the calculations of the truck emissions a combination of logistical information about the transport lanes and emission factors will be used.

Logistical information

This data is available from Heineken and is also used for the tenders that LSPs can bid for. This is either information about the transport lanes for the coming or past year. Table 4.2 shows the required input variables.

Table 4.2: Model input values

Input variable	**Symbol**	**Unit**
Item name	ID	String
Origin country	O_{co}	String
Origin postal code	O_{pc}	String
Origin city	O_{ci}	String
Destination country	D_{co}	String
Destination postal code	D_{pc}	String
Destination city	D_{ci}	String
Maximum transit time	t_{max}	Days
Estimated trips per year	f	#
Max. Payload	m	kg
Costs	C	Euro

The calculations later include some intermediate variables to arrive at the final outcome. For clarification, these are shown in table 4.3.

Table 4.3: Model intermediate values

Intermediate variable	**Symbol**	**Unit**
Distance truck	d_{truck}	km
Distance per country	$d_{truck,i}$	km
Trip emissions truck	$E_{truck,trip}$	kg CO2eq
Total emissions truck	$E_{truck,year}$	kg CO2eq
Emission factor truck	EF_{truck}	kg CO2eq /km

Emission factors

In addition to logistical information about Heineken's transport routes, data is needed to determine emissions. Emission factors from EWI are used for this purpose (EWI, 2022). As mentioned earlier, these values have been verified by GLEC and meet all reporting requirements. The emission factors have been measured for different modalities and determined for countries all over the world. The data provided is differentiated by modality, size, type and generation of power source, fuel and country. Where data was not available for a country, the value from an equivalent country was used. The emission factors are also available in different output forms. In this study, the 100% load well-to-wheel (WTW) value is used. Well-to-wheel is a method of assessing the efficiency and emissions of an energy source by considering its entire life cycle. It is the most complete and accurate way to measure energy consumption and greenhouse gas emissions. In addition, the 100% truckload figure is used because Heineken has been very strict and successful about utilisation projects that reduce both emissions and costs. In addition, the characteristics of the product to be transported have a high density and the trucks can therefore easily be loaded up to 100% weight utilisation. Therefore is assumed that truckloads are 100%.

The emission factors are then further simplified within Heineken itself. The type and generation of power source is generalised by taking the statistical mode of the fleet and using the emission factor of that type. This results in one emission factor per country per modality, fuel and payload. The fuel types used in the remainder of this study are diesel and electricity. Diesel is the most commonly used type of fuel for freight vehicles, while electricity is seen as the clean alternative for the future. Both emission factors are used in this study to explore scenarios. In order to make a representative comparison between truck and intermodal, it was decided in this study to take the truck type with a payload of 20-26 tonnes. This is comparable to the payload of a 40ft. container. But, if available, other emission factors for different truck payloads can be used. The emission factors determined can be found in appendix A.

4.2.2. Calculations

The first step in the calculation step is to obtain the distances travelled by truck. For this step, route planners such as Google Maps or an integrated Google Maps API in e.g. Excel can be used. The truck distance is based on the input variables for origin and destination as seen below.

$$\sum_{n=1}^{\infty} d_{truck}(O_{co}, O_{pc}, O_{ci}, D_{co}, D_{pc}, D_{ci})$$
$$\sum_{n=1}^{\infty} d_{truck} = 114 + 122 + 1033 + 472 = 1741\ km \tag{4.1}$$

With this information, Google Maps can give figures in kilometres for the distance travelled by the truck. Another number required is the distance travelled by a truck in each country, which can be estimated as a proportion of the total or given as an exact number. This number can then be used to calculate emissions using the emission factors specified per country.

$$E_{truck,\,trip} = \sum_{i=co}^{\infty} d_{truck,\,i} * EF_{truck}(m,\ i)$$
$$E_{truck,\,trip} = 114 * 1.279 + 122 * 1.501 + 1033 * 1.277 + 472 * 1.295 = 2259.4\ kg\ CO2eq \tag{4.2}$$

As can be seen from the formula above, the total emissions per trip are formulated as the sum of the proportional distance of the trip multiplied by the emission factor of the corresponding country crossed. The outcome for emissions per trip can then be used to calculate the annual emissions of the transport route by multiplying with the number of trips per year.

$$E_{truck,\,year} = E_{truck,\,trip} * f$$
$$E_{truck,\,year} = 2259.4 * 100 = 225.9\ t\ CO2eq \tag{4.3}$$

4.3. Intermodal emissions

This section outlines the methodology employed to calculate emissions from intermodal transportation options. It is important to note that the availability of data can vary and impact the method used. Specifically, the data accessible for intermodal options differs across regions, with some having information on loading points, debarking, travel time, and mode of transport. Meanwhile, other regions only have knowledge of the location of intermodal hubs. In some areas, data is even more scarce, requiring assumptions based on internet databases. The accuracy of the input data and therefore the outcome of the calculations are influenced by these varied methods. Firstly, the required input data will be outlined followed by the presentation of the calculation formulae.

4.3.1. Input data

To start, the same input data is used as described in section 4.2 as the info on the transport lanes to be replaced is the same. The additional data needed for this step is coming from an external databases if available. The needed information for the calculations is described in table 4.4, additional intermediate variables used in the calculations are shown in table 4.5.

Intermodal data

Ideally, objective data is obtainable regarding various intermodal alternatives to replace current transport routes. This information can be sourced from LSPs through tender bids or from a more generic database such as those provided by Ecorys or Routescanner. This information includes modalities,

Table 4.4: Intermodal input values

Input variable	Symbol	Unit
Point of loading	P_l	String
Point of debarking	P_d	String
Travel time	T	Days
Modality	M	String
Transship emission	E_t	kg CO2eq
Transshipments	t	#
Rail electrification	E_r	% Elec.

Table 4.5: Intermodal intermediate values

Intermediate variable	Symbol	Unit
Distance per modality&country	$d_{M,i}$	km
Distance first mile	d_{fm}	km
Distance last mile	d_{lm}	km
Emission factor	EF	kg CO2eq / km
Trip emissions modality	E_M	kg CO2eq
Trip emissions first mile	E_{fm}	kg CO2eq
Trip emissions last mile	E_{lm}	kg CO2eq
Trip emissions intermodal	$E_{im,trip}$	kg CO2eq
Total emissions intermodal	$E_{im,year}$	kg CO2eq

loading and unloading locations, weekly frequency and lead time. Moreover, in cases of LSP bids, pricing is also accessible. This study uses Ecorys' 2019 European intermodal database to validate the methodology and to make statements about intermodal comparisons. As the database is obsolete, the data is made available for research purposes.

If precise data on intermodal options is not available, the available information on a country's intermodal transshipment hubs can be considered. This approach assumes the existence of an intermodal connection between these hubs. In addition, precise information on travel times and costs for these regions is not available and will be determined in a different way. Data from the Intermodal Association North America database Intermodal Association North America et al. (n.d.) will be used in this study. This information is provided by Professor dr. ir. A. Verbraeck, and filtered to show the closest (in straight line distance) intermodal hub to the origins and destinations of Heineken's transport routes in the United States. However, an interactive map can be found on IANA's website to locate all other intermodal hubs in North America. As there are no inland waterway options in the US, the intermodal hubs are limited to rail transportation only.

Finally, if there is no database with information on intermodal hubs in a country, information from national websites combined with data on logistics infrastructure can be used. In this study, OpenRailwayMap.org is used. This website uses the open source Openstreetmap data and only shows railway lines. This can be used to identify opportunities for intermodal transport by rail. A similar option does not exist for inland waterways and is therefore not included in the study.

Intermodal emission factors

Another set of input data required for the calculations are again the emission factors from the EWI but also from the CCWG for sea-freight (CCWG, 2023; EWI, 2022). The only difference is that the factors for rail, inland waterways and short sea shipping are used. The same 100% load WTW value is used. Heineken has also further simplified the emission factors for generation vehicle and type of energy source based on the statistical mode of the fleet. In this study, the figure for 40-foot containers is used throughout the rest of the experiments and results. The factors can be found in appendix A.

Distribution rail propulsion

Rail transportation uses two different fuels: Diesel and electricity. However, it is difficult to determine which fuel is in use beforehand. Such information has to be determined region by region and may not always be clear. For instance, in the US, Diesel is used for all rail transportation, as there are no electrified lines. In Europe, on the other hand, a significant amount is electrified, but not all. Therefore, a determination of the appropriate (fractional) emission factor value must be made. This is done based on the amount of electrified rail compared to the total length of rail in a country. These numbers can be found for Europe on the Eurostat Data website 2023. For electric propulsion, we will utilise the emission factor for electricity that aligns with the national power generation, as we will not assume 100% renewable electricity.

Intermodal distances

One of the difficulties of calculating emissions of intermodal transport is determining the distance travelled using the intermodal mode. In order to obtain this figure two different websites are used. If train or barge transport is used, the website brouter.de can be used. This website has a built-in route optimiser based on openstreetmap data. The difference to other route optimisers it is also functional for rail and inland waterways and therefore suitable for this study. When the short-sea modality is used, another website can be useful, being app.searoutes.com. This website gives the distances from port to port in kilometres, with any circumnavigation routes included.

Transshipment emissions

In order to take into account the additional emissions associated with transshipment between modes, data on this should also be available. A joint study by - Fraunhofer IML, Politecnico di Milano, GreenRouter and Universidad de los Andes - has looked at three years of transshipment data to see what can be assumed for each transshipment (Kerstin et al., 2023). These figures also include emissions from local transport, embarkation and disembarkation processes and equipment, providing a holistic picture of environmental impact. According to the GLEC framework, these individual figures can be added to the emissions of the entire intermodal journey and help to accurately compare trucking and intermodal options (Smart Freight Centre and partners, 2021). For an inland terminal this results in an emission of 38 kg CO2eq/TEU, for the 40ft container used in this study this results in 76 kg CO2eq per transshipment.

4.3.2. Calculations

The first step in determining intermodal emissions is to find a suitable intermodal option from the available database. This choice is made on the basis of the shortest possible distance for the first and last mile together. From the option where this is the case, the information can be used as input data (as shown in table 4.4) for the next steps. This input data can be used to calculate the distance for the intermodal part of the journey using the earlier mentioned websites. Based on the distance and given modality the emissions can be calculated as seen in equation (4.4a) for short-sea and barg and equation (4.4c) for rail.

$$E_M = \sum_{i=co}^{\infty} d_{M,i} * EF_{im}(M,\ i) \tag{4.4a}$$

$$E_{M=r} = \sum_{i=co}^{\infty} d_{M=r,i} * (EF_{im,\,elec}(M=r,\ i) * E_r + EF_{im,\,diesel}(M=r,\ i) * (1-E_r)) \tag{4.4b}$$

$$\begin{split} E_{M=r} = 139 * (0.114 * 86.57\% + 0.538 * (1-86.57)) + 1014 * (0.06 * 59.33\% + 0.538 * \\ (1-59.33\%)) + 579.9 * (0.25 * 64.05\% + 0.538 * (1-64.05\%)) = 486.6\ kg\ CO2eq \end{split} \tag{4.4c}$$

The next step is to determine the emissions for the first and last mile. Based on the point of loading and debarking the distance can be determined using a conventional route planner such as google maps. The emission equation will then be the same as in equations (4.1) and (4.2).

$$\sum_{n=1}^{\infty} d_{fm}(O_{co}, O_{pc}, O_{ci}, P_l)$$
$$\sum_{n=1}^{\infty} d_{fm} = 114 + 20 = 134\ km \tag{4.5a}$$

$$\sum_{n=1}^{\infty} d_{lm}(P_D, D_{co}, D_{pc}, D_{ci})$$
$$\sum_{n=1}^{\infty} d_{lm} = 4.1\ km \tag{4.5b}$$

$$E_{fm} = \sum_{i=co}^{\infty} d_{fm,\,i} * EF_{truck}(m,\ i)$$
$$E_{fm} = 114 * 1.279 + 20{*}1.501 = 175.8\ kg\ CO2eq \tag{4.6a}$$

$$E_{lm} = \sum_{i=co}^{\infty} d_{lm,\,i} * EF_{truck}(m,\ i)$$
$$E_{lm} = 4.1 * 1.295 = 5.3\ kg\ CO2eq \tag{4.6b}$$

Using the values from (4.4), (4.5) and (4.6), along with the emissions from transshipment, we can calculate the total emissions for each intermodal trip and annually.

$$E_{im,\,trip} = E_{fm} + E_{lm} + E_M + E_t * t$$
$$E_{im,\,trip} = 175.8 + 5.3 + 486.6 + 76 * 2 = 819.8\ kg\ CO2eq \tag{4.7}$$

$$E_{im,\,year} = E_{im,\,trip} * f$$
$$E_{im,\,year} = 819.8 * 100 = 82.0\ t\ CO2eq \tag{4.8}$$

4.4. Comparison

This section explains the comparison between freight transport and the intermodal alternative. This is done in three areas: emissions, cost and lead time.

4.4.1. Emissions

Based on the calculations made in the previous chapters, it is easy to compare the emissions. It is chosen to compare annual emissions in order to better compare the overall impact of the alternative with other transport lines. To obtain the annual reductions the following equation is formulated:

$$\delta E = E_{im,\,year} - E_{truck,\,year}$$
$$\delta E = 82.0 - 225.9 = -144\ t\ CO2eq \tag{4.9}$$

If δE is negative, the outcome shows possible emission reductions using the intermodal alternative. With a positive value, no reductions of emissions can be achieved using the intermodal option.

4.4.2. Costs

When making the comparison for costs it is also needed to make an distinction based on the availability of data. The Benchmarking costs for trucking can be obtained based on the 2023 tender allocation information. For some regions a pre-tender can be executed focused on intermodal options. In this pre-tender, LSP's can quote a price in advance. This price can be used to compare with the trucking price of last years tender.

$$\delta C = C_{im,\,year} - C_{truck,\,year}$$
$$\delta C = 187.565,03 - 180.000,00 = € - 7.565.03 \tag{4.10}$$

Again, If δC is negative, the outcome indicates cost reductions using the intermodal alternative and positive difference vice versa.

When data is unavailable from a pre-tender, online databases can provide useful information. For instance, this study utilised the database for the online intermodal course (Intermodal Association North America et al., n.d.). The intermodal course website provides Q1 2023 prices for local truck rates per mile and the total cost of intermodal journeys. An indication of intermodal costs per mile can be given based on the specified distances of the intermodal part. Converted these result in 1.86 €/km for trucking and 0.95€/km for intermodal transport. These rates (r) can be converted to kilometres for use in equations (4.11).

$$C_{fm} = d_{fm} * r_{truck}(m,\, i)$$
$$C_{fm} = 134{*}1.68 = €225.12 \tag{4.11a}$$

$$C_{lm} = d_{lm} * r_{truck}(m,\, i)$$
$$C_{lm} = 4.1{*}1.68 = €6.89 \tag{4.11b}$$

$$C_M = d_M * r_M(i)$$
$$C_M = 138.1 * 0.95 = €1,643.31 \tag{4.11c}$$

$$C_{im,\,trip} = C_{fm} + C_{lm} + C_M$$
$$C_{im,\,trip} = 225.12 + 6.89 + 1.643.31 = €1.875,31 \tag{4.12}$$

$$C_{im,\,year} = C_{im,\,trip} * f$$
$$C_{im,\,year} = 1.875,31 * 100 = €187.565,03 \tag{4.13}$$

The outcome of equation (4.13) can then again be filled into equation (4.10) to compare emissions between trucking and the intermodal alternative.

4.4.3. Lead time

Finally, in relation to lead time, it needs to be acknowledged that these outcomes are less precise than those of emissions or costs. The transit time between different modes of transportation is heavily reliant on their respective timetables. There may be a delay of several days or even a week before the next modality departs, similar to having to wait for a train to depart. The successive scheduling of one mode to the next is hard to determine with the available information. Therefore, this comparison will assume a minimum lead time based on the average travel speeds and dwell times. The lead times' outcomes are also presented in days as it is the standard unit of measurement that accounts for the variability in transport speeds.

The lead time for the trucking option is determined by the regulated maximum distance truck drivers can travel per day. In the United States, this distance is limited to 11 hours, which equates to 500 miles or 804 kilometres per day (Beckmann, n.d.). In the European Union, a maximum driving time of 9 hours is enforced instead of the 11 in the US (European Commission, 2006). Assuming the same average speed as in the US, this results in a maximum of 657 kilometres per day. The local legislation in Nigeria, which is used as a reference for Africa, sets a maximum of 10 hours, which results in a maximum distance of 730 kilometres (Idoko Nicholas, 2023). Any distance figure exceeding a multiple of this thresholds, denoted as γ in the calculations, will result in an additional travel day.

Table 4.6: Maximum trucking distances

Region	Maximum distance (km/day) [γ]
Africa	730
United States	805
Europe	657

$$T_{truck} = ceil(\frac{d_{truck}}{\gamma})$$
$$T_{truck} = ceil(\frac{1741}{657}) = 3\ days \tag{4.14}$$

When examining the lead-time of the intermodal option, it is necessary to consider additional factors. The first and last mile are calculated according to the same method as for the truck option, with a minimum of 1 day for the first and last mile.

$$T_{im,\,truck} = ceil(\frac{d_{fm} + d_{lm}}{\gamma})$$
$$T_{im,\,truck} = ceil(\frac{134 + 4.1}{657}) = 1\ day \tag{4.15}$$

In addition, the dwell time, i.e. the time during which the freight is waiting for the next mode of transport, is taken into account at the intermodal hubs where the freight is transshipped. table 4.7 provides the average dwell-times later denoted as τ. For the purposes of this study, South Africa was selected as an illustrative country due to the availability of data. The average dwell time encompasses the unloading process from the initial modality, on-site storage, transportation and subsequent transfer to the following modality.

Table 4.7: Terminal dwell times, source: (Beacon, 2023)

Region	**Dwell time (days) [τ]**
United states	3.7
Europe	5.25
Africa	3.4

$$T_{dwell} = ceil(t * \tau)$$
$$T_{dwell} = ceil(2 * 5.25) = 11\ days \tag{4.16}$$

Subsequently, the duration of transportation via train, barge or ocean vessel is calculated utilising the average speed of the respective modality. The average speeds are provided in table 4.8 and are used to determine the total time required for the entire transportation process. However, the Intermodal database of Europe used in this study also includes travelling times and therefore this step can be skipped for the region of Europe.

Table 4.8: Average speed per modality

Region	**Modality**	**Speed (km/h) [v_{av}]**	**Source**
Africa	Rail	32.5	(African Union, n.d.)
Europe	Rail	50	(d-fine, 2022)
United states	Rail	41.8	(Leonard & Sumida, 2023)
Europe	Barge	15	(Visser et al., n.d.)
Global	Short-sea	35.2	(Ollila et al., 2022)

$$T_M = ceil(\frac{d_M}{v_{av} * 24})$$
$$T_M = ceil(\frac{1732.7}{50 * 24}) = 2\ days \tag{4.17}$$

$$T_{im} = T_{im,\,truck} + T_M + T_{dwell}$$
$$T_{im} = 1 + 2 + 11 = 14 \tag{4.18}$$

$$\delta T = 14 - 3 = 11\ days \tag{4.19}$$

Based on the results of these calculations, an approximate estimation can be made for the lead times of both truck and intermodal transport options as shown in equation (4.19). It's often argued that using intermodal transport results in longer lead times. However, this calculation allows examination as to whether there is indeed any additional lead time, and how much longer it would be. This information can then be used for procuring purposes or as a heads up for implementation if there is a switch to intermodal transport.

4.5. Input data flowchart

In order to clarify which data input are needed to be used a flow chart is generated to support. In figure figure 4.1 can be seen which data input sources can be used for the model to work.

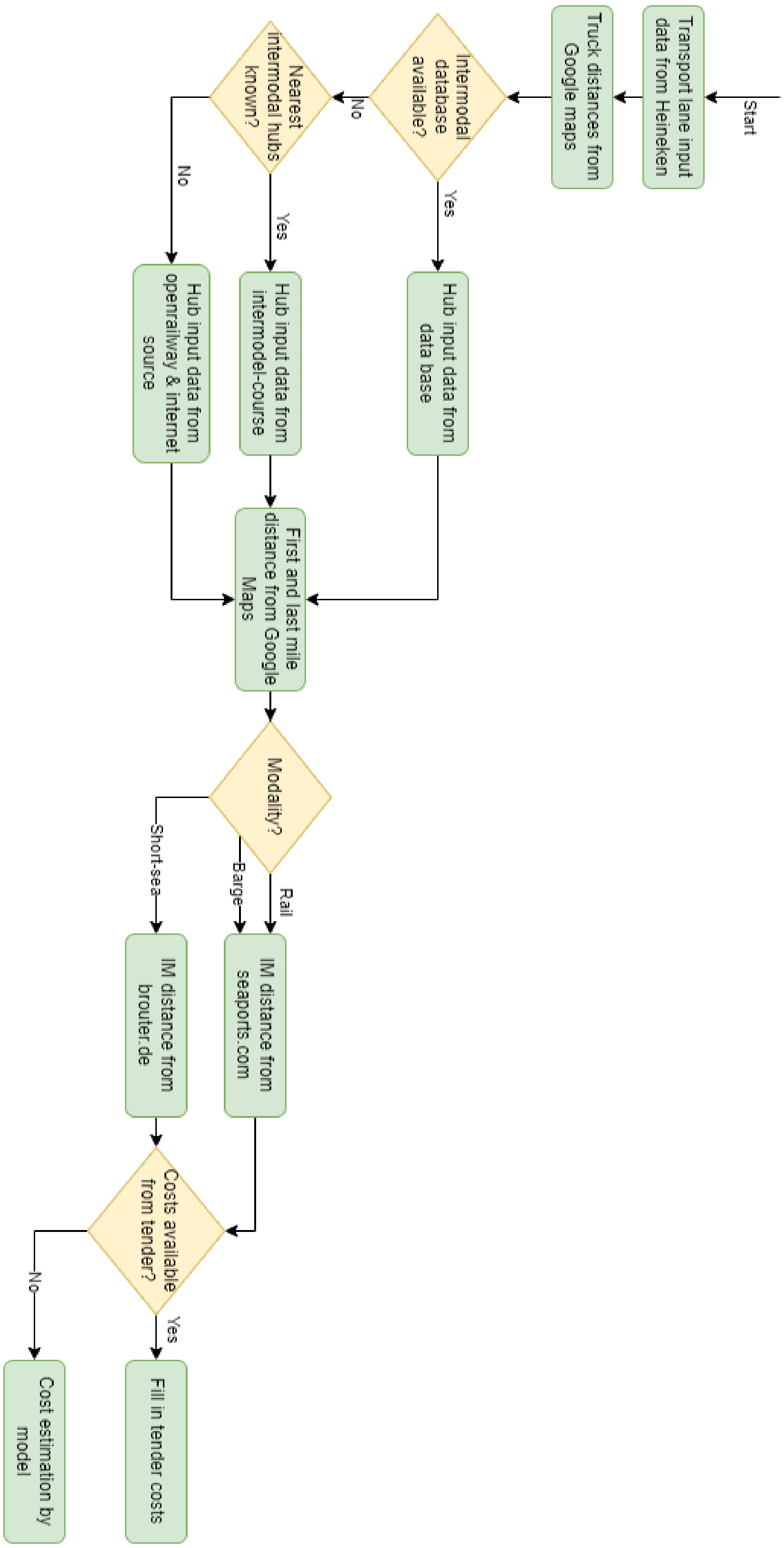


Figure 4.1: Input data flow chart

5
Verification and Validation

In this chapter, the model is verified and validated. Model verification and validation are critical processes in the development and deployment of models. It is done to ensure that a model accurately represents the system it is intended to evaluate and that its performance is reliable and trustworthy. The verification and subsequent the validation of the model is discussed in sections 5.1 and 5.2.

5.1. Verification

Verification involves assessing the mathematical formulations and implementation of the model to ensure that it faithfully represents the underlying principles of the system. The aim of this step is to confirm that the model is free from errors and meets the specified requirements. In this study, the verification will be carried out in two different ways. The first is done by performing a dummy calculation of an example case as described in section 5.1.1. The second form of verification is the discussion of the model with an expert, which is described in section 5.1.1. This is described in section 5.1.2

5.1.1. Example case calculation

In chapter 4 a example case is used to perform so-called dummy calculations. As well as explaining how calculations are performed in the model, it also verifies the performance of the model. By running through the entire model and performing all the calculations, it has been verified that the model works properly. Elaborations of the dummy calculation can be seen in appendix B. The dummy case has been successfully worked out and shows that the model is working as it was designed to and therefore has been verified.

5.1.2. Expert Verification

Another valuable aspect of verification is practical validation through interaction with potential end users. Presenting the model to Heineken's global logistics buyers adds a real-world perspective to the verification process. This step involves gathering feedback on the usability of the model, its ability to compare intermodal alternatives and its effectiveness in supporting the procurement process. This practical validation not only helps to confirm the accuracy of the model, but also assesses its relevance and applicability in the context of users' needs and expectations. Consultations were held with logistics buyers before and during the development of the model. This allowed their needs to be taken into account to ensure the accuracy of the model, but also to support their work after the study had been carried out. The model was adapted where necessary and verified by the buyers.

5.2. Validation

Validation, on the other hand, focuses on determining the extent to which the model's predictions or simulations align with real-world observations or data. It involves comparing the model's output with empirical data to assess its accuracy and reliability. Validation is essential for establishing the credibility of a model and its suitability for making informed decisions or predictions.

The dummy calculation of chapter 4 in the model will be compared with the routescanner.com emissions calculation tool as part of the validation process. Any discrepancies will be analysed alongside the calculation method used by routescanner.com to ascertain whether they indicate significant flaws or limitations in the model.

When applying the same lane inputs as in the example case, routescanner.com suggests the same optional rail route via the terminal in Antwerp. The chosen route is identical to that selected for our dummy calculations, and is thus appropriate for validation. The routescanner.com website provides emissions data per twenty-foot equivalent unit (TEU). To make a valid comparison with the model calculations, which are based on a forty-foot container equivalent (two TEUs), these emissions values must be multiplied by 2. Please refer to table 5.1 for summaries of Routescanner.com and our model results. The full original results from Routescanner.com can be found in appendix C. The comparison of costs is not possible, as Routescanner.com does not provide this information.

Table 5.1: Model validation results in kg/ CO2 eq

	Routescanner.com	**Model**
Total trip emissions	886	819.8
Truck Zoeterwoude - Antwerp	190	175.8
Rail Antwerp - Madrid	610	486.6
Truck Madrid - Madrid	-	5.3
Transshipment	76	152
Reduction per trip	1714	1439.5
Lead-time	4 days	14 days

Upon examining the figures for overall emissions, it becomes apparent that the 886 kg CO2 eq is similar to, and in the same order of magnitude as, the 819 kg CO2 eq calculated by the model. A closer inspection reveals that there is a difference in the emissions for the truck trip, which equates to 190 kg CO2 eq as opposed to 175.8. This variation is explained by the higher emission factors used by Routescanner.com. These emission factors are general for regions, in this case Europe, and therefore less accurate than the emission factors used in the model. Additionally, the same discrepancy can be seen for the emissions of the rail part. This can be explained by the same reasons as for the truck section, but also by the use of both the diesel and electricity emission factors related to the percentage of rail electrification in the model. The truck journey from the terminal to the destination has no emissions for routescanner.com. This is due to the nature of Routescanner, which only allows its users to generate routes to points of interest such as city centres, terminals, or ports. However, as the distance only covers 4.1 kilometres, it will not significantly affect this validation analysis. Consequently, transshipment emissions are twice as high, as the route includes only one transshipment. Besides, the number for a single transshipment is identical because the source is Routescanner.com. Next, the lead times are compared. It is noted that there is a significant difference of 10 days. However, when looking at the details, it can be seen that Routescanner.com does not take dwell time into account. It has only taken into account the transport times for each mode. Without the inclusion of the dwell-time, the transport time is four days, which is consistent with that of routescanner.com. Even though the dwell time (10 days) is responsible for the discrepancy, it may still be worthwhile to investigate and analyse it further. However, upon examining the small and explainable differences, it can be concluded that the model is valid.

6
Experiments

To find out what characteristics of transport lanes have the most impact on the emissions, costs and lead-time, experiments will be done. In this chapter the experimental setup and subsequently the experimental design will be explained. The conducted experiments can be found in appendix D.

6.1. Experimental setup

Based on the findings of the literature review in chapter 3, characteristics are identified that have a potential influence on the emissions, costs and lead times of truck and intermodal transport. In order to identify these influences on Heineken's transport routes, these characteristics will be varied and the resulting results analysed. The analysis of the results will examine distances as a factor alongside emissions, costs, and lead times, providing an explanation for any observed differences. The results of each experiment will be shown as the output in tables 6.1 and 6.2 below.

Table 6.1: Example output distances

Experiment -	
Truck distance:	- km
First/last mile distance:	- km
Intermodal distance:	- km

Table 6.2: Example output

Ex: -	**Emissions t CO2eq**	**Costs EUR**	**Lead-time Days**
Truck	-	€ -	-
Intermodal	-	€ -	-
Difference	-	€ -	-
	-%	-%	-%

6.2. Experimental design

To make valid statement on the influence of lane characteristics on the emissions costs and load-times, a good experimental design has to be made. The characteristics of the examined transport lanes will be varied in a way that the results will show what impact the different configurations have on the outputs.

6.2.1. Lane characteristics

In this section the lane characteristics that will be varied in the experiments will be discussed. The first characteristic that will be varied is the region in which the transport lane is located. The chosen regions within were Heineken operates are: Europe, United States and Africa. These are chosen because of their distinctions of infrastructure. Europe has a wide network of transport infrastructure of road, rail, barge and short-sea options with also access to cleaner electric rail propulsion. The U.S. transport infrastructure only consists of road and rail as there are no options for barge, furthermore arriving goods are already shipped to the closed port as nature of Heineken's logistics for US market. Another difference between the European and U.S. market will be the distances as the US is less dense than Europe. The third region that will be included in the analysis is Africa with Ethiopia to be specific. The options for intermodal are way less extensive as the other two regions with only a few railway lines and no other intermodal options. It will be interesting to see what the scarcity of intermodal options does to the outcomes. Ethiopia is chosen as reference country because this one of the largest markets for Heineken in Africa and specific transport lane information is available.

Besides the different regions, other characteristics will also be looked at, starting with overall distance. For this, low (below 600 km) and high (above 600 km) distances will be taken respectively with the average local transport distances. However, we always work with a minimum distance of above 300 km because before that they are already known to be enviable for intermodal transport as described in chapter 3. Another characteristic to include in the analysis is the distance of origin or destination from a transshipment hub. If a cargo has to take a large diversions by truck to get to a hub, this can affect the emissions, costs and lead time of the entire trip. A final characteristic that will be varied is modality. Here the trade-off is that modalities such as barge and short-sea have lower emission factors but will affect first and last mile distance because of naturally determined locations. As described earlier, only Europe has access to all these modalities so the variation will be varied only for this region. The characteristics that will be varied are summarised in the table below.

Table 6.3: Experiment input variables

Lane characteristic	**Variations**
Region	Europe, U.S., Ethiopia
Lane distance	Low, High
Hub distance	Low, High
Modality (Europe only)	Rail, Barge, Short-sea

Combining the varying lane characteristics and performing the results in 20 configurations. Each configuration will be assessed twice using different user cases resulting in 40 experiments as shown in table 6.4. Associated with each line will be a corresponding transport line from Heineken that matches its characteristics. However, specific details regarding the lines' origin, destination, and frequency will be withheld due to their sensitive nature. For Experiments 12 and 16, no suitable transport route was identified due to the low number of intermodal options in this configuration. Consequently, these experiments are not included in the further analysis. The same problem occurs for the second user case for all lanes in the Africa region, therefore these configurations have only one experiment.

Table 6.4: Experimental design

Ex #	Region	Lane distance	Hub distance	Modality
Ex 1 & 2	Europe	Low	Low	Rail
Ex 3 & 4	Europe	High	Low	Rail
Ex 5 & 6	Europe	Low	High	Rail
Ex 6 & 7	Europe	High	High	Rail
Ex 8 & 9	Europe	Low	Low	Barge
Ex 11 & 12	Europe	High	Low	Barge
Ex 13 & 14	Europe	Low	High	Barge
Ex 15 & 16	Europe	High	High	Barge
Ex 17 & 18	Europe	Low	Low	Short-sea
Ex 19 & 20	Europe	High	Low	Short-sea
Ex 21 & 22	Europe	Low	High	Short-sea
Ex 23 & 24	Europe	High	High	Short-sea
Ex 25 & 26	U.S.	Low	Low	Rail
Ex 27 & 28	U.S.	High	Low	Rail
Ex 29 & 30	U.S.	Low	High	Rail
Ex 31 & 32	U.S.	High	High	Rail
Ex 33	Africa	Low	Low	Rail
Ex 34	Africa	High	Low	Rail
Ex 35	Africa	Low	High	Rail
Ex 36	Africa	High	High	Rail

6.2.2. Scenario's

As outlined in the methodology in section 2.7, two additional scenarios will be computed in addition to the aforementioned baseline scenario. These scenarios involve the application of renewable electric trucks for the intermodal alternative and the scenario with an increasing carbon price. The input for these scenarios will be consistent with those outlined in table 6.4 to allow for the base case to act as a benchmark for comparison.

Under the scenario where renewable electric trucks are used, emissions during the first and last mile will be eliminated, leaving only emissions during the intermodal leg.

In the scenario where the carbon price increases, the cost will include the price increase per tonne of CO2. This will place the more polluting alternative at a financial disadvantage. The European Central Bank predicts a rise to €140 per tonne, as opposed to the €85 euro in 2021 (Brand et al., 2023). This discrepancy of €55 per tonne will serve as input in the model.

7
Results

In this chapter the result of the experiments will be discussed. Graphs for the general outcomes can be found in section 7.1. The overall outcomes from the experiments can be found in appendix D. Section 7.1 discusses the results of the base scenario focusing on the influence of the lane characteristics on the emissions, costs and lead-time. Hereafter the outcomes of both the renewable electricity trucks and the increasing carbon price scenario are discussed in section 7.2.

7.1. Base case

In this section the results of the base scenario are discussed for each individual output variable. Below, the results are shown in two graphs. The first graph plots the difference in emissions between truck and intermodal transport versus lane distance.

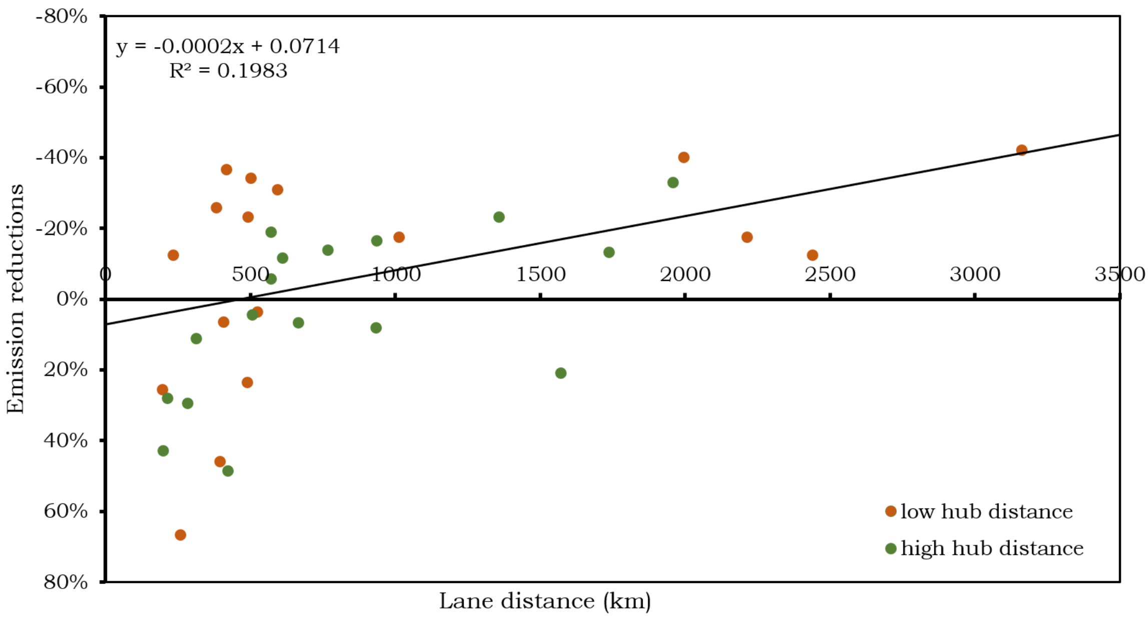


Figure 7.1: Lane distance vs. emission reductions

The second graph shows the same results plotted against the percentage of the first and last mile compared to the total intermodal distance.

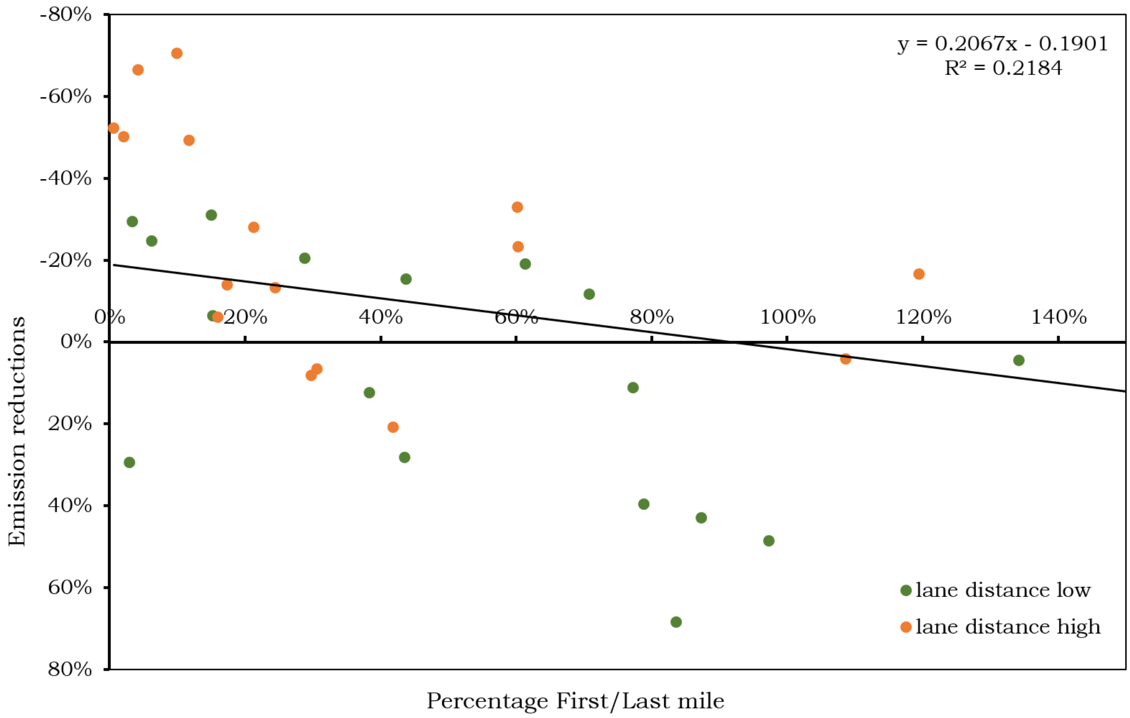


Figure 7.2: Percentage first and last mile vs. emission reductions

Each data point in the graphs above resemble the outcome of one experiment. Colour coding is used to differ high and low hub distance and respectively high and low lane distance.

The differences in costs and emissions ranked by region and mode are also shown in the two graphs below.

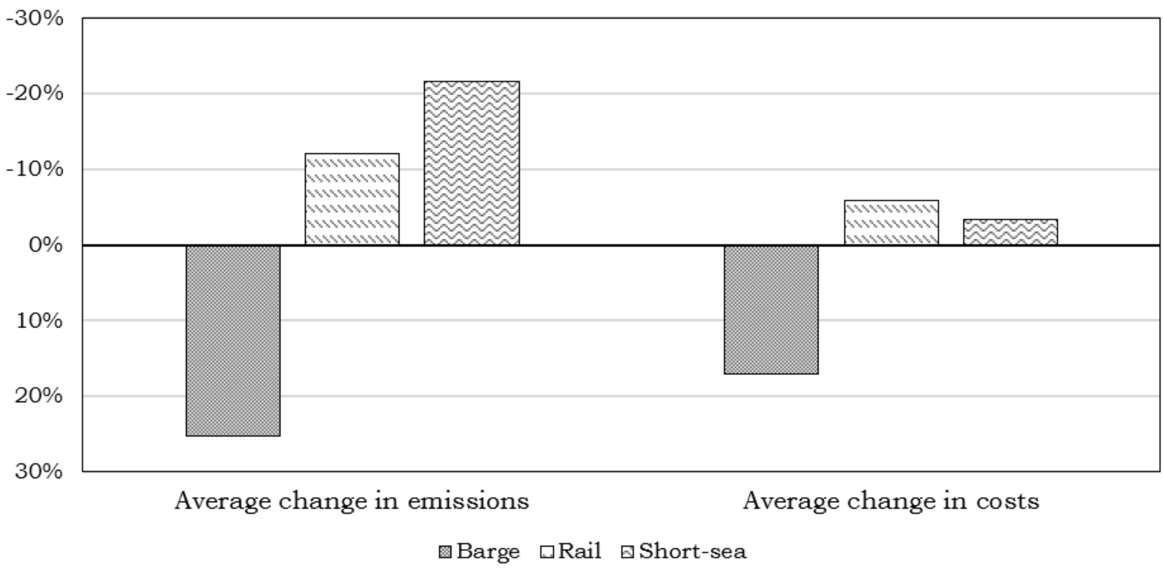


Figure 7.3: Changes per modality on emissions and costs

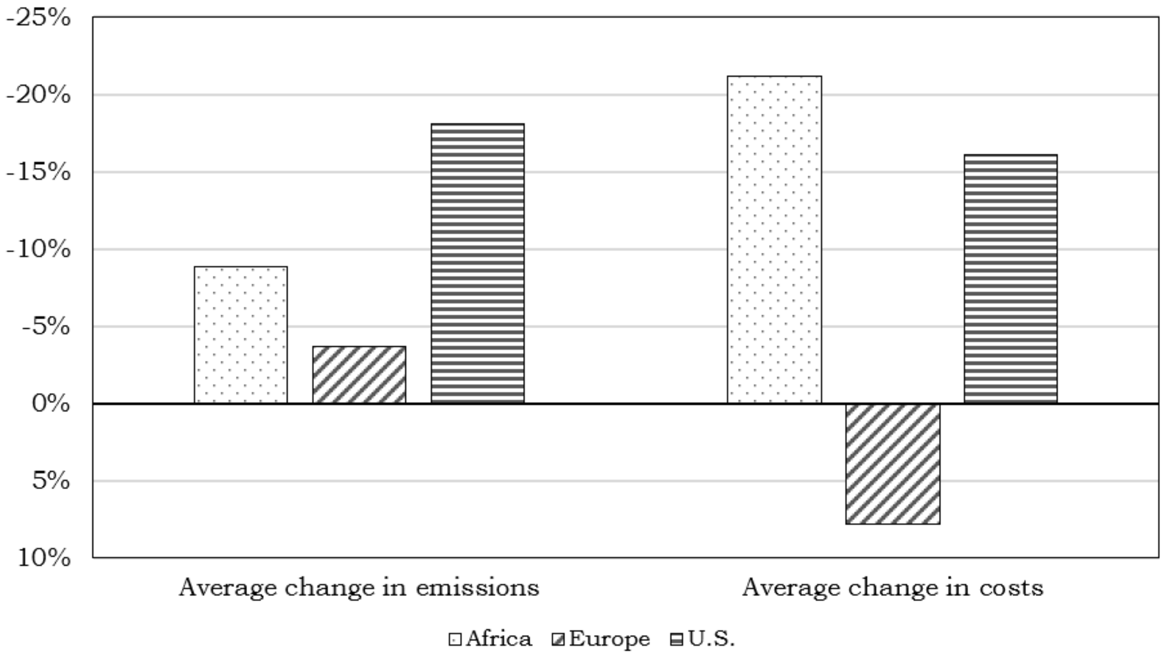


Figure 7.4: Changes per region on emissions and costs

7.1.1. Emissions

Examining the emissions, it is clear that the intermodal alternative results in emission reductions in 21 of the 36 lines (58%). Looking at figure 7.1 shows that longer distances have an positive effect on the emissions. Among the 21 reducing lanes, 12 have the long lane distances characteristic of the 16 total long distance lines, suggesting that lane distance robustly impacts the emissions. Additionally, it can be seen that routes with a low lane distance can also have emission reductions when combined with a low hub distance. Looking at the long-distance lanes over 600 km, the intermodal option leads to emission reductions in almost all cases.

Looking at the influence of the percentage of first and last mile compared to the total intermodal distance, it can be seen that higher drayage has a negative impact on emission reductions. The first and last mile can only be below 30% of the intermodal distance to be sure of reductions. Above this threshold, some reductions are still possible in some cases. Above 70%, however, this is not the case for low-distance lanes.

When analysing transportation modes displayed in figure 7.3, the focus is solely on European routes to enable comparison. It can be seen that both rail and short sea are beneficial in terms of emissions, with short sea being the most effective. However, it is worth noting the limited availability of short sea shipping options. The availability of short sea options is limited due to its geographical limitations, whereas rail is widely available. In addition, the barge option could help to reduce emissions, but is only effective when the lane distance is long and the first and last mile distances are short, again with limited options due to geographical limitations.

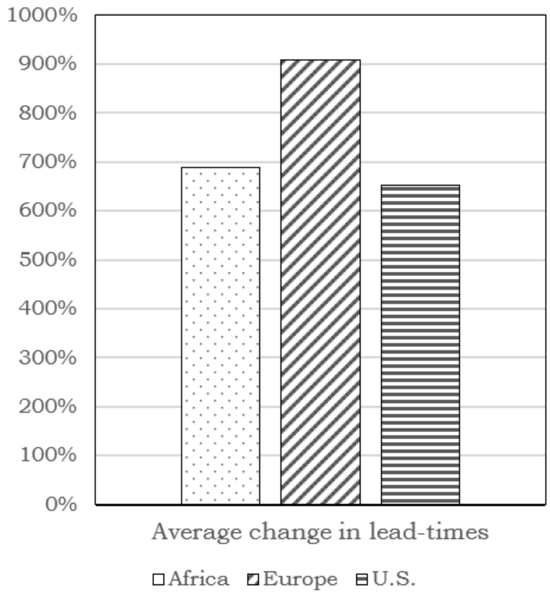
The results for the differences per region are also shown in figure 7.4. It can be seen that the highest reductions can be made in the US, which can be explained by the longer distances of the transport routes. The average reduction for Europe can be explained in part by the shorter distances, but also by the inclusion of the less reducing barge option, which pulls down the average.

7.1.2. Costs

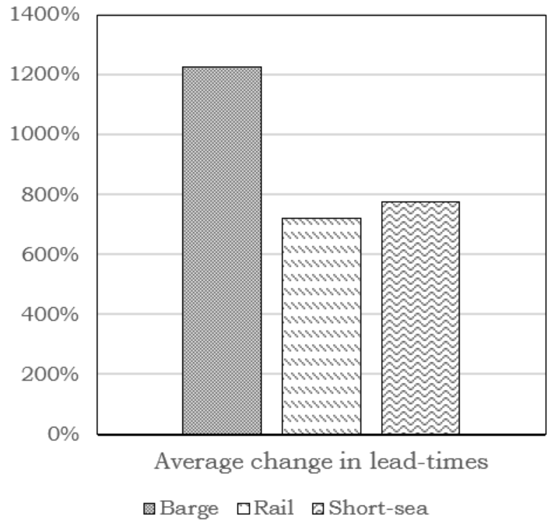
Looking again at figure 7.3 and focusing on the costs of intermodal transport, we can see that they are not higher for rail and short sea shipping than for road, as is often assumed. Moreover, of the 21 lanes that reduce emissions, 16 lanes (76%) also reduce costs. These transport lanes show a 22% reduction on average. Again for costs, barge does not appear to be advantageous. The differences in costs per region are shown in figure 7.4. On average, the largest cost reductions can be achieved in the US and Ethiopia. These results are estimates based on US truck and intermodal rates from Q1

2023. All these lanes show lower costs, which can be explained by the relatively low intermodal rates compared to truck and the long distances typical of the US. Europe shows an increase in costs, which can be explained by the results for barge and some rail options, which are also not effective in reducing emissions. In addition, the costs for Europe are based on real bids from LSPs and are therefore more reliable. Although the average is negative, there are still options in Europe for reducing both emissions and costs by short sea shipping or long distance rail.

7.1.3. Lead-time



(a) Region



(b) Modality

Figure 7.5: Changes in lead-time

Looking at the lead time, it can be seen that it is always longer for intermodal transport. This is due to the high average dwell time at transshipment points. The time itself varies even more if there is an extra transshipment step in the process, such as a change of rail carrier in the U.S. If the dwell time is not taken into account, it can be seen that intermodal transport has similar transport times to the truck option with at most one day extra transport time. This is due to the slightly lower average speed, but is compensated by the fact that there is no legal maximum working time per day as there is for trucks. Furthermore, can be seen that lead-times are the longest in the US caused again by longer average dwell times. Looking at modalities the lead-times for barge are the longest due to the slow movement speed.

7.2. Scenarios

For all experiments, the scenario outcomes are also examined. The average results from the base case and the two scenarios are showed in the figure below.

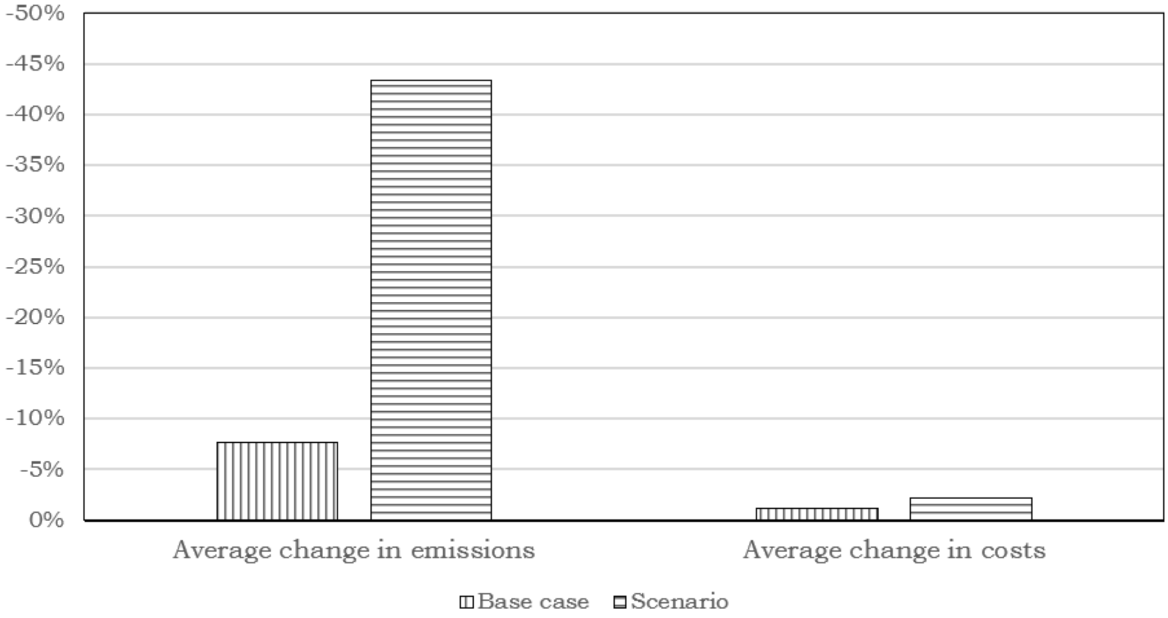


Figure 7.6: Changes per scenario

7.2.1. Renewable electricity trucks scenario

When looking at the results of the renewable electricity trucks the focus is on emissions as this is the only output that varies from the base scenario. Overall the most obvious result is that the 21 lanes that were already giving a reduction in emissions are now reducing even more. Especially the lanes with higher hub distances where emissions are reduced by several tens in percentages more. Furthermore, the use of emission-free trucks results in an additional 12 transport lines with lower emissions for the intermodal alternative. The only transport line remaining is a short-haul barge where transshipment emissions account for most of the emissions. Looking at figure 7.6 it shows that on average reductions raise from 7.5% to 42.5%.

7.2.2. Increasing carbon price scenario

In the scenario of rising carbon prices, the costs of both truck and intermodal journeys increases according to their respective emissions. Therefore, this analysis will only focus on the costs output. Automatically, this situation offers an advantage solely if the intermodal alternative exhibits lower emissions. If it fails to do so, the difference in costs between the truck and intermodal increases and becomes unfavourable towards intermodal. However, the impact of the carbon price is noteworthy only if the intermodal carbon emissions are lower than that of truck and costs are the opposite. In this instance, the cost difference becomes smaller and intermodal becomes more attractive to the shipper. In certain cases, intermodal can become a more cost-effective option when costs are already equal. This makes intermodal the both more affordable and environmentally friendly choice. However, the impact of the carbon price on the total costs is minimal, as evidenced by the results shown in figure 7.6. Despite the rise in carbon price, it remains a minor portion in relation to overall costs. Thus, it is unlikely to significantly impact the decision-making process between truck and intermodal transport options.

8 Discussion

In this chapter, the key findings will be summarised and interpreted. This is followed by a discussion of the limitations of the research. Section 8.1 summarises the most important results. Section 8.2 highlights the implications for Heineken. The information will flow logically with causal connections between statements. Finally, section 8.3 on limitations and recommendations addresses the scientific limitations of the research and proposes suggestions for future studies.

8.1. Results

This study investigates whether intermodal transport is preferable to trucking for transporting Heineken products in terms of emissions, cost and lead time. The experiments show that the intermodal alternative is better for longer distances in terms of both emissions and costs. The findings regarding emissions align with prior research discussed in chapter 3. For shorter journeys, this is only true if the first and last mile distances are below 30% of the total intermodal distance. In other cases, reductions are still possible but is specific per case.

In terms of the cost of intermodal transport, we would take into account how much more it would be. Nevertheless, the findings demonstrate that in cases where intermodal transport has lower emissions, the transportation cost is also lower. This differs from previous literature and can be explained by rising fuel prices and the increase in intermodal options.

However, Intermodal transport is always a slower option in terms of lead time due to the time needed for transshipment and waiting for the next mode of transport.

It is worth noting that there is a variance between different intermodal modes. On average short-sea offers the biggest reductions in emissions. But, this option is only available for transport lanes within coastal countries. Then rail is a good option for reductions and also accounts for the biggest savings in costs. Also, options for rail are more widely available and offered by LSPs. Then barge is the least favourable option due to its scarce availability and only reducing for high distance low first and last mile transport lanes. Therefore, would it be needed to concentrate on a single method, the rail option would be advised.

Looking at the difference of intermodal options per region is can be noted that the biggest reductions in costs and emissions lay in the U.S.. Nevertheless Europe also shows reduction options and a wider connected intermodal infrastructure and therefore in total number, more options. The user case of Ethiopia shows it is possible to gain reductions using intermodal but the options are very limited.

It is also possible to draw conclusions from various scenarios. For example, the use of renewable electric trucks makes all transport lines more favourable compared to trucking. It should be noted that electric trucks can also be used for the truck alternative, which also reduces emissions. However, these trucks are less desirable for long distances due to their limited range. For longer distances, a combination of intermodal transport and electric lorry will therefore remain of interest in the future.

The scenario with an increased carbon price demonstrates that this has little impact on costs since the carbon price is significantly lower than the transport price. An increase in the carbon price does not directly result in intermodal lanes becoming more cost-effective. Though, intermodal alternatives that previously had lower costs become even more advantageous. Therefore, selecting these options in the future is financially beneficial.

8.2. Limitations for Heineken

This section looks at the limitations of the research on Heineken. The first limitation relates to lead times. The high lead time results for intermodal can be explained by the high dwell times (e.g. 5.25 days in Europe). Due to these dwell times, the lead times for all intermodal alternatives are significantly higher than for road. For Heineken, such dwell times are also an obstacle to switching to intermodal transport. In reality, these dwell times are also expected to be significantly lower, perhaps no more than one day. However, no data could be found for this study other than the average dwell times used. It would be interesting to find out, in consultation with LSPs, what realistic dwell times would be for intermodal transport and to include these in the model.

Furthermore, only a few transport lines were investigated for the experiments. Examining even more lines of Heineken would help understand the influence of different characteristics even better. A model that could do this for multiple lines simultaneously would therefore also be useful. This was not possible due to the manual input of distance data required for the model to work. Unfortunately, there is no automation for this yet either.

Finally, for costs, only actual tender prices were used for the transport lines of Europe. Average transport ratios were used for U.S. and Ethiopia. It would be interesting to request tender prices for intermodal transport from these countries as well and compare them with trucking prices.

8.3. Research limitations and recommendations

Finally, this section discusses the other limitations of the study, after which recommendations are made for possible follow-up research. The first limitation results from the scoping of the study, as only Heineken's transport lines are considered. It was also decided to focus on Europe, the US and Ethiopia, as data was available, many of Heineken's emissions are in these regions, and the infrastructures differ from each other. Finally, data from Ecorys from 2019 on intermodal transport options was used for Europe. This data is outdated, so there may be new, more suitable options for intermodal transport. Also, new infrastructure or intermodal terminals built in the future may lead to different results.

In addition to scoping, there are methodological limitations. For example, the GHG protocol is used as described, which is a useful method for greenhouse gases, but does not take into account emissions that have a local effect, such as nitrogen. Furthermore, Brouter.de was used for the distance of intermodal options. Yet, this method of measuring distance always uses the shortest route. As a result, the distances do not always correspond to how a mode of transport is actually driven. Furthermore, the study only compared transport routes for which an intermodal alternative was available. Nonetheless, this is by no means the case for all routes, and for these routes truck will still be the chosen option. For Ethiopia, for example, only a small number of routes were available for comparison.

For further research, other countries and regions could be investigated to see if intermodal transport is feasible there as well. As already mentioned in the limitations for Heineken, only a small number of transport lines were used for the analysis. A large data-set with more lines and results would be an interesting follow-up research. By looking at more intermodal alternatives, a data analysis of the results can be carried out and more precise statements can be made about them. To this end, it would also be useful to extend the model and automate any data input, so that several transport routes can be calculated at the same time. This would make it possible to obtain more information more quickly and at the same time. Finally, it would be interesting to compare the transport routes of other types of companies. For example, Heineken has very dispersed sites and breweries in almost every country from which it transports. A company with more centralised production, such as Ikea, may have much longer transport distances on average, making an intermodal alternative more attractive.

9

Conclusion

The aim of this chapter is to draw conclusions from the findings and to answer the main research question and the sub-questions. The sub-questions will be addressed first, and then a conclusion will be drawn on the main research question.

The main objective of this study is to find out where Heineken's potential for reducing transport emissions through the use of intermodal transport lies. This includes looking at the cost and lead time of the alternative. To this end, a model and methodology has been developed that allows a comparison to be made between road and intermodal transport based on the availability of data.

The study also included experiments with Heineken's existing transport routes. By changing the characteristics of these routes and comparing routes from different regions, it is possible to determine which routes are suitable for reducing emissions through intermodal transport and what the impact of this is on costs and lead times.

Although there is some literature on this subject, the question is whether this also applies to Heineken's transport routes. With the literature study, the calculation model and the experiments the main question can be answered:

> "What is the impact of intermodal transport on Heineken's emissions, costs and lead-time compared to the current mode of transport?"

In order to answer this research question, the following sub-questions were formulated:

1. What transport lanes of Heineken and their accompanying characteristics are interesting to further explore in order to determine where intermodal possibilities lay for Heineken?
2. How to calculate the current carbon emissions of Heineken's transport lanes?
3. What are the potential carbon emission savings by intermodal transport?
4. What is the difference in costs and lead-time of intermodal transport compared to conventional truck transport?

9.1. Lane characteristics

The literature shows that certain characteristics affect the emissions of both truck and intermodal transport. Starting with the distance the vehicle has to cover, it is logical that the longer the distance, the more emissions are produced. Furthermore, for intermodal transport, the distance of the first and last mile is of great importance. If the use of intermodal transport requires a truck to travel long distances to and from a transshipment terminal, there is less room to reduce emissions by using intermodal transport. The region where the transport takes place also has an impact on emissions. This is due to differences in the landscape, such as altitude, but also to the existing transport infrastructure. In Europe, for example, it is possible to use different modes of transport such as rail, inland waterways and short sea shipping. These networks are also very compact. In addition, in Europe, most trains are electrically powered, whereas in the US, only diesel trains can be used. In a country like Ethiopia, very little intermodal transport is possible, down to a single railway line and a few terminals.

In order to determine how much of an impact all these characteristics have on emissions, they were further used in the study.

9.2. Calculation of carbon emissions

The first step was to determine the current carbon emissions from trucks according to the GHG Protocol. The model calculated the emissions based on the distance travelled per truck for each country crossed and the corresponding emission factor. This set the benchmark for intermodal emissions. These were calculated in the same way, but also taking into account first and last mile distances and transshipment emissions. The results of the experiments showed that intermodal transport is more effective in terms of emissions when the route distance is relatively long, with a minimum of 600 km for each modality. However, for some shorter distances, intermodal transport can also reduce emissions if the first and last mile are below 30% of the intermodal part.

When electric trucks are used for first and last mile transport, they are less polluting than the truck alternative on almost all the routes assessed. One possibility would be for the truck alternative to also switch to renewable electricity, but this is not possible for longer distances due to the battery range. This makes the intermodal option with electric trucks more interesting.

9.3. Costs and lead-time

The model can also make cost comparisons. This can be done by inputting existing data, for example from a pre-tender. But also through an approach using historic average cost rates. This shows that intermodal is the obvious option for longer distances in Europe, also in terms of costs. For the USA and Ethiopia, intermodal transport is estimated to be cheaper in almost all cases. The results of the model also show that the predicted price on carbon has minimal impact on the total cost of transport. As a result, it will not affect decision making.

In terms of lead time, intermodal transport will always lose out to road transport. This is due to the time needed for transshipment, waiting for the next transport and the speed of the transport. In consultation with the LSPs, it can investigated how this time can be reduced to make intermodal more competitive in this area. However, the increased lead-time can be anticipated for in planning.

9.4. Possibilities for Heineken

Based on the answers to the sub-questions above, the main question can be answered. The opportunities for emission reduction through intermodal transport are mainly on transport lanes above 600 km and transported by either short-sea or rail. In addition, the costs of intermodal transport are also more favourable than truck for these lanes. In addition, for some shorter transport lanes with a combined first and last mile below 30% of the intermodal distance, intermodal transport can also reduce emissions and make savings. It is worth noting that this is more complex due to the importance of the first and last mile distances. It is therefore advisable to first focus on the use of intermodal transport for the longer distances and then look more closely at the shorter distances to find a perfect match. In terms of lead time, it is important to consider this in advance. To further reduce emissions thereafter, the choice can be made to have the first and last mile transported by renewable electric trucks. This will achieve zero emissions from these legs and also significantly reduce the overall emissions of the trip.

It is also advisable to check intermodal costs with LSPs for the USA and possibly Ethiopia to get a more accurate indication. It should be noted, however, that for Ethiopia there are only a few suitable interchangeable transport lines due to the scarcity of intermodal options. In consultation with LSPs, it is also possible to verify what the actual lead times would be in order to get a better estimate and adjust planning accordingly in advance.

Finally, the model can be used internally in the future to compare truck and intermodal options for lanes at a detailed level, something that has not been possible on a one-to-one basis. To further explore intermodal options and integrate tools with real-time transport data from LSPs, a collaboration with routescanner.com can be explored. This company collects transport data from carriers and applies it to a route optimiser focused on reducing emissions. Paid products can be applied to large data sets to calculate emissions and possible reductions, and suggest intermodal transport options with actual transport times and dates.

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A

Emission factors

For confidentially reasons, the emission factors are not made public in this version.

B

Calculation Model

This appendix provides a visual overview of the calculation model described in chapter 5. The tool can be used to analyse truck transport routes with an intermodal alternative based on emissions, costs and lead time. The model is built using Microsoft Excel and is further described using images.

The "Sheet Overview" in figure B.1 shows an overview of all sheets in the Excel model. Sheets that have information in them are colour coded, while support data sheets are blank.

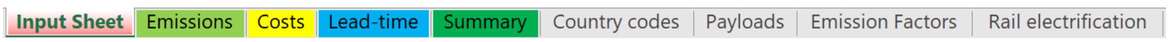

Figure B.1: Excel sheet overview

The 'Input Sheet' shown in figure B.2 is the central sheet that requires the input of the lane details and the intermodal alternative. Green cells indicate mandatory inputs, light green cells are optional for additional detail and therefore accuracy, and grey cells are automatically generated based on the information provided.

Next, the 'Emissions Sheet' (figure B.3) facilitates calculations comparing emissions between trucking and the intermodal alternative. Similarly, the "Cost Sheet" in figure B.4 deals with the financial aspect, with the method of calculation depending on the availability of a cost figure from an intermodal database. Otherwise, the costs will be estimated on the basis of cost ratios. In figure B.5 the "Lead-Time Sheet" focuses on the travel time aspect and presents calculations and results for lead times in both modes.

The 'Summary Sheet' below in figure B.6 summarises the analysis and provides a concise overview of the main results in terms of emissions, costs and lead time. Through these sheets, the Calculation Model aims to provide a systematic and transparent framework for evaluating transport alternatives.

	A	B	C	D	E	Notes	Legend
1							
2	Item Name	9999					
3	Region	Europe					
4	Origin Country	NL	Netherlands			*For correct country code see the 'Country codes' sheet*	*Required field*
5	Origin Postal code	2382					*Optional field*
6	Origin city	Zoeterwoude					*Auto-filled*
7							
8	Destination Country	ES	Spain				
9	Destination Postal Code	28053					
10	Destination city	Madrid					
11							
12	Est. Trips per year	100					
13	Equipment Type	Container 40 ft					
14							
15	Benchmark annual costs	180000					
16							
17	**Truck**						
18		km	Country code	Country			
19	Truck distances:	114	NL	Netherlands			
20	(Crossing countries)	122	BE	Belgium		*Distance per country can be specified for increased accuracy*	
21		1033	FR	France			
22		472	ES	Spain			
23				#N/A			
24				#N/A			
25				#N/A			
26				#N/A			
27				#N/A			
28		1741 km					
29							
30	**Intermodal**						
31							
32	Point of loading	Antwerp Terminal				*Port or transshipment hub*	
33	Point of debarking	Madrid abronigal				*Port or transshipment hub*	
34	Travel time					*If available in intermodal database*	
35	Transshipments	2				*Amount of transshipments between modalities (Origin and destination excluded)*	
36	Intermodal quoting available?	No				*If no, leave next cell empty*	
37	Quoted costs Intermodal					*Based on pre-tender*	
38							
39							
40		km	Country code	Country	Modality		
41	First mile:	114	NL	Netherlands	Truck		
42		20	BE	Belgium	Truck		
43	Last mile:	4.1	ES	Spain	Truck		
44				#N/A	Truck		
45	Intermodality:	139	BE	Belgium	Train	*Distance per country can be specified for increased accuracy*	
46	(Crossing countries)	1014	FR	France	Train		
47		579.7	ES	Spain	Train	*For short-sea: Select Ocean as modality*	
48				#N/A		*For short-sea: Use region code instead of Country code (EU,US,AFR)*	
49				#N/A			
50				#N/A			
51				#N/A			
52		1870.8 km					
53							

Figure B.2: Input sheet

	Item Name	9999				Equipment:	Truck 26 - 40 t
	From:	Zoeterwoude, NL		Point of loading:	Antwerp Terminal		
	To:	Madrid, ES		Point of debarking:	Madrid abronigal		
Truck							
	km	Country code		Emission factor truck	Emissions truck leg		
Truck distances:	114	NL	Netherlands	1.279	145.81		
(Crossing countries)	122	BE	Belgium	1.501	183.12		
	1033	FR	France	1.277	1319.14		
	472	ES	Spain	1.295	611.24		
	0	0	#N/A	#N/A	#N/A		
	0	0	#N/A	#N/A	#N/A		
	0	0	#N/A	#N/A	#N/A		
	0	0	#N/A	#N/A	#N/A		
	0	0	#N/A	#N/A	#N/A		
	1741 km			Emission truck trip:	2259.3 kg CO2 eq		
Est. Number of trips:	100						
			Annual emissions truck:		225.9 kton CO2 eq		

Intermodal			Region:	Europe	Transshipments:	2	Equipment: Container 40 ft
	km	Country code	Country	Modality	Emission factor	Emission leg	Electrification rail
First mile:	114	NL	Netherlands	Truck	1.279	145.806	-
	20	BE	Belgium	Truck	1.501	30.020	-
Last mile:	4.1	ES	Spain	Truck	1.295	5.310	-
			#N/A	Truck	#N/A	#N/A	-
Intermodality:	139	BE	Belgium	Train	0.1709	23.760	86.57%
(Crossing countries)	1014	FR	France	Train	0.2544	257.945	59.33%
	579.7	ES	Spain	Train	0.3535	204.941	64.05%
	0	0	#N/A	0	#N/A	#N/A	#N/A
	0	0	#N/A	0	#N/A	#N/A	#N/A
	0	0	#N/A	0	#N/A	#N/A	#N/A
	0	0	#N/A	0	#N/A	#N/A	#N/A
Transshipments			no.	2	76	152	
	1870.8 km				Emission intermodal trip:	819.8 kg CO2 eq	
			Annual emissions intermodal:		82.0 kton CO2 eq		
			Annual reductions:		-144.0 kton CO2 eq		

Figure B.3: Emissions sheet

	A	B	C	D	H	I
1						
2	Intermodal quoting available?	No			US truck rate	1.68 €/km
3	Quoted costs Intermodal	€ -		*0 if not quoted*	US intermodal rate	0.95 €/km
4	Quoted costs truck	€ 180,000.00		*0 if not quoted*		
5	Include price on carbon?	Yes			Euro Carbon price 2021	85 €/t CO2 eq
6					Expected carbon price 2030	140 €/t CO2 eq
7					Expected carbon price increase	55 €/t CO2 eq
8	**Truck**					
9	Distance truck	1741	km			
10	Costs truck	€ 2,929.13	EUR			
11						
12	Emissions truck	225.93	t CO2 eq			
13	Annual carbon costs increase	€ 12,426.20	EUR			
14						
15	Estimated annual truck costs	€ 305,338.92	EUR			
16						
17	Annual truck costs	€ 192,426.20	EUR			
18						
19	**Intermodal**					
20	Distance truck	138.1	km			
21	Distance intermodal	1732.7	km			
22						
23	Costs truck	€ 232.34	EUR			
24	Costs intermodal	€ 1,643.31	EUR			
25	Costs intermodal trip	€ 1,875.65	EUR			
26						
27	Emissions intermodal	33.31	t CO2 eq			
28	Annual carbon costs increase	€ 1,832.25	EUR			
29						
30	Estimated annual intermodal costs	€ 189,397.28				
31						
32	Annual intermodal costs	€ 189,397.28	EUR			
33						
34						
35	Additional costs / Difference	-€ 3,028.92	EUR			
36						
37	Emission reduction	-192.61735	t CO2 eq			
38						
39						
40	Costs/ kg CO2 eq	-0.015725063	€/kg CO2 eq			

Figure B.4: Costs sheet

	A	B	C	E	I	J	K
1	Region:	Europe					
2					Region	Maximum distance threshold (km/day)	
3					Africa	730	
4	**Truck**				U.S.	805	
5	Truck distance:	1741	km		Europe	657	
6	Travel time truck:	3	days				
7							
8					Region	Modality	Speed (km/h)
9	**Intermodal**				Africa	Train	32.5
10	Travel time in database:	0	days	*0 if not in database*	Europe	Train	50
11					U.S.	Train	41.8
12	First mile distance:	134	km		Europe	Barge	15
13	Last mile distance:	4.1	km		Global	Ocean	35.2
14	Travel time IM truck:	1	days				
15					Region	Average dwell time (Days)	
16	Modality:	Train			Africa	3.4	
17	Distance modality:	1732.7	km		U.S.	3.7	
18	Travel time modality:	2	days		Europe	5.25	
19							
20	Transshipments:	2					
21	Dwell-time:	11	days				
22							
23							
24	Estimated travel time IM:	14	days				
25							
26							
27	Difference:	11	days	*Travel time in database is used if available, otherwise estimation*			
28							

Figure B.5: Lead-time sheet

Item Name	9999
From:	Zoeterwoude, NL
To:	Madrid, ES

Modality:	Train
Point of loading:	Antwerp Terminal
Point of debarking:	Madrid abronigal

	Emissions	Costs	Lead-time
	kton CO2eq	EUR	Days
Truck	225.93	180000	3
Intermodal	81.98	187565	14
Difference	-143.95	7565	11

Cost of reduction 52.55 €/kg CO2eq

Figure B.6: Summary sheet

C Model Validation

In this appendix the results from Routescanner.com are shown. The recommended route can be seen in figure C.1. Figures C.2 and C.3 show the lead time, emissions and distance of the respective legs. Figure C.4 show the potential reductions compared to truck and figure C.5 shows the emission factors used by Routescanner.com.

Figure C.1: Intermodal transport route

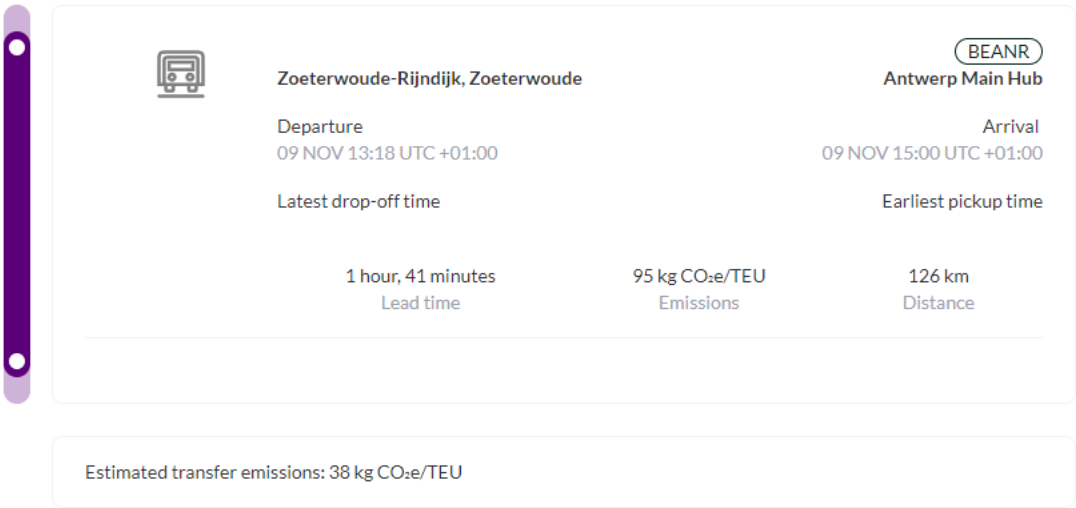

Figure C.2: Leg details truck Zoeterwoude - Antwerp

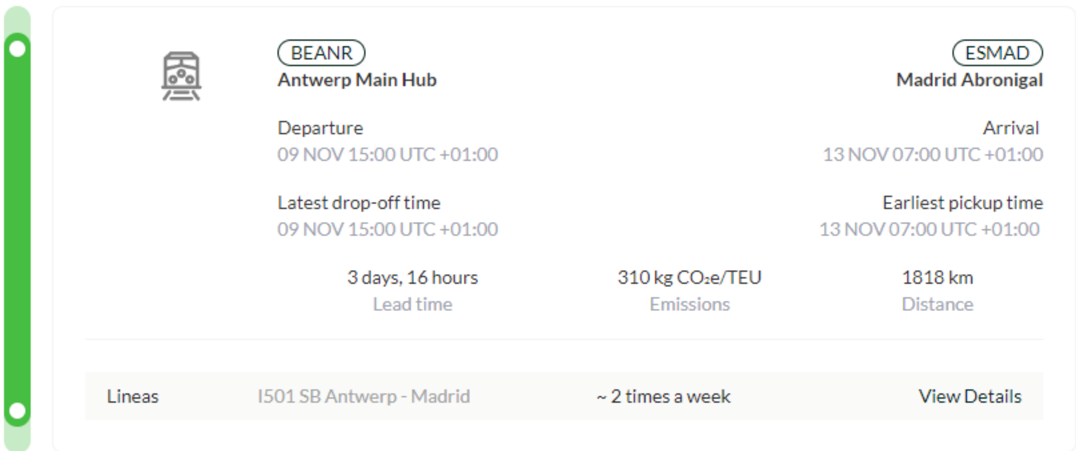

Figure C.3: Leg details rail Antwerp - Madrid

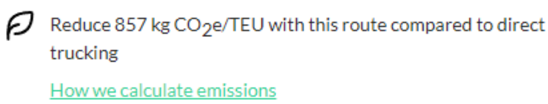

Figure C.4: Trip reduction compared to truck

Average carbon emissions per mode of transport

The average carbon emissions per mode of transport, per geographical area or per tradelane, are the following (all amounts are in g CO_2e per km, per TEU). Please note that in the GLEC Framework documentation for mode of transports rail, truck and barge, the amounts are given in kg CO_2e per km, per ton. These amounts are converted to g CO_2e per km, per TEU; the average weight of a loaded container per TEU is used to convert.

Mode Of Transport	Area/Tradelane	Amount (g CO_2e per km per TEU)
Barge	Other	260
Rail	Europe	170
Rail	North America, South America, Asia, Africa	160
Rail	Other	160
Truck	North America	970
Truck	Europe, South America	750
Truck	Asia, Africa	915
Truck	Other	970

Figure C.5: Emission factors used by Routescanner.com

D Experiments

D.1. Experiment 1: Low lane distance, Low hub distance, Rail, Europe

Table D.1: Exp. 1 Distances

Experiment 1	
Truck distance:	397 km
First/last mile distance:	78.1 km
Intermodal distance:	512.6 km

Table D.2: Exp. 1 Results

Ex: 1a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	12.82	€ 18,825.00	1
Intermodal	12.01	€ 27,500.00	13
Difference	-0.82	€ 8,675.00	12
Percentage	-6%	46%	1200%

Table D.3: Exp. 1 Renewable electric truck scenario results

Ex: 1b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	12.82	€ 18,825.00	1
Intermodal	9.50	€ 27,500.00	13
Difference	-3.32	€ 8,675.00	12
Percentage	-26%	46%	1200%

Table D.4: Exp. 1 Carbon price scenario results

Ex: 1c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	12.82	€ 19,530.25	1
Intermodal	12.01	€ 28,160.42	13
Difference	-0.82	€ 8,630.17	12
Percentage	-6%	44%	1200%

D.2. Experiment 2: Low lane distance, Low hub distance, Rail, Europe

Table D.5: Exp. 2 Distances

Experiment 2	
Truck distance:	409 km
First/last mile distance:	187 km
Intermodal distance:	427 km

Table D.6: Exp. 2 Results

Ex: 2a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	267.17	€ 321,300.00	1
Intermodal	226.15	€ 342,523.00	13
Difference	-41.02	€ 21,223.00	12
Percentage	-15%	7%	1200%

Table D.7: Exp. 2 Renewable electric truck scenario results

Ex: 2b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	267.17	€ 321,300.00	1
Intermodal	147.11	€ 342,523.00	13
Difference	-120.06	€ 21,223.00	12
Percentage	-45%	7%	1200%

Table D.8: Exp. 2 Carbon price scenario results

Ex: 2c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	267.17	€ 335,994.47	1
Intermodal	187.14	€ 352,815.96	13
Difference	-80.03	€ 16,821.50	12
Percentage	-30%	5%	1200%

D.3. Experiment 3: High lane distance, Low hub distance, Rail, Europe

Table D.9: Exp. 3 Distances

Experiment 3	
Truck distance:	1015 km
First/last mile distance:	116.2 km
Intermodal distance:	994 km

Table D.10: Exp. 3 Results

Ex: 3a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	1358.07	€ 2,837,000.00	2
Intermodal	688.62	€ 2,340,000.00	13
Difference	-669.45	-€ 497,000.00	11
Percentage	-49%	-18%	550%

Table D.11: Exp. 3 Renewable electric truck scenario results

Ex: 3b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	1358.07	€ 2,837,000.00	2
Intermodal	531.06	€ 2,340,000.00	13
Difference	-827.01	-€ 497,000.00	11
Percentage	-61%	-18%	550%

Table D.12: Exp. 3 Carbon price scenario results

Ex: 3c	Emissions	Costs	Lead-time
	t CO2eq	EUR	Days
Truck	1358.07	€ 2,911,693.87	2
Intermodal	688.62	€ 2,377,874.28	13
Difference	-669.45	-€ 533,819.59	11
Percentage	-49%	-18%	550%

D.4. Experiment 4: High lane distance, Low hub distance, Rail, Europe

Table D.13: Exp. 4 Distances

Experiment 4	
Truck distance:	490 km
First/last mile distance:	303 km
Intermodal distance:	279 km

Table D.14: Exp. 4 Results

Ex: 4a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	150.69	€ 125,550.00	1
Intermodal	156.93	€ 155,250.00	13
Difference	6.24	€ 29,700.00	12
Percentage	4%	24%	1200%

Table D.15: Exp. 4 Renewable electric truck scenario results

Ex: 4b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	150.69	€ 125,550.00	1
Intermodal	63.77	€ 155,250.00	13
Difference	-86.92	€ 29,700.00	12
Percentage	-58%	24%	1200%

Table D.16: Exp. 4 Carbon price scenario results

Ex: 4c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	150.69	€ 133,837.96	1
Intermodal	156.93	€ 163,881.09	13
Difference	6.24	€ 30,043.13	12
Percentage	-5%	22%	1200%

D.5. Experiment 5: Low lane distance, High hub distance, Rail, Europe

Table D.17: Exp. 5 Distances

Experiment 5	
Truck distance:	507 km
First/last mile distance:	351.6 km
Intermodal distance:	262 km

Table D.18: Exp. 5 Results

Ex: 5a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	20.70	€ 26,040.00	1
Intermodal	21.62	€ 32,400.00	13
Difference	0.92	€ 6,360.00	12
Percentage	4%	24%	1200%

Table D.19: Exp. 5 Renewable electric truck scenario results

Ex: 5b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	20.70	€ 26,040.00	1
Intermodal	7.55	€ 32,400.00	13
Difference	-13.16	€ 6,360.00	12
Percentage	-64%	24%	1200%

Table D.20: Exp. 5 Carbon price scenario results

Ex: 5c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	20.70	€ 27,178.70	1
Intermodal	21.62	€ 33,589.02	13
Difference	0.92	€ 6,410.33	12
Percentage	4%	24%	1200%

D.6. Experiment 6: Low lane distance, High hub distance, Rail, Europe

Table D.21: Exp. 6 Distances

Experiment 6	
Truck distance:	423 km
First/last mile distance:	428 km
Intermodal distance:	439.7 km

Table D.22: Exp. 6 Results

Ex: 6a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	29.02	€ 21,150.00	1
Intermodal	43.10	€ 21,900.00	13
Difference	14.08	€ 750.00	12
Percentage	49%	4%	100%

Table D.23: Exp. 6 Renewable electric truck scenario results

Ex: 6b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	29.02	€ 21,150.00	1
Intermodal	13.88	€ 21,900.00	13
Difference	-15.14	€ 750.00	12
Percentage	-52%	4%	100%

Table D.24: Exp. 6 Carbon price scenario results

Ex: 6c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	29.02	€ 22,745.99	1
Intermodal	43.10	€ 24,270.47	13
Difference	14.08	€ 1,524.48	12
Percentage	49%	7%	1200%

D.7. Experiment 7: High lane distance, High hub distance, Rail, Europe

Table D.25: Exp. 7 Distances

Experiment 7	
Truck distance:	1959 km
First/last mile distance:	797 km
Intermodal distance:	1325 km

Table D.26: Exp. 7 Results

Ex: 7a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	200.41	€ 175,425.00	3
Intermodal	134.34	€ 168,000.00	15
Difference	-66.06	-€ 7,425.00	12
Percentage	-33%	-4%	400%

Table D.27: Exp. 7 Renewable electric truck scenario results

Ex: 7b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	200.41	€ 175,425.00	3
Intermodal	50.48	€ 168,000.00	15
Difference	-149.93	-€ 7,425.00	12
Percentage	-75%	-4%	400%

Table D.28: Exp. 7 Carbon price scenario results

Ex: 7c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	200.41	€ 186,447.28	3
Intermodal	134.34	€ 175,388.86	15
Difference	-66.06	-€ 11,058.42	12
Percentage	-33%	-6%	400%

D.8. Experiment 8: High lane distance, High hub distance, Rail, Europe

Table D.29: Exp. 8 Distances

Experiment 8	
Truck distance:	767 km
First/last mile distance:	169.7 km
Intermodal distance:	976.6 km

Table D.30: Exp. 8 Results

Ex: 8a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	177.04	€ 193,375.00	2
Intermodal	152.33	€ 218,750.00	13
Difference	-24.70	€ 25,375.00	11
Percentage	-14%	13%	550%

Table D.31: Exp. 8 Renewable electric truck scenario results

Ex: 8b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	177.04	€ 193,375.00	2
Intermodal	113.04	€ 218,750.00	13
Difference	-64.00	€ 25,375.00	11
Percentage	-36%	13%	550%

Table D.32: Exp. 8 Carbon price scenario results

Ex: 8c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	177.04	€ 203,112.06	2
Intermodal	152.33	€ 227,128.29	13
Difference	-24.70	€ 24,016.23	11
Percentage	-14%	12%	550%

D.9. Experiment 9: Low lane distance, Low hub distance, Barge, Europe

Table D.33: Exp. 9 Distances

Experiment 9	
Truck distance:	198 km
First/last mile distance:	112.9 km
Intermodal distance:	135 km

Table D.34: Exp. 9 Results

Ex: 9a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	2.72	€ 4,930.00	1
Intermodal	4.58	€ 6,200.00	18
Difference	1.86	€ 1,270.00	17
Percentage	68%	26%	1700%

Table D.35: Exp. 9 Renewable electric truck scenario results

Ex: 9b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	2.72	€ 4,930.00	1
Intermodal	2.92	€ 6,200.00	18
Difference	0.19	€ 1,270.00	17
Percentage	7%	26%	1700%

Table D.36: Exp. 9 Carbon price scenario results

Ex: 9c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	2.72	€ 5,079.66	1
Intermodal	4.58	€ 6,452.00	18
Difference	1.86	€ 1,372.34	17
Percentage	68%	27%	1700%

D.10. Experiment 10: Low lane distance, Low hub distance, Barge, Europe

Table D.37: Exp. 10 Distances

Experiment 10	
Truck distance:	236 km
First/last mile distance:	85.8 km
Intermodal distance:	224 km

Table D.38: Exp. 10 Results

Ex: 10a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	73.78	€ 96,544.00	1
Intermodal	82.90	€ 84,672.00	13
Difference	9.12	-€ 11,872.00	12
Percentage	12%	-12%	1200%

Table D.39: Exp. 10 Renewable electric truck scenario results

Ex: 10b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	73.78	€ 96,544.00	1
Intermodal	57.68	€ 84,672.00	13
Difference	-16.10	-€ 11,872.00	12
Percentage	-22%	-12%	1200%

Table D.40: Exp. 10 Carbon price scenario results

Ex: 10c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	73.78	€ 100,601.86	1
Intermodal	82.90	€ 89,231.71	13
Difference	9.12	-€ 11,370.16	12
Percentage	12%	-11%	1200%

D.11. Experiment 11: High lane distance, Low hub distance, Barge, Europe

Table D.41: Exp. 11 Distances

Experiment 11	
Truck distance:	525 km
First/last mile distance:	122.6 km
Intermodal distance:	768.7 km

Table D.42: Exp. 11 Results

Ex: 11a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	111.23	€ 106,950.00	1
Intermodal	104.49	€ 110,850.00	15
Difference	-6.74	€ 3,900.00	14
Percentage	-6%	4%	1400%

Table D.43: Exp. 11 Renewable electric truck scenario results

Ex: 11b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	111.23	€ 106,950.00	1
Intermodal	77.11	€ 110,850.00	15
Difference	-34.12	€ 3,900.00	14
Percentage	-31%	4%	1400%

Table D.44: Exp. 11 Carbon price scenario results

Ex: 11c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	111.23	€ 113,067.51	1
Intermodal	104.49	€ 116,596.97	15
Difference	-6.74	€ 3,529.46	14
Percentage	-6%	3%	1400%

D.12. Experiment 12: High lane distance, Low hub distance, Barge, Europe

No second transport lane with high lane distance and high hub distance for barge so no data to compare.

D.13. Experiment 13: Low lane distance, High hub distance, Barge, Europe

Table D.45: Exp. 13 Distances

Experiment 13	
Truck distance:	198 km
First/last mile distance:	117.9 km
Intermodal distance:	135 km

Table D.46: Exp. 13 Results

Ex: 13a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	2.72	€ 4,930.00	1
Intermodal	3.89	€ 5,880.00	13
Difference	1.17	€ 950.00	12
Percentage	43%	19%	1200%

Table D.47: Exp. 13 Renewable electric truck scenario results

Ex: 13b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	2.72	€ 4,930.00	1
Intermodal	2.16	€ 5,880.00	13
Difference	-0.57	€ 950.00	12
Percentage	-21%	19%	1200%

Table D.48: Exp. 13 Carbon price scenario results

Ex: 13c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	2.72	€ 5,079.66	1
Intermodal	3.89	€ 6,093.84	13
Difference	1.17	€ 1,014.18	12
Percentage	43%	20%	1200%

D.14. Experiment 14: Low lane distance, High hub distance, Barge, Europe

Table D.49: Exp. 14 Distances

Experiment 14	
Truck distance:	214 km
First/last mile distance:	95.7 km
Intermodal distance:	220 km

Table D.50: Exp. 14 Results

Ex: 14a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	259.54	€ 339,388.00	1
Intermodal	332.52	€ 510,384.00	13
Difference	72.97	€ 170,996.00	12
Percentage	28%	50%	1200%

Table D.51: Exp. 14 Renewable electric truck scenario results

Ex: 14b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	259.54	€ 339,388.00	1
Intermodal	221.88	€ 510,384.00	13
Difference	-37.67	€ 170,996.00	12
Percentage	-15%	50%	1200%

Table D.52: Exp. 14 Carbon price scenario results

Ex: 14c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	259.54	€ 353,662.93	1
Intermodal	332.52	€ 528,672.33	13
Difference	72.97	€ 175,009.40	12
Percentage	28%	49%	1200%

D.15. Experiment 15: High lane distance, High hub distance, Barge, Europe

Table D.53: Exp. 15 Distances

Experiment 15	
Truck distance:	665 km
First/last mile distance:	273.4 km
Intermodal distance:	893 km

Table D.54: Exp. 15 Results

Ex: 15a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	6.93	€ 11,920.00	2
Intermodal	7.39	€ 13,800.00	15
Difference	0.46	€ 1,880.00	13
Percentage	7%	16%	650%

Table D.55: Exp. 15 Renewable electric truck scenario results

Ex: 15b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	6.93	€ 11,920.00	2
Intermodal	4.58	€ 13,800.00	15
Difference	-2.35	€ 1,880.00	13
Percentage	-34%	16%	650%

Table D.56: Exp. 15 Carbon price scenario results

Ex: 15c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	6.93	€ 12,301.02	2
Intermodal	7.39	€ 14,206.25	15
Difference	0.46	€ 1,905.24	13
Percentage	7%	15%	650%

D.16. Experiment 16: High lane distance, High hub distance, Barge, Europe

No transport lane with high lane distance and high hub distance for barge so no data to compare.

D.17. Experiment 17: Low lane distance, Low hub distance, Short-sea, Europe

Table D.57: Exp. 17 Distances

Experiment 17	
Truck distance:	493 km
First/last mile distance:	91 km
Intermodal distance:	607 km

Table D.58: Exp. 17 Results

Ex: 17a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	16.06	€ 18,700.00	1
Intermodal	11.08	€ 14,375.00	13
Difference	-4.97	-€ 4,325.00	12
Percentage	-31%	-23%	1200%

Table D.59: Exp. 17 Renewable electric truck scenario results

Ex: 17b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	16.06	€ 18,700.00	1
Intermodal	8.16	€ 14,375.00	13
Difference	-7.90	-€ 4,325.00	12
Percentage	-49%	-23%	1200%

Table D.60: Exp. 17 Carbon price scenario results

Ex: 17c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	16.06	€ 19,583.04	1
Intermodal	11.08	€ 14,984.43	13
Difference	-4.97	-€ 4,598.61	12
Percentage	-31%	-23%	1200%

D.18. Experiment 18: Low lane distance, Low hub distance, Short-sea, Europe

Table D.61: Exp. 18 Distances

Experiment 18	
Truck distance:	260 km
First/last mile distance:	213 km
Intermodal distance:	270 km

Table D.62: Exp. 18 Results

Ex: 18a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	74.96	€ 92,250.00	1
Intermodal	104.67	€ 153,750.00	13
Difference	29.70	€ 61,500.00	12
Percentage	40%	67%	1200%

Table D.63: Exp. 18 Renewable electric truck scenario results

Ex: 18b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	74.96	€ 92,250.00	1
Intermodal	47.05	€ 153,750.00	13
Difference	-27.92	€ 61,500.00	12
Percentage	-37%	67%	1200%

Table D.64: Exp. 18 Carbon price scenario results

Ex: 18c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	74.96	€ 96,372.92	1
Intermodal	104.67	€ 159,506.64	13
Difference	29.70	€ 63,133.72	12
Percentage	40%	66%	1200%

D.19. Experiment 19: High lane distance, Low hub distance, Short-sea, Europe

Table D.65: Exp. 19 Distances

Experiment 19	
Truck distance:	2214 km
First/last mile distance:	197.2 km
Intermodal distance:	1983 km

Table D.66: Exp. 19 Results

Ex: 19a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	154.20	€ 156,060.00	4
Intermodal	45.48	€ 129,000.00	15
Difference	-108.73	-€ 27,060.00	11
Percentage	-71%	-17%	275%

Table D.67: Exp. 19 Renewable electric truck scenario results

Ex: 19b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	154.20	€ 156,060.00	4
Intermodal	43.27	€ 129,000.00	15
Difference	-110.94	-€ 27,060.00	11
Percentage	-72%	-17%	275%

Table D.68: Exp. 19 Carbon price scenario results

Ex: 19c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	154.20	€ 164,541.23	4
Intermodal	45.48	€ 131,501.14	15
Difference	-108.73	-€ 33,040.09	11
Percentage	-71%	-20%	275%

D.20. Experiment 20: High lane distance, Low hub distance, Short-sea, Europe

Table D.69: Exp. 20 Distances

Experiment 20	
Truck distance:	2441 km
First/last mile distance:	1122 km
Intermodal distance:	2646 km

Table D.70: Exp. 20 Results

Ex: 20a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	79.39	€ 66,975.00	4
Intermodal	26.60	€ 58,750.00	16
Difference	-52.79	-€ 8,225.00	12
Percentage	-66%	-12%	300%

Table D.71: Exp. 20 Renewable electric truck scenario results

Ex: 20b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	79.39	€ 66,975.00	4
Intermodal	22.79	€ 58,750.00	16
Difference	-56.61	-€ 8,225.00	12
Percentage	-71%	-12%	300%

Table D.72: Exp. 20 Carbon price scenario results

Ex: 20c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	79.39	€ 71,341.51	4
Intermodal	26.60	€ 60,212.95	16
Difference	-52.79	-€ 11,128.57	12
Percentage	-66%	-16%	300%

D.21. Experiment 21: Low lane distance, High hub distance, Short-sea, Europe

Table D.73: Exp. 21 Distances

Experiment 21	
Truck distance:	313 km
First/last mile distance:	180 km
Intermodal distance:	233 km

Table D.74: Exp. 21 Results

Ex: 21a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	137.90	€ 371,960.00	1
Intermodal	153.22	€ 386,400.00	13
Difference	15.32	€ 14,440.00	12
Percentage	11%	4%	1200%

Table D.75: Exp. 21 Renewable electric truck scenario results

Ex: 21b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	137.90	€ 371,960.00	1
Intermodal	73.54	€ 386,400.00	13
Difference	-64.35	€ 14,440.00	12
Percentage	-47%	4%	1200%

Table D.76: Exp. 21 Carbon price scenario results

Ex: 21c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	137.90	€ 379,544.23	1
Intermodal	153.22	€ 394,827.10	13
Difference	15.32	€ 15,282.87	12
Percentage	11%	4%	1200%

D.22. Experiment 22: Low lane distance, High hub distance, Short-sea, Europe

Table D.77: Exp. 22 Distances

Experiment 22	
Truck distance:	571 km
First/last mile distance:	287 km
Intermodal distance:	468 km

Table D.78: Exp. 22 Results

Ex: 22a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	70.06	€ 176,843.00	1
Intermodal	56.73	€ 178,536.00	13
Difference	-13.32	€ 1,693.00	12
Percentage	-19%	1%	1200%

Table D.79: Exp. 22 Renewable electric truck scenario results

Ex: 22b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	70.06	€ 176,843.00	1
Intermodal	36.93	€ 178,536.00	13
Difference	-33.12	€ 1,693.00	12
Percentage	-47%	1%	1200%

Table D.80: Exp. 22 Carbon price scenario results

Ex: 22c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	70.06	€ 180,696.12	1
Intermodal	56.73	€ 181,656.35	13
Difference	-13.32	€ 960.24	12
Percentage	-19%	1%	1200%

D.23. Experiment 23: High lane distance, High hub distance, Short-sea, Europe

Table D.81: Exp. 23 Distances

Experiment 23	
Truck distance:	1357 km
First/last mile distance:	557 km
Intermodal distance:	924 km

Table D.82: Exp. 23 Results

Ex: 23a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	51.70	€ 74,480.00	3
Intermodal	39.69	€ 44,450.00	14
Difference	-12.01	-€ 30,030.00	11
Percentage	-23%	-40%	367%

Table D.83: Exp. 23 Renewable electric truck scenario results

Ex: 23b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	51.70	€ 74,480.00	3
Intermodal	14.60	€ 44,450.00	14
Difference	-37.09	-€ 30,030.00	11
Percentage	-72%	-40%	367%

Table D.84: Exp. 23 Carbon price scenario results

Ex: 23c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	51.70	€ 77,323.28	3
Intermodal	39.69	€ 46,632.92	14
Difference	-12.01	-€ 30,690.36	11
Percentage	-23%	-40%	367%

D.24. Experiment 24: High lane distance, High hub distance, Short-sea, Europe

Table D.85: Exp. 24 Distances

Experiment 24	
Truck distance:	1737 km
First/last mile distance:	733.9 km
Intermodal distance:	2998 km

Table D.86: Exp. 24 Results

Ex: 24a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	113.13	€ 59,760.00	3
Intermodal	98.08	€ 56,850.00	17
Difference	-15.04	-€ 2,910.00	14
Percentage	-13%	-5%	467%

Table D.87: Exp. 24 Renewable electric truck scenario results

Ex: 24b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	113.13	€ 59,760.00	3
Intermodal	50.62	€ 56,850.00	17
Difference	-62.51	-€ 2,910.00	14
Percentage	-55%	-5%	467%

Table D.88: Exp. 24 Carbon price scenario results

Ex: 24c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	113.13	€ 65,981.99	3
Intermodal	98.08	€ 62,244.57	17
Difference	-15.04	-€ 3,737.42	14
Percentage	-13%	-6%	467%

D.25. Experiment 25: Low lane distance, Low hub distance, Rail, U.S.

Table D.89: Exp. 25 Distances

Experiment 25	
Truck distance:	419 km
First/last mile distance:	26.2 km
Intermodal distance:	425.1 km

Table D.90: Exp. 25 Results

Ex: 25a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	137.85	€ 176,235.54	1
Intermodal	103.80	€ 111,811.97	10
Difference	-34.06	-€ 64,423.57	9
Percentage	-25%	-37%	900%

Table D.91: Exp. 25 Renewable electric truck scenario results

Ex: 25b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	137.85	€ 176,235.54	1
Intermodal	95.18	€ 111,811.97	10
Difference	-42.68	-€ 64,423.57	9
Percentage	-31%	-37%	900%

Table D.92: Exp. 25 Carbon price scenario results

Ex: 25c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	137.85	€ 183,817.35	1
Intermodal	103.80	€ 117,520.74	10
Difference	-34.06	-€ 66,296.61	9
Percentage	-25%	-36%	900%

D.26. Experiment 26: Low lane distance, Low hub distance, Rail, U.S.

Table D.93: Exp. 26 Distances

Experiment 26	
Truck distance:	595 km
First/last mile distance:	23 km
Intermodal distance:	689 km

Table D.94: Exp. 26 Results

Ex: 26a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	117.45	€ 150,157.73	1
Intermodal	82.97	€ 103,865.00	10
Difference	-34.49	-€ 46,292.73	9
Percentage	-29%	-31%	900%

Table D.95: Exp. 26 Renewable electric truck scenario results

Ex: 26b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	117.45	€ 150,157.73	1
Intermodal	78.43	€ 103,865.00	10
Difference	-39.03	-€ 46,292.73	9
Percentage	-33%	-31%	900%

Table D.96: Exp. 26 Carbon price scenario results

Ex: 26c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	117.45	€ 156,617.64	1
Intermodal	82.97	€ 108,428.17	10
Difference	-34.49	-€ 48,189.48	9
Percentage	-29%	-31%	900%

D.27. Experiment 27: High lane distance, Low hub distance, Rail, U.S.

Table D.97: Exp. 27 Distances

Experiment 27	
Truck distance:	3162 km
First/last mile distance:	20.4 km
Intermodal distance:	3217 km

Table D.98: Exp. 27 Results

Ex: 27a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	1664.48	€ 2,127,949.53	4
Intermodal	794.24	€ 1,234,139.31	17
Difference	-870.24	-€ 893,810.22	13
Percentage	-52%	-42%	325%

Table D.99: Exp. 27 Renewable electric truck scenario results

Ex: 27b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	1664.48	€ 2,127,949.53	4
Intermodal	783.50	€ 1,234,139.31	17
Difference	-880.98	-€ 893,810.22	13
Percentage	-53%	-42%	325%

Table D.100: Exp. 27 Carbon price scenario results

Ex: 27c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	1664.48	€ 2,219,495.75	4
Intermodal	794.24	€ 1,277,822.34	17
Difference	-870.24	-€ 941,673.41	13
Percentage	-52%	-42%	325%

D.28. Experiment 28: High lane distance, Low hub distance, Rail, U.S.

Table D.101: Exp. 28 Distances

Experiment 27	
Truck distance:	1996 km
First/last mile distance:	43.5 km
Intermodal distance:	2045 km

Table D.102: Exp. 28 Results

Ex: 28a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	428.16	€ 547,378.34	3
Intermodal	213.45	€ 328,089.40	12
Difference	-214.71	-€ 219,288.94	9
Percentage	-50%	-40%	300%

Table D.103: Exp. 28 Renewable electric truck scenario results

Ex: 28b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	428.16	€ 547,378.34	3
Intermodal	204.13	€ 328,089.40	12
Difference	-224.03	-€ 219,288.94	9
Percentage	-52%	-40%	300%

Table D.104: Exp. 28 Carbon price scenario results

Ex: 28c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	428.16	€ 570,927.03	3
Intermodal	213.45	€ 339,829.28	12
Difference	-214.71	-€ 231,097.75	9
Percentage	-50%	-40%	300%

D.29. Experiment 29: Low lane distance, High hub distance, Rail, U.S.

Table D.105: Exp. 29 Distances

Experiment 29	
Truck distance:	611 km
First/last mile distance:	269 km
Intermodal distance:	380 km

Table D.106: Exp. 29 Results

Ex: 29a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	21.71	€ 27,755.21	1
Intermodal	19.18	€ 21,950.22	10
Difference	-2.53	-€ 5,804.99	9
Percentage	-12%	-21%	900%

Table D.107: Exp. 29 Renewable electric truck scenario results

Ex: 29b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	21.71	€ 27,755.21	1
Intermodal	9.62	€ 21,950.22	10
Difference	-12.09	-€ 5,804.99	9
Percentage	-56%	-21%	900%

Table D.108: Exp. 29 Carbon price scenario results

Ex: 29c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	21.71	€ 28,949.26	1
Intermodal	19.18	€ 23,005.23	10
Difference	-2.53	-€ 5,944.03	9
Percentage	-12%	-21%	900%

D.30. Experiment 30: Low lane distance, High hub distance, Rail, U.S.

Table D.109: Exp.30 Distances

Experiment 30	
Truck distance:	572 km
First/last mile distance:	175 km
Intermodal distance:	607 km

Table D.110: Exp. 30 Results

Ex: 30a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	575.86	€ 736,201.89	1
Intermodal	542.29	€ 665,647.17	10
Difference	-33.56	-€ 70,554.73	9
Percentage	-6%	-10%	900%

Table D.111: Exp. 30 Renewable electric truck scenario results

Ex: 30b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	575.86	€ 736,201.89	1
Intermodal	366.10	€ 665,647.17	10
Difference	-209.75	-€ 70,554.73	9
Percentage	-36%	-10%	900%

Table D.112: Exp. 30 Carbon price scenario results

Ex: 30c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	575.86	€ 767,873.93	1
Intermodal	542.29	€ 695,473.26	10
Difference	-33.56	-€ 72,400.68	9
Percentage	-6%	-9%	900%

D.31. Experiment 31: High lane distance, High hub distance, Rail, U.S.

Table D.113: Exp. 31 Distances

Experiment 31	
Truck distance:	1570 km
First/last mile distance:	901 km
Intermodal distance:	2155 km

Table D.114: Exp. 31 Results

Ex: 31a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	103.31	€ 132,071.50	2
Intermodal	124.86	€ 177,984.79	13
Difference	21.55	€ 45,913.29	11
Percentage	21%	35%	550%

Table D.115: Exp. 31 Renewable electric truck scenario results

Ex: 31b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	103.31	€ 132,071.50	2
Intermodal	65.57	€ 177,984.79	13
Difference	-37.74	€ 45,913.29	11
Percentage	-37%	35%	550%

Table D.116: Exp. 31 Carbon price scenario results

Ex: 31c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	103.31	€ 137,753.33	2
Intermodal	124.86	€ 184,851.84	13
Difference	21.55	€ 47,098.50	11
Percentage	21%	34%	550%

D.32. Experiment 32: High lane distance, High hub distance, Rail, U.S.

Table D.117: Exp. 32 Distances

Experiment 32	
Truck distance:	933 km
First/last mile distance:	376.73 km
Intermodal distance:	1264 km

Table D.118: Exp. 32 Results

Ex: 32a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	44.20	€ 56,509.78	2
Intermodal	47.80	€ 65,974.04	11
Difference	3.60	€ 9,464.27	9
Percentage	8%	17%	450%

Table D.119: Exp. 32 Renewable electric truck scenario results

Ex: 32b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	44.20	€ 56,509.78	2
Intermodal	29.95	€ 65,974.04	11
Difference	-14.25	€ 9,464.27	9
Percentage	-32%	17%	450%

Table D.120: Exp. 32 Carbon price scenario results

Ex: 32c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	44.20	€ 58,940.88	2
Intermodal	47.80	€ 68,603.11	11
Difference	3.60	€ 9,662.23	9
Percentage	8%	16%	450%

D.33. Experiment 33: Low lane distance, Low hub distance, Rail, Ethiopia

Table D.121: Exp. 33 Distances

Experiment 33	
Truck distance:	384 km
First/last mile distance:	14.4 km
Intermodal distance:	478 km

Table D.122: Exp. 33 Results

Ex: 33a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	58.85	€ 73,656.91	1
Intermodal	46.81	€ 54,628.99	9
Difference	-12.04	-€ 19,027.92	8
Percentage	-20%	-26%	800%

Table D.123: Exp. 33 Renewable electric truck scenario results

Ex: 33b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	58.85	€ 73,656.91	1
Intermodal	44.60	€ 54,507.62	9
Difference	-14.25	-€ 19,149.30	8
Percentage	-24%	-26%	800%

Table D.124: Exp. 33 Carbon price scenario results

Ex: 33c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	58.85	€ 70,420.19	1
Intermodal	46.81	€ 52,054.68	9
Difference	-12.04	-€ 18,365.51	8
Percentage	-20%	-26%	800%

D.34. Experiment 34 High lane distance, Low hub distance, Rail, Ethiopia

Table D.125: Exp. 34 Distances

Experiment 34	
Truck distance:	503 km
First/last mile distance:	90.9 km
Intermodal distance:	427 km

Table D.126: Exp. 34 Results

Ex: 34a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	0.71	€ 846.27	1
Intermodal	0.51	€ 557.90	9
Difference	-0.20	-€ 288.36	8
Percentage	-28%	-34%	800%

Table D.127: Exp. 34 Renewable electric truck scenario results

Ex: 34b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	0.71	€ 846.27	1
Intermodal	0.38	€ 557.90	9
Difference	-0.33	-€ 288.36	8
Percentage	-46%	-34%	800%

Table D.128: Exp. 34 Carbon price scenario results

Ex: 34c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	0.71	€ 885.16	1
Intermodal	0.51	€ 585.93	9
Difference	-0.20	-€ 299.24	8
Percentage	-28%	-34%	800%

D.35. Experiment 35 Low lane distance, High hub distance, Rail, Ethiopia

Table D.129: Exp. 35 Distances

Experiment 35	
Truck distance:	284 km
First/last mile distance:	237.7 km
Intermodal distance:	57.5 km

Table D.130: Exp. 35 Results

Ex: 35a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	0.40	€ 477.81	1
Intermodal	0.52	€ 454.45	9
Difference	0.12	-€ 23.36	8
Percentage	30%	-5%	800%

Table D.131: Exp. 35 Renewable electric truck scenario results

Ex: 35b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	0.40	€ 477.81	1
Intermodal	0.52	€ 454.45	9
Difference	0.12	-€ 23.36	8
Percentage	30%	-5%	800%

Table D.132: Exp. 35 Carbon price scenario results

Ex: 35c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	0.40	€ 499.77	1
Intermodal	0.52	€ 482.89	9
Difference	0.12	-€ 16.88	8
Percentage	30%	-3%	800%

D.36. Experiment 36 High lane distance, High hub distance, Rail, Ethiopia

Table D.133: Exp. 36 Distances

Experiment 36	
Truck distance:	937 km
First/last mile distance:	510.2 km
Intermodal distance:	427 km

Table D.134: Exp. 36 Results

Ex: 36a	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	1.32	€ 1,576.45	2
Intermodal	1.10	€ 1,263.35	9
Difference	-0.22	-€ 313.10	7
Percentage	-17%	-20%	350%

Table D.135: Exp. 36 Renewable electric truck scenario results

Ex: 36b	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	1.63	€ 1,576.45	2
Intermodal	1.10	€ 1,263.35	9
Difference	-0.53	-€ 313.10	7
Percentage	-32%	-20%	350%

Table D.136: Exp. 36 Carbon price scenario results

Ex: 36c	Emissions t CO2eq	Costs EUR	Lead-time Days
Truck	1.32	€ 1,648.90	2
Intermodal	1.10	€ 1,323.80	9
Difference	-0.22	-€ 325.10	7
Percentage	-17%	-20%	350%