INDUSTRIAL ENGINEERING AND MANAGEMENT

BACHELOR THESIS

Assessing the Impact of a New Container Depot in Hengelo on CO_2 Emissions and Fuel Consumption

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Management Summary

This thesis investigates the potential environmental benefits of establishing a new container depot in Hengelo for Cleaning Twente (CT) and Inland Terminals Group (ITG). The research specifically focuses on reducing CO_2 emissions and fuel consumption in the companies' logistics processes by comparing the current situation where containers are moved to and from seaports in Rotterdam and Antwerp with a proposed future scenario in which containers are processed locally in Hengelo.

To structure the research, the CRISP-DM methodology was used, guiding the project through the phases of Business Understanding, Data Understanding, Data Preparation, Modeling, Evaluation, and Deployment. In parallel, a Systematic Literature Review (SLR) following the PRISMA framework was conducted to identify appropriate emission calculation methods. Two main methods were selected: the Wheel-to-Wheel (WTW) method and the Emission Factor-Based Approach. These methods were applied across three key components of the logistics chain: container handling, truck transport, and barge transport.

The data for the analysis was drawn primarily from real operational figures provided by CT and ITG for the years 2018 and 2019. Results show that truck transport is the most emission-intensive component, with an average of 0.913 kg CO_2 emitted per kilometer based on 2019 data. Barge transport, while more sustainable, showed slightly increased emissions per TEU in 2019 compared to 2018. Container handling emissions improved over time, with a decrease in diesel reliance and better energy efficiency per handling.

One of the key findings is that introducing a local depot in Hengelo could reduce annual truck kilometers by over 1.28 million, saving more than 382,000 liters of diesel and cutting CO_2 emissions by around 1.23 million kilograms annually a reduction of roughly 43%. These environmental improvements stem mainly from the elimination of long-distance return trips for empty containers and more localized handling and storage operations.

The thesis contributes practical value to CT and ITG by offering data-driven evidence for the sustainability benefits of investing in a local depot. It also demonstrates the applicability of the CRISP-DM framework to real-world logistics challenges. Although the study focused on two main routes and limited time periods, the methods used are scalable and can be applied to other routes or extended to future decision-making processes.

In conclusion, the research shows that the proposed depot in Hengelo has strong potential to enhance operational sustainability. The findings provide a foundation for CT and ITG to reduce emissions, optimize fuel use, and take a significant step toward greener container logistics in the Eastern Netherlands.

Preface

This thesis marks the final stage of my Bachelor's degree in Industrial Engineering and Management at the University of Twente. It was an insightful and rewarding project in which I had the opportunity to apply the knowledge and skills I acquired during my studies to a real-world case in the field of sustainable logistics.

The research was conducted in collaboration with CT and ITG, who are exploring the possibility of establishing a new container depot in Hengelo. The main goal of this project was to evaluate whether this new depot could reduce CO_2 emissions and fuel consumption by shortening container transport routes and improving logistics efficiency.

Throughout this project, I have learned a great deal about the importance of data-driven decision-making, sustainability in logistics, and the practical use of models such as CRISP-DM and WTW. It also gave me the chance to collaborate with professionals in the field, conduct interviews, and analyze real operational data experiences that I believe will be valuable for my future career.

I would like to thank my supervisors from the University of Twente for their support, guidance, and constructive feedback throughout the process. I would also like to express my gratitude to the representatives of CT and ITG for their time, data, and valuable insights, which were crucial to the success of this research.

I hope this thesis provides useful insights for both the companies and future research in the area of sustainable logistics and emission reduction.

Iyad Rasea
University of Twente
April 2025

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List of Abbreviations

CO_2: Carbon Dioxide

CSRD: Corporate Sustainability Reporting Directive

CT: Cleaning Twente

DIB: Depot in Barge

DOB: Depot out Barge

ERB: Export Roundtrip Barge

ERT: Export Roundtrip Truck

ESB: Export Singletrip Barge

EST: Export Singletrip Truck

GHG: Greenhouse Gas

IRB: Import Roundtrip Barge

IRT: Import Roundtrip Truck

ISB: Import Singletrip Barge

IST: Import Singletrip Truck

ITG: Inland Terminals Group

LCA: Life Cycle Assessment

MDO: Marine Diesel Oil

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

SLR: Systematic Literature Review

TEU: Twenty-foot Equivalent Unit

TTW: Tank-to-Wheel

WTT: Wheel-to-Tank

WTW: Wheel-to-Wheel

1. Introduction

This section begins by introducing Carbon dioxide (CO_2) in Section 1.1, explaining its role as a greenhouse gas (GHG) and why it is relevant to this research. In Section 1.2, the background of the project is discussed, including information about the companies involved, CT and ITG. Section 1.3 focuses on identifying the core problem by using tools like the why-why analysis and the problem cluster to break down the causes and effects. Finally, Section 1.4 presents the research design, where the main research question and supporting sub-questions are outlined, along with how the study is set up to evaluate the environmental impact of building a new depot in Hengelo.

1.1. Background and Involved Companies

The research is conducted at Cleaning Twente (CT) and Inland Terminals Group (ITG). CT was founded in 1987, and it is a high-quality tank cleaning company in Hengelo. In over 30 years, CT gained a lot of experience and reputation to become one of the key companies in the cleaning and transporting containers sector (Sanderman Cleaning Group, 2022). There are three different services provided by the company, which are tank container cleaning, inspection and minor repairs, and ensuring the containers meet the safety and quality to be reused. Moving on, ITG which is a company focused on containers transport and has succeeded in cutting their the CO_2 emissions in half (Inland Terminals Group, 2023). ITG operates 17 different terminals and aims to establish a depot in Hengelo, as there is currently no depot in the Eastern Netherlands. Both CT and ITG are exploring the opportunity of establishing an empty container depot in Hengelo. This research focuses on the sustainability impact of this new container depot.

The companies are exploring the possibility of establishing a new container depot in Hengelo to support logistical activities such as cleaning, repairing, and storing containers within the eastern region of the Netherlands. The primary intention behind this initiative is to reduce the dependency on transporting empty containers to and from Rotterdam and Antwerp. This study aims to assess whether localizing these operations through a Hengelo depot can effectively reduce transport distances, lower CO_2 emissions and fuel consumption, and ultimately enhance the overall efficiency of the companies' logistics processes.

1.2. Current Situation

In Figure 1 is the existing logistics setup, containers are transported either by barge over a distance of 238 km or by truck over 209 km from the Rotterdam depot to the Hengelo terminal. Upon arrival in Hengelo, containers are transferred onto trucks for final delivery to customers within the region.

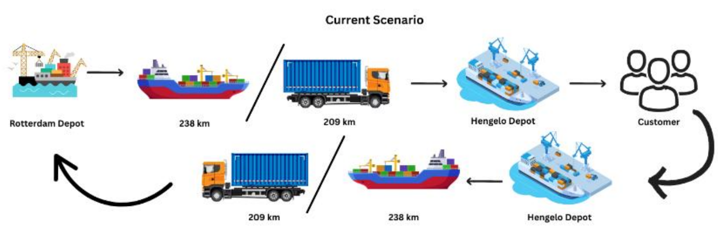

Figure 1: Current Situation

After being unloaded at the customer location, the containers are returned to the Hengelo terminal, where they are prepared for transport back to Rotterdam either by barge or by truck, depending on operational needs.

Because there is no local depot in Hengelo, empty containers must make the return journey to Rotterdam for cleaning, storage, or further handling. This generates additional transport movements, resulting in higher fuel consumption, increased CO_2 emissions, longer lead times, and elevated operational costs.

1.3. New Depot Situation

In Figure 2 is the proposed new scenario, the logistics flow is optimized by introducing a local container depot in Hengelo.

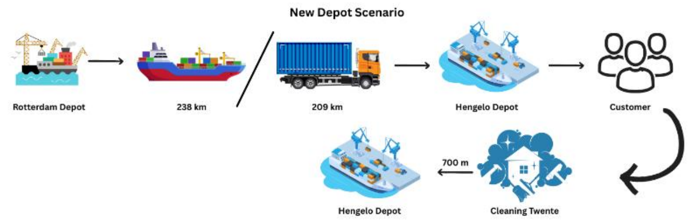

Figure 2: New Depot Situation

Containers are initially transported from the Rotterdam depot to the Hengelo terminal, either by barge (238 km) or truck (209 km), as in the current process. From the terminal, they are delivered by truck directly to customers.

Once unloaded, instead of being returned to Rotterdam, containers are moved to CT, located just 700 meters from the Hengelo terminal. After cleaning, the containers are stored at the newly established Hengelo depot, making them readily available for future customer orders or reloading.

This new flow eliminates the need for long-distance returns to Rotterdam, significantly reducing transport distances, diesel consumption, CO_2 emissions, and overall logistics costs. It also shortens lead times and enhances the sustainability and efficiency of logistics operations.

1.4. Problem Identification

ITG and CT are exploring the opportunity of establishing a new depot in the Eastern part of the Netherlands. Four projects are being conducted to create a lay-out design, collaborative business processes, assess the financial feasibility, and evaluate the sustainability aspects. This project would help both companies to have their depot in the East of the Netherlands which would make it easier for them to transport the containers more effectively as well as more environmentally friendly. The aim of this project is to calculate the CO_2 emissions and fuel consumption for the new depot which would be in Hengelo and then compare it with the current practice in Rotterdam and Antwerp. The project will focus on two different routes: from Rotterdam to Hengelo and from Antwerp to Hengelo.

To identify the core problem and get into the roots of it, a why-why analysis was conducted, as shown in Figure 3. This helped to visualize the problem and make it clear what are the causes so that a problem cluster can be developed after that.

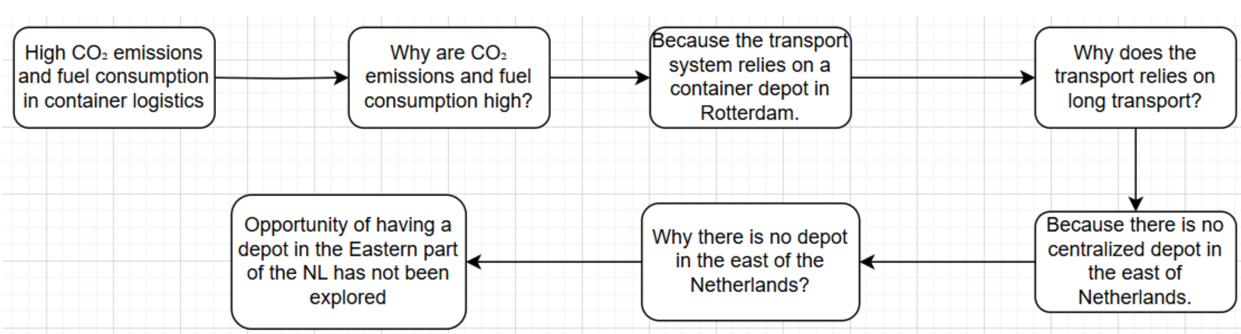

Figure 3: Why-why analysis

The why-why analysis is used to break down a problem into its root causes in a structured way (Kumar et al., 2020). In this study, the main issue identified is the high level of CO_2 emissions and fuel consumption in container logistics. As shown in Figure 3, one of the key reasons for this is the transport system's dependence on a container depot located in Rotterdam.

This reliance on long-distance transport exists because there is no centralized depot available in the eastern part of the Netherlands. In addition, the possibility of setting up a local depot in the east has not yet been fully explored, meaning that companies continue to rely on the depots in Rotterdam.

By conducting the why-why analysis, the core reasons behind the high emissions and fuel consumption have been made clear, providing a basis for developing the problem cluster and guiding the focus of this research.

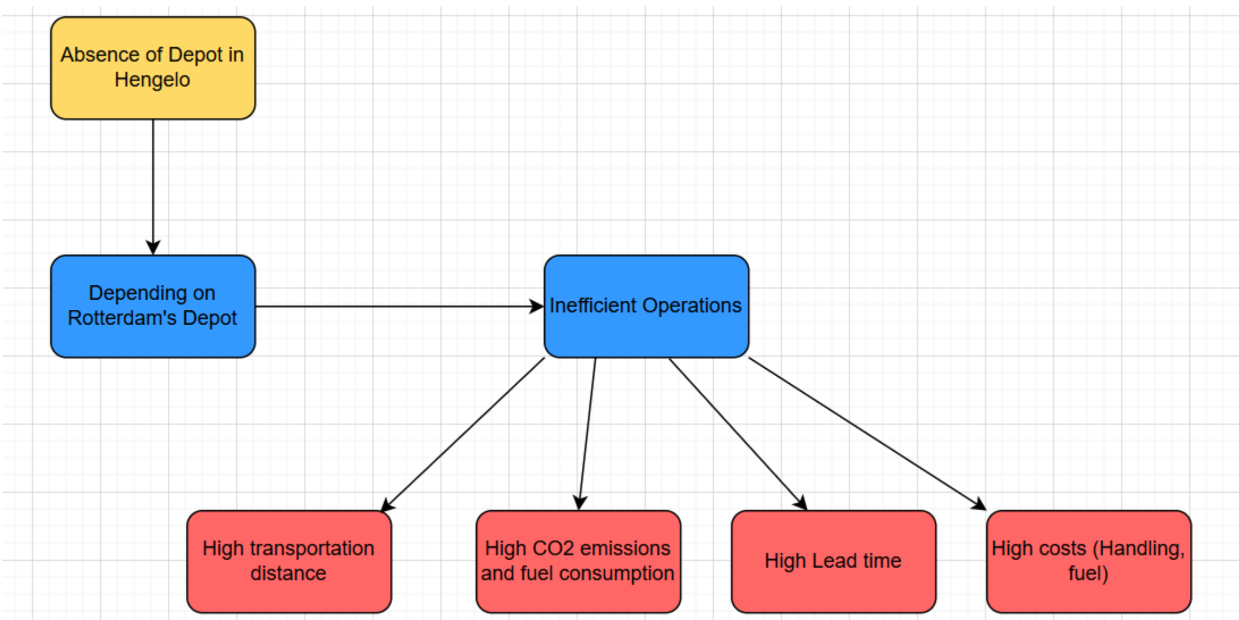

Figure 4: Problem Cluster

The problem cluster shown in Figure 4 illustrates the core issue of this research: the absence of a container depot in Hengelo, located in the eastern region of the Netherlands. Because there is no local depot, companies currently depend on the ITG depot in Rotterdam for services such as cleaning, repairing, and storing containers. The distance between Rotterdam and Hengelo ranges from approximately 202 to 209 kilometers, depending on the specific route (Google Maps, 2024).

This reliance on a distant depot leads to several operational challenges. Empty containers must be transported back to Rotterdam after customer delivery, which results in longer transport distances of over 200 kilometers. This, in turn, causes higher fuel consumption, increased CO_2 emissions, and longer lead times. Transporting a container by truck from Hengelo to Rotterdam typically takes around 2 to 3 hours. Additionally, operational costs, particularly those related to fuel usage and handling activities, are significantly higher compared to a scenario with a local depot.

Figure 4 highlights the consequences of this dependency, showing how it results in inefficient operations, including high transportation distances, high emissions and fuel consumption, long lead times, and increased operational costs. However, the figure only visualizes the problem drivers; it does not yet quantify the exact impact or confirm the improvements. Therefore, further analysis in this study is necessary to measure and validate the potential benefits of establishing a depot in Hengelo.

The goal is to move from the current situation, which heavily relies on Rotterdam, to a future situation where a local depot supports shorter distances, reduced emissions, lower costs, and improved logistical efficiency.

1.5. Research Design

This section describes the research design applied in this thesis. It explains the main research objective and question, the structure of the research process, and the methods used to address the problem. The research design follows the CRISP-DM methodology to ensure a systematic and structured approach to data collection, analysis, and modeling.

1.5.1. Aim and Main Research Question

This research focuses on assessing the environmental impact of setting up a new container depot in Hengelo, with a specific focus on CO_2 emissions and fuel consumption in container logistics. The main research question guiding this project is:

"To what extent can a new container depot in Hengelo reduce the environmental footprint in container logistics by decreasing CO_2 emissions and fuel consumption?"

The purpose of this question is to compare the current logistics situation, where containers are mostly transported from Rotterdam and Antwerp, with a possible future scenario where a local depot in Hengelo would be available. This involves calculating CO_2 emissions and fuel usage for both situations to determine whether having a depot closer to the East of the Netherlands would make logistics more environmentally friendly.

In this research, the norm refers to the ideal situation having a fully operational depot in Hengelo. This would allow for services like cleaning, repairing, and storing containers to happen locally, which reduces the distance containers need to travel. As a result, it could significantly lower fuel consumption and related emissions.

The reality is that Hengelo currently does not have such a depot. Because of that, companies like ITG still depend on the main depots in Rotterdam and Antwerp, which are far away. This leads to more road transportation, especially for empty containers, which increases emissions and fuel consumption.

By comparing the norm to the current situation, this research aims to assess the potential environmental benefits of establishing a container depot in Hengelo for CT and ITG. The study specifically investigates how localizing container operations in this context could support improvements in sustainability and operational efficiency. The findings are based on the case of Hengelo and are not intended to be generalized to all container logistics settings.

The assignment has some limitations and scopes such as the time frame of approximately 10 weeks and regarding the different types of data and calculations. Data is gathered from the companies regarding emissions and fuel consumption. Additional data is gathered from public sources.

1.5.2. Research Questions and Methods

The CRISP-DM methodology (Wirth & Hipp, n.d.) was chosen for this thesis because it offers a clear and systematic framework for handling data-driven projects in a structured way. Since container logistics projects often involve complex operational data that needs to be prepared, modeled, and evaluated carefully, CRISP-DM is particularly well suited to this type of research. It supports step-by-step refinement and ensures that data analysis follows a logical sequence, making it easier to manage and process large datasets effectively (Wirth & Hipp, n.d.).

CRISP-DM consists of six phases: Business Understanding, Data Understanding, Data Preparation, Modeling, Evaluation, and Deployment. These phases structure the research activities in this thesis and will be explained in more detail in the following section.

Table 1 shows how each sub-research question is linked to a specific phase of the CRISP-DM methodology, along with the type of research and the method used to answer each question.

Sub Research Questions	Type of research	Phase	Method
1. What are the key objectives for establishing the new depot?	Exploratory research	Business understanding	Interview with stakeholder.
2. Which data is required to calculate/estimate emissions and fuel consumption?	Exploratory research	Data understanding and preparation	Data analysis
3. What tools or software are capable of modeling emissions and fuel consumptions for the current and future situation?	Theoretical research	Modeling	Literature review
4. Which specific sustainability and operational metrics (e.g., CO_2 emissions, fuel consumption) need to be evaluated?	Explanatory research	Evaluation	Interview

Table 1: Research Design

Table 1 presents the sub-research questions that support the main research focus of this thesis. Each question is linked to a specific type of research, the corresponding phase of the CRISP-DM methodology, and the method used to answer it. The first question investigates the key goals for setting up a new depot in Hengelo, which is explored during the Business Understanding phase through interviews with stakeholders. This helps clarify the companies' intentions and expectations. The second question focuses on identifying what kind of data is required to calculate emissions and fuel usage, and how this data can be organized and validated. This is covered in the Data Understanding and Data Preparation phases using data analysis. The third question addresses which tools or models can be used to estimate emissions, which are theoretical in nature and handled during the Modeling phase by reviewing literature on relevant tools and approaches. The final question focuses on which sustainability and operational indicators should be evaluated, such as CO_2 output and fuel consumption. This is explored during the Evaluation phase using interviews to understand what matters most to the companies from a sustainability point of view.

1.6. Report Structure

To help guide the reader, the structure of this thesis is outlined below. Each chapter is designed to build logically upon the previous one, following the research process step-by-step. The thesis starts by introducing the problem and research design, then explains the problem-solving approach using the CRISP-DM methodology. After that, the research methods, data analysis, and results are presented, leading to conclusions and recommendations. The table below provides an overview of the structure and content of each chapter.

Chapter	Title	Description
1	Introduction	Introduces the background, the research problem, objectives, research questions, and research design.
2	Problem-Solving Approach	Explains the application of the CRISP-DM methodology and how it structures the research process.
3	Systematic Literature Review	Describes the PRISMA framework and reviews methods and tools for calculating CO_2 emissions and fuel consumption.
4	Business Understanding	Presents insights from interviews with CT and ITG and outlines current transport flows and logistics challenges.
5	Data Understanding	Describe the data collection process and categorize the main datasets for container handling, trucking, and barges.
6	Data Preparation	Explains how the collected data was prepared, cleaned, and structured for further modeling and evaluation.
7-8	Modeling and Evaluation	Details the modeling of CO_2 emissions and fuel consumption for different logistics scenarios and evaluates the potential environmental impact of the new depot.
9	Deployment Plan	Discusses how the research results can be applied practically by CT and ITG, including recommendations for future implementation and tracking.
10	Conclusion and Recommendations	Summarizes the main findings, discusses contributions and limitations, and offers recommendations for practice and future research.

Table 2: Report Structure

2. Problem-Solving Approach

This section explains how the CRISP-DM framework was applied throughout the research. CRISP-DM offers a step-by-step structure that helped organize the project, from identifying the goals of the companies to preparing and analyzing the data. Each stage of the method is linked to the sub-research questions, helping to evaluate CO_2 emissions and fuel consumption in a systematic and clear way.

2.1. CRISP-DM

For the approach, the CRISP-DM method is used for this research as it provides the approach to analyze the CO_2 emissions and fuel consumption. It was chosen for the assignment since the CRISP-DM methodology is used for systematic approaches, mostly used for data mining and data science projects. The CRISP-DM methodology goes through six different steps and is shown in Figure 5 which are: Business Understanding, Data Understanding, Data Preparation, Modeling, Evaluation and Deployment. Each cycle will be explained individually below for more understanding.

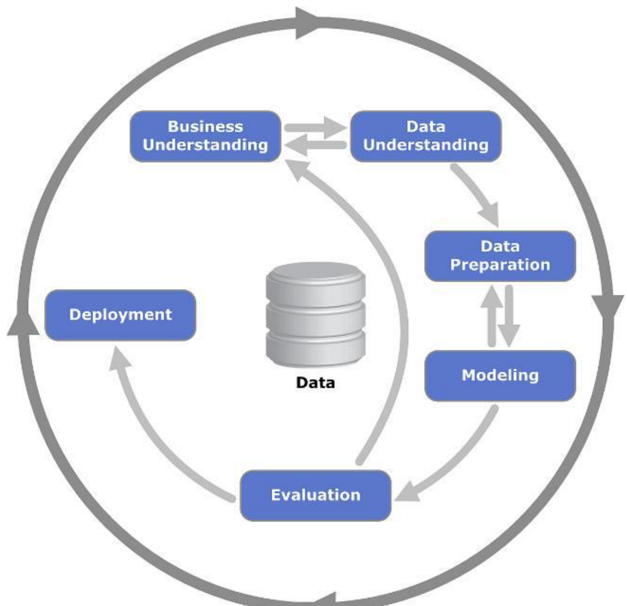

Figure 5: CRISP-DM method (Chumbar, 2023)

2.2. Use of CRISP-DM

The research follows the CRISP-DM methodology to ensure a structured and systematic approach in analyzing the environmental impact of the logistics processes. Each phase of the CRISP-DM cycle: Business Understanding, Data Understanding, Data Preparation, Modeling, Evaluation, and Deployment is carefully applied and adapted to the needs of this study. The following sections explain how each phase was carried out and how they contributed to answering the sub-research questions.

2.2.1. Business Understanding

The first phase of the CRISP-DM methodology, as described by Wirth and Hipp (n.d.), focuses on developing a clear understanding of the business goals and defining the problem that needs to be solved. This stage helps to shape the direction of the research by identifying the core and action problems, and by formulating the main and sub-research questions. To answer Sub Research Question 1, it was important to understand what the companies involved in this project aim to achieve. For this reason, semi-structured interviews were held with representatives from both companies. These interviews were useful because they allowed some flexibility in the discussion while still focusing on the key objectives. The insights gained helped clarify what the companies expect from the project and why reducing CO_2 emissions and fuel consumption is important to them. This also guided how data analysis would be used to support their sustainability goals. The interviews conducted with representatives from CT and ITG are further detailed in Appendix E – Interview Summary 1and Appendix F – Interview Summary 2, where the interview summaries and participants' roles are provided.

2.2.2. Data Understanding

The data understanding phase focuses on identifying which types of data are important for the research and how this data can be collected and interpreted (Wirth & Hipp, n.d.). This step is essential for answering Sub Research Question 2, which investigates the data needed to estimate CO_2 emissions and fuel consumption. For this thesis, most of the data sets were provided directly by the companies involved, CT and ITG. These datasets offer accurate insights into real-life operations and will be described in more detail in the following sections. In addition to company data, external information was collected from trusted public sources to support the analysis. Examples include emission factors for diesel and electricity obtained from the Climate Neutral Group (2021) and marine diesel oil (MDO) emission factors from CarbonFootprinting.org. Gaining a clear understanding of both internal and external data sources ensures that the next steps in the project are based on reliable, consistent, and relevant information.

2.2.3. Data Preparation

The data preparation stage is a key part of the CRISP-DM process, as it ensures that the data used in the research is accurate, consistent, and ready for analysis (Wirth & Hipp, n.d.). In this phase, the raw data collected from the companies and external sources is cleaned by checking for errors, filling in missing values if necessary, and removing any irrelevant information. Sometimes, new variables are also created to support specific calculations, such as CO_2 emissions or fuel consumption. By doing this, the data becomes structured and more suitable for analysis and modelling, which helps ensure that the results of the study are valid and can be used with confidence in the modeling and evaluation steps.

2.2.4. Modelling

During the modeling phase, specific calculation models were built to estimate CO_2 emissions and fuel consumption for different logistics scenarios (Wirth & Hipp, n.d.). These models used the WTW method and an emission factor-based approach to quantify the environmental impact of transportation and container handling activities. For this research, models were developed to simulate two main transport routes: Rotterdam–Hengelo and Antwerp–Hengelo. Both the current situation (without a local depot) and the proposed future situation (with a depot in Hengelo) were modeled. The main objective was to calculate and compare the CO_2 emissions and fuel consumption for each route and scenario. The results from the modeling phase provided concrete insights into the potential sustainability gains from establishing a depot in Hengelo and formed the basis for the evaluation and recommendations sections.

2.2.5. Evaluation

During the evaluation phase, the models created in the earlier stages are reviewed to determine how well they reflect the actual logistics situation and whether they provide meaningful results. The goal is to assess the impact of establishing a new depot in Hengelo by comparing it with the current setup that depends on depots in Rotterdam and Antwerp. By using emission factor-based calculations and real operational data from the companies, the differences in CO_2 emissions and fuel consumption are examined. While no complex statistical tools were used, the comparison still provides a solid understanding of how logistics efficiency and sustainability could improve with the new depot. This analysis directly contributes to answering sub-research question 4 and offers valuable insights for companies to consider in future planning and sustainability strategies.

2.2.6. Deployment

The deployment phase is about how the results of this research could be used by the companies in practice. Even though actual deployment is not part of the scope of this thesis, the developed model can support future decisions at ITG and CT. Since the research only focuses on a limited number of transport routes and is based on available data, full implementation would require further work and more detailed input. Still, the outcomes offer valuable insights into the environmental impact of different logistics setups. To help guide future use, a general implementation plan and recommendations have been included, so the companies can apply the model when considering operational changes or evaluating sustainability improvements.

2.3. Summary and Conclusion

Using the CRISP-DM approach provides a clear structure to guide this research. The business goals are explored through interviews, the necessary data are collected and prepared, and models are built to compare the current logistics situation with the potential impact of a new depot in Hengelo. The CRISP-DM method ensures that the analysis of emissions and fuel use is conducted in a systematic and reliable way, aiming to provide both companies with useful insights for improving sustainability in the future.

3. Methodology

In the previous chapter, the CRISP-DM methodology was introduced to structure the research process. After identifying the business goals and understanding the available data, the next step is to determine how to accurately calculate CO_2 emissions and fuel consumption for the logistics activities under investigation. Since the research focuses on container transportation by truck, barge, and handling operations at terminals, it is important to apply scientifically validated methods for emissions calculation. To ensure that the chosen methods are appropriate, a systematic literature review (SLR) was conducted.

This chapter explains the research methods selected to support the environmental calculations required in this study. It begins by introducing the PRISMA framework (Moher et al., 2009), which was used to perform the SLR in a structured and transparent way. After that, the key variables and formulas used for emissions calculations in truck transport, barge transport, and container handling are described. Additionally, different calculation methods, such as WTW (Wheel-to-Wheel), TTW (Tank-to-Wheel), and the Emission Factor-Based approach, are discussed. More advanced tools like BigMile, EcoTransIT, and GaBi are also reviewed to show possible alternatives. Finally, the chapter explains why the selected methods are considered reliable and most suitable for this research.

3.1. Systematic Literature Review

The methodology used for the SLR is based on the PRISMA framework, a structured approach designed to ensure transparency, accuracy, and replicability in systematic reviews (Moher et al., 2009). PRISMA consists of four key phases: identification, screening, eligibility, and inclusion (Page et al., 2021). During the identification phase, academic databases such as Scopus, Web of Science, GreenFile, and ScienceDirect were used to find relevant studies. Specific search terms related to CO_2 emissions, fuel consumption, and logistics operations were applied to ensure a broad and relevant scope.

In the screening phase, duplicates and irrelevant papers were removed based on predefined inclusion and exclusion criteria. In the eligibility phase, the remaining articles were reviewed in full text to assess their quality, methodology, and relevance to the research topic. Finally, during the inclusion phase, only the most appropriate and peer-reviewed studies were selected for detailed analysis. The study design and templates for data extraction and quality assurance are included in Appendix B - Study Design

The SLR was necessary because this study compares different methods for calculating CO_2 emissions and fuel consumption, including WTW, TTW, Emission Factor-Based models, and Life Cycle Assessment (LCA) approaches. A systematic review ensures that only high-quality and scientifically validated methods are used as the basis for the environmental impact analysis carried out in the next chapters. Additionally, following the PRISMA methodology increases the transparency, consistency, and academic rigor of the study, allowing future researchers or company stakeholders to reproduce or extend the research in a structured way.

3.2. Analysis of SLR Results

This section analyzes the results of the systematic literature review (SLR) conducted to answer Sub Research Question 3. By using the PRISMA framework, a transparent selection and screening process was followed to ensure only high-quality and relevant studies were included. The outcomes of this process are summarized and explained below.

3.2.1. Prisma Flowchart

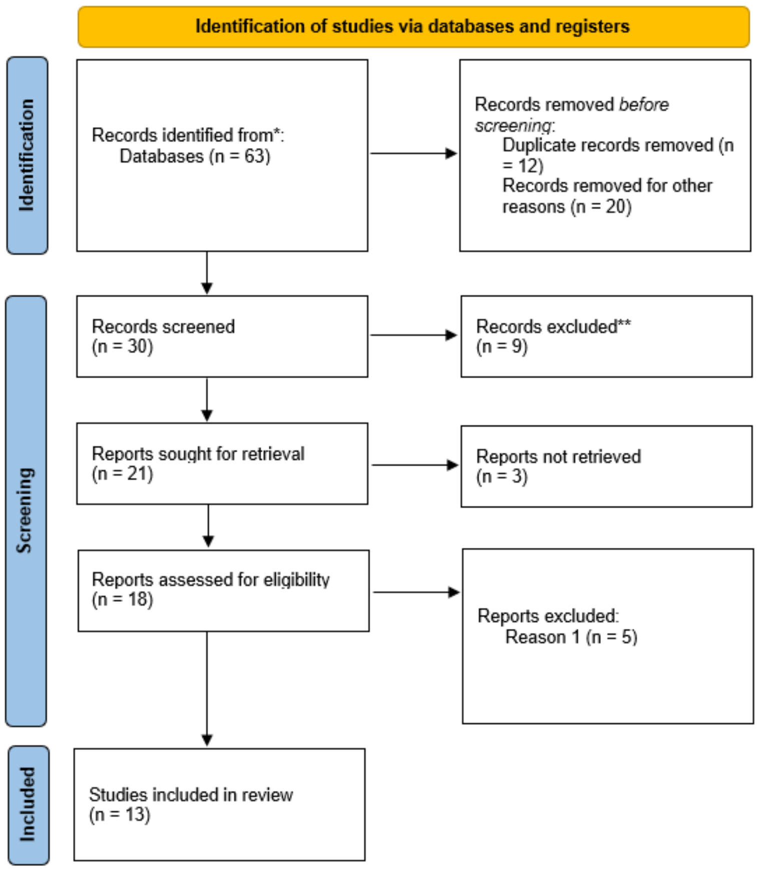

Figure 6: Prisma Flowchart (PRISMA, 2020)

To show how the sources for the SLR were selected, the PRISMA 2020 flowchart was used which is shown in Figure 6 (Page et al., 2021). This method provides a structured and transparent overview of the steps taken to collect, screen, and include the most relevant articles for the research.

The review process began by identifying 63 records through database searches in Scopus, Web of Science, and GreenFile. After removing 12 duplicate records and 20 records for other reasons (e.g., wrong focus, conference abstracts), 30 articles remained for screening based on title and abstract. During this screening phase, 9 articles were excluded because they did not align with the research topic or lacked a focus on CO_2 emissions and fuel consumption.

Subsequently, 21 articles were sought for full-text retrieval, of which 3 could not be accessed. Of the 18 full-text articles assessed for eligibility, 5 were excluded because they either used outdated methods, did not report clear emission calculation approaches, or were not applicable to the logistics sector analyzed in this study.

As a result, 13 key articles were included in the systematic review to support Sub Research Question 3. Additionally, through reference checking and snowballing techniques, 25 more related articles were identified and reviewed to strengthen the theoretical background and gain further insights. These additional sources were not part of the structured review but helped in understanding various tools and models, including WTW, TTW, LCA, and emission factor-based approaches.

Overall, the PRISMA process ensured that the selection of studies was systematic, transparent, and focused on high-quality sources relevant to emissions and fuel consumption calculations in container logistics.

3.2.2. Methods and Tools to Calculate the CO_2 emissions

There are different ways to calculate CO_2 emissions for logistics operations. To precisely assess the environmental impact, it is important to distinguish between calculation methods and software tools. First, three commonly used methods will be explained: the WTW method, the TTW method, and the Emission Factor-Based Approach. These methods provide the theoretical basis for calculating emissions depending on the fuel lifecycle and transportation activities. Afterwards, three tools that apply these methods in practice will be introduced: GaBi, BigMile, and EcoTransIT. These tools offer practical solutions for modeling CO_2 emissions across different logistics scenarios and transportation modes.

Each of the methods and tools provides a different level of detail and focus, allowing for a comprehensive analysis of the environmental impact of container transportation and handling activities.

3.2.2.1. Wheel-to-wheel (WTW) and Tank-to-wheel (TTW)

The Wheel-to-Wheel (WTW) approach examines the environmental impacts of fuel and energy usage across their entire life cycle, from the production phase to their final consumption in vehicles (Stettler et al., 2023). WTW can be divided into two stages: Wheel-to-Tank (WTT) and TTW. The WTT stage focuses on the extraction, production, and transportation of the fuel from its source until it reaches the distribution point. In contrast, the TTW stage measures emissions and energy efficiency associated with the actual use of the fuel in vehicles (Stettler et al., 2023). By combining both WTT and TTW stages, the WTW method provides a complete overview of the environmental impact of fuels throughout their entire life cycle (Krause et al., 2024).

Based on the findings from the studies of Stettler et al. (2023) and Krause et al. (2024), it can be concluded that the WTW approach is suitable for this research to calculate the fuel life cycle emissions during the usage phase. Nevertheless, other methods and tools are also available and will be discussed in the following sections.

3.2.2.2. Emission Factor-Based Approach

The Emission Factor-Based Approach provides a standardized method to calculate CO_2 emissions by multiplying activity data (such as fuel consumption or distance traveled) with specific emission factors assigned to different types of transport modes, fuels, and handling machinery (Budiyanto et al., 2024). This approach is widely used in logistics operations, particularly for calculating emissions from container handling at terminals.

The general formula for this method is:

$$CO_2 = Distance\ (km) \times Fuel\ consumption\ \left(\frac{L}{km}\right) \times Emission\ Factor\ (\frac{kg\ CO_2}{L})$$

Equation 1: General Formula for Container Handling

For container handling, a specialized version of the formula is applied:

$$CO_2(Handling) = Number\ of\ moves\ \times Fuel\ consumption\ per\ move\ \times Emission\ factor$$

Equation 2: Container Handling

Where:

- Number of Moves: The number of times a container is handled (e.g., lifting, shifting, storing).
- Fuel Consumption per Move: The fuel used per operation.
- Emission Factor: The CO_2 emissions per unit of fuel consumed.

To illustrate the application of this method, Figure 7 shows a practical example from an inland shipping terminal. In this case, a terminal transships 170,000 tons of cargo annually, consuming 450,000 kWh of electricity and 200,000 liters of diesel fuel. By applying appropriate emission factors for electricity and diesel (sourced from emissionfactoren.nl), the total emissions are calculated, resulting in an average of approximately 5.16 kg CO_2 per ton of cargo transshipped.

Figure 7: Transshipment Cargo (CarbonFootprint, n.d.)

This example highlights how emission factor-based calculations offer a clear, practical, and scalable way to estimate emissions across different logistics activities, supporting sustainable decision-making.

3.2.2.3. GaBi Tool

According to Herrmann and Moltesen (2015), GaBi (short for "Ganzheitliche Bilanzierung", meaning "holistic balancing" in German) is a well-established LCA tool used to model and evaluate the environmental impacts of products, processes, and services. Developed in 1992 by a German company, GaBi supports the calculation of carbon footprints across the entire lifecycle from raw material extraction to disposal or recycling stages. The software requires detailed data regarding logistics processes, including transport modes, fuel consumption, container quantities, and operational steps. Once the complete supply chain is modeled, GaBi calculates the associated emissions and environmental impacts based on international LCA databases and standards. GaBi is particularly useful for logistics emissions analysis because it allows detailed modeling of complex multi-stage processes and supports comparisons between different transport setups.

3.2.2.4. BigMile

BigMile is an emissions analysis tool designed specifically for the logistics and transport sector. It quantifies greenhouse gas emissions by processing operational data such as traveled distance, vehicle type, fuel type, and transported load (measured in tonnes or Twenty-foot Equivalent Units (TEUs)). BigMile follows established international standards, including EN 16258 and ISO 14083, ensuring that the results are credible and suitable for official carbon reporting (Carbonfootprinting.org, n.d.). Compared to traditional manual calculations, BigMile offers a user-friendly interface and standardized reporting formats. It enables companies to analyze emissions at different levels, such as shipment per ton-kilometer, or per container movement. In the context of emission modeling, BigMile can be particularly effective for evaluating the impacts of route choices, vehicle usage, and cargo efficiency in multi-modal transport scenarios.

3.2.2.5. EcoTransIT

EcoTransIT (Ecological Transport Information Tool) is a software tool designed to calculate the environmental impacts of freight transport. It models emissions based on several key parameters, including distance travel, vehicle type, fuel type, energy efficiency, and cargo load factor. EcoTransIT is well-suited for analyzing multimodal transport chains that involve combinations of ships, trucks, trains, and barges.

Unlike broader LCA tools, EcoTransIT focuses specifically on transport emissions and energy consumption. Users must input origin and destination points, transport modes, and cargo details, after which the tool calculates total CO_2 emissions and other environmental indicators (Carbonfootprinting.org, n.d.). EcoTransIT is particularly useful when comparing different logistics scenarios or transport strategies, offering a flexible and relatively fast way to estimate emissions for a variety of routes and setups.

3.2.2.6. Used Tool

Although tools such as BigMile, EcoTransIT, and GaBi offer advanced capabilities for calculating CO_2 emissions and assessing the full environmental impacts of logistics operations, they were not applied in this thesis. The primary reason for this is that these tools require paid licenses or company-specific access, which was not available for this research. Additionally, while the company provided useful operational data such as diesel consumption figures, transport distances, and container movement counts, it did not always supply the highly detailed and standardized input data needed for these software tools (e.g., exact fuel types, energy sources, specific load factors, or detailed lifecycle inventory data). Given these limitations, the thesis relied on two scientifically recognized and practical calculation methods: the WTW method and the emission factor-based approach. These methods were selected because they align with the type and level of detail of the available data. They also allow for a transparent, reproducible calculation process across different transport modes and scenarios.

The overview of BigMile, EcoTransIT, and GaBi was nevertheless included in the systematic literature review to provide a broader context. It highlights alternative tools that could be used for more detailed future analyses when more comprehensive data and software access are available. This comparison between traditional methods and advanced tools demonstrates the range of possibilities for modeling CO_2 emissions and supports informed decision-making for future sustainability assessments.

3.2.3. Validation and Reliability

The data used in this research, such as CO_2 emissions, fuel consumption, and travel distances, was provided directly by CT and ITG. Since this information comes from the companies involved in the logistics process, it is considered trustworthy and relevant for the study. The emission calculation methods used WTW, TTW, and Emission Factor-Based Approaches are based on well-established techniques supported by previous research (Stettler et al., 2023; Climate Neutral Group, 2021). These methods were chosen to make sure the results are accurate and scientifically sound. The steps taken in the calculations and the sources of data have been explained clearly, which helps make the research transparent and easy to reproduce. Although there may be small variations due to external factors like weather or equipment types, these have been considered by using consistent methods and reliable sources.

3.3. Summary and Conclusion

In summary, this section explained the research methods and tools used for analyzing CO_2 emissions and, indirectly, fuel consumption in logistics operations. While advanced tools such as GaBi, BigMile, and EcoTransIT offer detailed environmental assessments, they were not applied in this research due to limited access and the specific data requirements they demand. Instead, more practical approaches, namely the WTW method and the emission factor-based approach, were selected. These methods were chosen because they aligned well with the available company data, such as diesel consumption and transport distances, and allowed for reliable calculation of both emissions and fuel use. Although more sophisticated tools exist, the simpler methods were preferred due to limited access and the nature of the available data. Overall, the approach adopted in this research provided a clear and transparent basis for comparing current logistics practices with the potential environmental benefits of establishing a container depot in Hengelo.

4. Business Understanding

This section outlines the business context and logistics practices related to the project. Section 4.1 explains the goals and expectations of the two companies involved, CT and ITG, based on insights gained through semi-structured interviews. Following this, in Section 4.2 the various types of container transport flows used in current operations are introduced. These flows help illustrate the complexity of the logistics processes and provide context for evaluating how a new depot in Hengelo could improve sustainability and efficiency.

4.1. Interview Findings

To better understand the expectations of the companies involved in this project, semi-structured expert interviews were conducted with representatives from both CT and ITG (see Appendix E – Interview Summary 1and Appendix F – Interview Summary 2). These interviews revealed that both companies aim to enhance the sustainability of their transport operations, particularly by reducing long-distance container movements that contribute to high CO_2 emissions and fuel consumption.

This phase also supports the first knowledge question from the research design: "What are the key objectives for establishing the new depot?" According to the interview findings, the primary objective is to establish Hengelo as a central hub for container-related services such as cleaning, repair, and storage. Currently, these services are concentrated in Rotterdam and Antwerp, leading to frequent long-distance transport often involving empty containers which increases operational costs and environmental impact. By developing a depot in Hengelo, CT and ITG aim to reduce this burden and improve logistical efficiency.

The insights gained from the expert interviews helped shape the research question and ensured that the project is aligned with the companies' practical needs and sustainability goals.

4.2. Transport Types

To provide a better understanding of the logistics involved, this section outlines the different transportation modes currently used by ITG. The aim is not to analyze each option in detail, but rather to give the reader an overview of how container transport is handled within the company. ITG makes use of barges, trucks, and a combination of both for transporting containers. These transport modes are applied in various ways, including transfers from seaports to the depot, deliveries to clients, and shorter trips between local facilities.

A typical container trip may involve several sequential actions. For example, a container may first be placed from a barge or truck onto the terminal at Hengelo. It can then be moved within the terminal such as from a barge to a truck or vice versa depending on the next stage of its journey. Finally, it may be transferred from the truck and placed into storage at the Hengelo depot, where it awaits further processing or dispatch. Although terminal operations have not yet been fully discussed, it is relevant to briefly mention that container handling is supported by cranes and forklifts. These are used for loading and unloading containers between transport modes and for placing them into storage at the depot. Additionally, containers are occasionally moved approximately 700 meters to CT, where they are cleaned either before being shipped out or after arrival.

While this section is only meant to provide background information, it helps build a more complete picture of ITG's logistics processes and supports the analysis that follows. A clearer distinction between export and import flows will be made in the following section.

4.2.1. Import Types

4.2.1.1. Import Roundtrip Barge (IRB)

The IRB illustrates in Figure 8 the import logistics process where containers are transported inland via barge and then delivered to the final customer by truck. After unloading, the empty containers are returned using the same route. This roundtrip involves multiple handling activities at both the port and the inland terminal. It emphasizes the cyclical nature of container flow, including both loaded and empty moves, which impact fuel consumption and emissions.

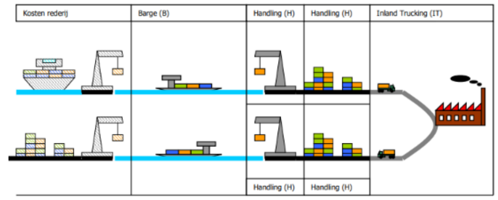

Figure 8: Import Roundtrip Barge (IRB) (Inland Terminals Group, 2023)

4.2.1.2. Import Roundtrip Truck (IRT)

In IRT Figure 9, all transport is done by truck. Import containers are picked up from the seaport and delivered directly to the customer. Once unloaded, the same truck returns the empty containers to the port. This method is more straightforward but usually results in higher emissions due to full reliance on road transport over long distances, especially when dealing with empty backhauls.

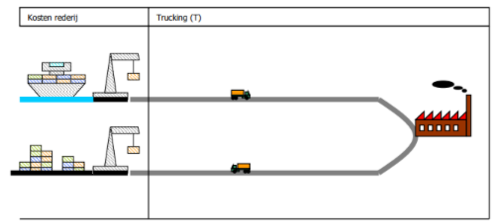

Figure 9: Import Roundtrip Truck (IRT) (Inland Terminals Group, 2023)

4.2.1.3. Import Singletrip Barge (ISB)

In Figure 10, this type displays an import singletrip where loaded containers are transported by barge to an inland terminal, then delivered to the customer by truck. There is no return of empty containers included in this process. This setup may be used when return flows are managed differently or when only inbound shipments are needed.

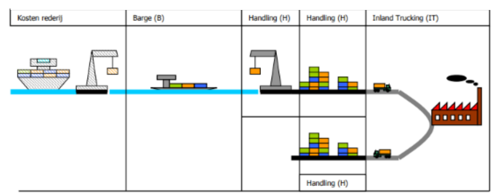

Figure 10:Import Singletrip Barge (ISB) (Inland Terminals Group, 2023)

4.2.1.4. Import Singletrip Truck (IST)

The IST outlines the direct delivery of imported containers from the port to the customer using trucks in Figure 11. The process includes container handling at the delivery site but does not involve returning the empty container to the port. This model may increase fuel consumption and emissions due to the lack of route optimization and return planning.

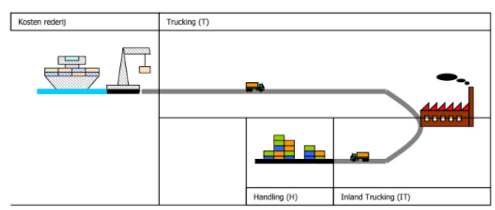

Figure 11: Import Singletrip Truck (IST) (Inland Terminals Group, 2023)

4.2.1.5. Depot in Barge (DIB)

In Figure 12 DIB refers to moving empty containers from the seaport to an inland depot using barge transportation. This approach helps with container repositioning and stock management while making use of waterways, which can be more sustainable compared to full road transport.

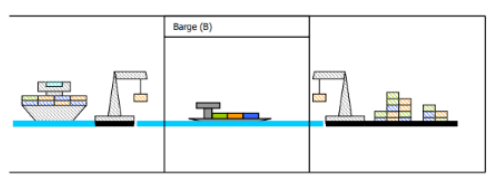

Figure 12: Depot in Barge (DIB) (Inland Terminals Group, 2023)

4.2.2. Export Types

4.2.2.1. Export Roundtrip Barge (ERB)

The ERB Figure 13 represents the export roundtrip process using barge transportation. Containers are first transported by truck from the shipper to the inland terminal, where they are then transferred onto a barge and shipped to the port. After unloading, the barge returns with empty containers, which are sent back to the original location. This model involves several handlings and highlights the need for efficient planning to reduce emissions and improve operational effectiveness.

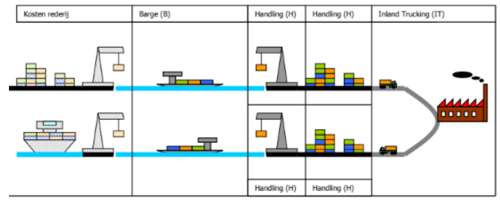

Figure 13: Export Roundtrip Barge (ERB) (Inland Terminals Group, 2023)

4.2.2.2. Export Roundtrip Truck (ERT)

The ERT type shows how export logistics are handled entirely by truck in Figure 14. Containers are picked up from the shipper, delivered to the port, and then the truck returns with an empty container. Similar to IRT, this method is convenient but less environmentally friendly due to the dependency on trucks and the emissions associated with long-distance road transport.

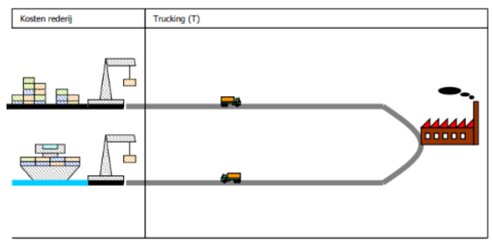

Figure 14: Export Roundtrip Truck (ERT) (Inland Terminals Group, 2023)

4.2.2.3. Export Singletrip Barge (ESB)

The ESB structure represents an export movement where containers are picked up from the customer by truck in Figure 15, transferred to the barge at the inland terminal, and then transported to the port. The process does not include a return trip of empty containers. It is effective for one-way transport, focusing solely on outbound logistics.

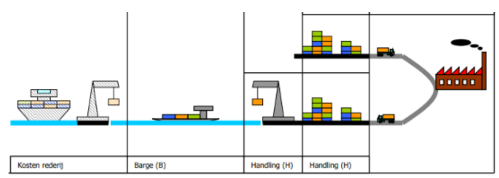

Figure 15: Export Singletrip Barge (ESB) (Inland Terminals Group, 2023)

4.2.2.4. Export Singletrip Truck (EST)

In EST Figure 16, full containers are transported by truck from the customer to the port for export. Like IST, this is a one-way trip with no return of empty containers included. Although operationally simple, this method contributes to higher transport costs and carbon emissions due to truck-only logistics.

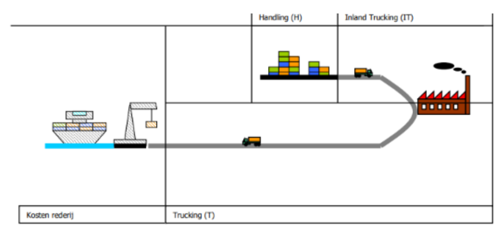

Figure 16: Export Singletrip Truck (EST) (Inland Terminals Group, 2023)

4.2.2.5. Depot Out Barge (DOB)

DOB is the reverse process of DIB, where empty containers are transported from an inland depot to the seaport shown in Figure 17. These containers are then available at the port for export use. This flow helps balance container availability and can improve efficiency when coordinated properly using inland waterway transport.

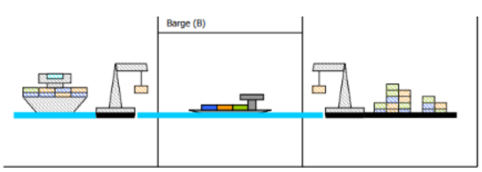

Figure 17: Depot Out Barge (DOB) (Inland Terminals Group, 2023)

4.3. Summary and Conclusion

This chapter explored the business needs and current logistics flows of CT and ITG. Interviews confirmed that both companies aim to reduce unnecessary transport movements and emissions by establishing a new depot in Hengelo. This would allow container services like cleaning and storage to take place closer to the customer base, improving efficiency and sustainability.

Sub-Research Question 1 was addressed by identifying the key objectives behind the depot: cutting down long-distance transport, reducing fuel use, and aligning operations with sustainability goals. Additionally, the chapter outlined the different transport modes used by ITG and provided context on import and export flows, offering a clearer picture of the current logistics set-up. These insights set the stage for evaluating the environmental impact in the next chapter.

5. Data Understanding

The Data Understanding phase within the CRISP-DM framework is aimed at exploring and interpreting the data needed for the analysis. This part of the research lays the foundation for accurately assessing CO_2 emissions and fuel usage. The chapter begins with an overview of how the data was collected in section 5.1, followed by detailed explanations of the main data categories used in this study: container handling, truck transport, and barge transport in the subsections of section 5.1.

5.1. Data Gathering

To answer the second sub-research question "Which data are required to calculate/estimate emissions and fuel consumption?" data was collected from both primary and secondary sources. Most of the core operational data, such as fuel usage, travel distances, electricity consumption, and container handling volumes, was obtained directly from CT and ITG. Since this information comes straight from the companies' daily logistics operations, it provides a reliable and realistic basis for calculating emissions. To support and complement the internal data, emission factors were sourced from publicly available and trusted databases, including the Climate Neutral Group (2021) and Carbon Emission Factors: More than Just a Number (n.d.). These were used particularly in the WTW and emission factor-based approaches. The combination of company-specific data and standardized emission values ensures that the analysis is transparent, consistent, and scientifically grounded. The next sections will explain how this data is categorized and applied across three main transport components: container handling, truck operations, and barge transportation.

5.1.1. Container Handling

For container handling, the research requires information on energy usage during loading, unloading, and internal movement of containers. This includes both electric-powered equipment (e.g., cranes, office buildings, etc.) and diesel-powered equipment (e.g., forklifts, terminal tractors, and reach stackers). The total electricity consumption in kilowatt hours (kWh) and the diesel consumption in liters are needed. Moreover, the number of container moves is also essential, as the CO_2 emissions for handling are typically calculated per move (Veuger, 2020). According to standard emission factors, electricity consumption produces 0.556 kg of CO_2 per kWh, and diesel use results in 3.23 kg of CO_2 per liter (Climate Neutral Group, 2021). This data helps assess how much energy is being used just to handle containers at depots and terminals like the one proposed in Hengelo.

5.1.2. Truck Transport

In terms of truck transportation, the research focuses on the road journeys between Rotterdam, Antwerp, and Hengelo. For this part, the key data includes fuel consumption, which can be provided as liters per kilometer or total liters per trip. The distance traveled, whether the container is full or empty, and container weight (if calculating per ton-kilometer) are also required. These inputs allow for accurate CO_2 emission estimations for each route. The emission factor for diesel trucks remains 3.23 kg CO_2 per liter (Climate Neutral Group, 2021), which is applied uniformly unless further fuel-specific values are given. Since the company sometimes moves empty containers, it is important to differentiate these trips from loaded ones, as they may still consume the same amount of fuel but contribute less value logistically, making them more environmentally inefficient.

5.1.3. Barge Transport

For barge transportation (inland shipping), the necessary data includes the amount of MDO used, the distance traveled, and the number of containers moved, expressed in TEU. This helps calculate emissions either per container or per distance travel. The standard emission factor for MDO is slightly higher than for regular diesel, at 3.53 kg of CO_2 per liter (Climate Neutral Group, 2021). Additionally, it's important to consider whether the containers are full or empty, and how many fractional TEUs are involved in each trip, as this helps fairly allocate emissions based on actual container usage.

5.2. Summary and Conclusion

In this section, the key datasets used for the analysis of CO_2 emissions, fuel usage, and energy consumption in the transportation routes between Rotterdam, Antwerp, and Hengelo were introduced. The collected data was divided into three main categories: container handling, truck transport, and barge transport. These datasets included values such as fuel and electricity consumption, container volumes, and distances travelled, which are essential for calculating emissions using methods like WTW and the emission factor-based approach.

To answer Sub Research Question 2 "Which data are required to calculate/estimate the emissions and fuel consumption?" both primary and secondary data were used. The operational data provided by CT and ITG ensured realistic input, while reliable public sources supported the emission factors, making the calculations scientifically valid.

In conclusion, this phase helped confirm that the required data was not only accessible but also suitable for further analysis. It provided a solid foundation for the modeling and evaluation stages of the research and ensured that the results would reflect both real-life operations and recognized emission standards.

6. Data Preparation

In this phase of the CRISP-DM methodology, the focus is on organizing and structuring the data to ensure it is suitable for analysis. For this research, primary operational data was provided directly by the participating companies. This included information such as fuel consumption, distances traveled, energy usage from cranes and forklifts, and the number of container handling operations.

An advantage of the data provided was that it was already cleaned, structured, and formatted consistently by the companies. As a result, minimal filtering or correction was required prior to analysis. All values were presented using appropriate units liters for diesel, kWh for electricity, and kilometers for distance making it possible to directly apply standard emission factors, such as 3.23 kg CO_2 per liter of diesel and 3.53 kg CO_2 per liter of MDO (Climate Neutral Group, 2021).

The dataset included figures from both 2018 and 2019, enabling year-over-year comparisons of fuel use, energy consumption, and emissions to evaluate changes in operational efficiency and environmental impact. To facilitate emission calculations, the data was grouped and structured to allow analysis per kilometer, per TEU, and per container handling operation.

Additionally, the following sections will provide a more detailed overview of the datasets used for container handling, truck transport, and barge transport. These sections explain the type of data that was received, its structure, and how it contributes to the emission calculations in this research.

6.1. Container Handling Data

Consumption of electricity CTT cranes Hengelo		
Year 2018	mWh	kWh
Jan-18	35.674	35674
Feb-18	29.729	29729
Mar-18	28.844	28844
Apr-18	19.075	19075
May-18	9.963	9963
Jun-18	11.369	11369
Jul-18	14.827	14827
Aug-18	22.4	22400
Sep-18	21.297	21297
Oct-18	30.495	30495
Nov-18	32.505	32505
Dec-18	30.661	30661
Total consumption 2018	**286.839**	**286839**
Year 2019		
Jan-19	35.616	35616
Feb-19	34.832	34832
Mar-19	32.023	32023
Apr-19	27.617	27617
May-19	23.934	23934
Jun-19	19.826	19826
Jul-19	24.12	24120
Aug-19	23.18	23180
Sep-19	30.027	30027
Oct-19	39.3	39300
Nov-19	42.132	42132
Dec-19	45.057	45057
Total consumption 2019	**377.664**	**377664**

Consumption of diesel forklifts Hengelo	
Year 2018	
Jan-18	5691.47
Feb-18	4811.7
Mar-18	5472.24
Apr-18	2729.51
May-18	5787.16
Jun-18	8919.94
Jul-18	7412.27
Aug-18	5707.36
Sep-18	5197.84
Oct-18	5253.8
Nov-18	5007.62
Dec-18	3523.04
Total consumption 2018	**65514**
Year 2019	
Jan-19	4766.4
Feb-19	4428.08
Mar-19	4408.79
Apr-19	3775.09
May-19	5982.23
Jun-19	3765.12
Jul-19	0
Aug-19	5747.45
Sep-19	3829.28
Oct-19	4547.01
Nov-19	1427.58
Dec-19	3840.02
Total consumption 2019	**46517.1**

Handlings Hengelo	
Year 2018	
Handling IN	72263
Handling OUT	72416
Total number of Handling 2018	**144679**
Year 2019	
Handling IN	73678
Handling OUT	73884
Total number of Handling 2019	**147562**

Overview 2018	
Number of actions	144679
Power consumption in kWh	286839
Diesel consumption in liters	65514
Power consumption in kWh per handling	1.9826
Diesel consumption in liters per handling	0.4528
Kg CO2 emissions per kWh per handling	1.1023
Kg CO2 emissions from diesel per handling	1.4626
Kg CO2 emissions per handling	2.5649
Overview 2019	
Number of actions	147562
Power consumption in kWh	377664
Diesel consumption in liters	46517.1
Power consumption in kWh per transaction	2.5594
Diesel consumption in liters per handling	0.3152
Kg CO2 emissions per kWh per handling	1.4230
Kg CO2 emissions from diesel per handling	1.0182
Kg CO2 emissions per handling	2.4412

Figure 18: Container Handling Data

The Container Handling sheet shown in Figure 18 provides monthly data for the years 2018 and 2019 regarding container operations at the Hengelo terminal. Specifically, it includes the electricity consumption for cranes (in kilowatt-hours) and the diesel consumption for forklifts (in liters) recorded each month. In addition to energy consumption, the sheet also reports the number of container handlings performed during each month of both years. This dataset allows for an analysis of the operational energy demand and the efficiency of container handling activities over time.

6.2. Truck Data

The truck data collected from ITG and CT serves as the foundation for analyzing the emissions from road transport. To present the information clearly, the data is split into two sections. The ITG dataset gives a detailed overview of long-distance truck operations throughout 2019, while the CT dataset focuses on short-distance transport activities linked to container cleaning over a three-month period. Together, these datasets help to better understand the different transport patterns and provide important input for comparing the current logistics setup with the potential benefits of introducing a local depot in Hengelo.

6.2.1. ITG Data

Consumption 2019			
Vehicle	**Distance in**	**mption Total in liters**	**Amount of liter p**
02-BGL-5	101771	29394.5	0.288829824
03-BJT-8	117913	30825	0.261421557
11-BKZ-7	105019	27979	0.266418458
14-BJT-1	118462	33202.5	0.280279752
15-BFF-9	108413	31783.5	0.293170561
21-BJR-4	88211	24868	0.281914954
24-BJL-5	58956	19225	0.326090644
29-BBR-4	69958	21307.5	0.304575603
30-BKX-1	131271	34760.5	0.264799537
31-BHL-7	112228	31688	0.28235378
32-BHL-7	142916	38446.5	0.269014666
32-BLH-6	141539	40037.5	0.282872565
37-BFG-1	140502	42932.5	0.305565045
53-BGX-8	113265	41550.5	0.366843244
54-BGX-8	99071	37066	0.374135721
68-BGK-7	129097	33267	0.257689954
82-BJV-5	141679	44227.5	0.312166941
86-BLK-1	59682	18242	0.305653296
87-BKB-2	137805	35684.5	0.25894924
88-BKB-2	93037	25534	0.27444995
95-BGS-2	92603	27014	0.291718411
96-BGS-2	63081	22380	0.354781947
98-BDZ-6	65901	20684	0.313864736
98-BJL-5	83429	22819.5	0.273519999
98-BLF-6	116688	32870.5	0.281695633
99-BKT-5	104883	27248	0.259794247
99-BLF-6	83157	22999.5	0.276579242
BV-GL-24	53760	9941.5	0.184923735
BV-XJ-46	2896	11.5	0.003970994
BX-XX-07	47424	18681	0.393914474
BZ-DV-45	65797	16655	0.253127042
BZ-LX-23	100260	30211	0.301326551
Total	**3090674**	**893537**	0.289107489
Average liter per km			**0.2827**

Figure 19: Inland Terminals Group Truck Data

The Trucks Data sheet shown in Figure 19 contains information for the year 2019, detailing truck operations. For each vehicle, the sheet lists the distance driven (in kilometers), the total diesel consumption (in liters), and the diesel consumption rate (in liters per kilometer). Furthermore, an average diesel consumption value (liters/km) is calculated across all vehicles. Based on this data, an assumption was made to adjust the transport distances for the proposed new depot scenario, and new calculations were performed. These adjustments and recalculations will be explained in more detail in the following sections of the report.

6.2.2. CT Data

January									
Driver	Code	Fuel consumbtion (L/100km)	Driving fuel consumbtion (L/100km)	Fuel consumbtion per day (L/day)	Total distiance traveled (km)	Total fuel (L)	Driving fuel (L)	CO2 emissions (kg)	CO2 emissions per km (kg/km)
Sander I	8589	25.97	25.81	31.56	3,766.95	978.29	972.24	3159.8767	0.83884222
February									
Driver	Code	Fuel consumbtion (L/100km)	Driving fuel consumbtion (L/100km)	Fuel consumbtion per day (L/day)	Total distiance traveled (km)	Total fuel (L)	Driving fuel (L)		
Sander I	8589	25.28	25.12	45.06	5,526.65	1,396.93	1,388.29	4512.0839	0.816422951
March									
Driver	Code	Fuel consumbtion (L/100km)	Driving fuel consumbtion (L/100km)	Fuel consumbtion per day (L/day)	Total distiance traveled (km)	Total fuel (L)	Driving fuel (L)		
Sander I	8589	25.3	25.3	51.1	6,261.25	1,583.97	1,583.97	5116.2231	0.817124871

Figure 20: Cleaning Twente Truck Data

The Data from CT sheet shown in Figure 20 contains operational information collected over a three-month period. It records the total distance driven (in kilometers) and the total diesel consumption (in liters) related to container transport activities between the Hengelo terminal and the CT facility. Although limited to three months, this data is valuable for estimating the transport emissions associated with cleaning operations under the new depot scenario.

6.3. Barge Data

Consumption 2018			
Name of barge	Liters used per year	TEU Total	Liters/TEU Total
Argus	132370.38	5245.25	25.24
Borelli	241032.29	19495.4	12.36
Martinique	332708.2	19590.9	16.98
Nautictrans	293389.11	19887.5	14.75
Paradox			
Scopus	296868.82	17169.25	17.29
Total	**1296368.8**	**81388.3**	
Average liter per TEU			**17.33**

Consumption 2019			
Name of barge	Liters used per year	TEU Total	Liters/TEU Total
Argus	165539.62	6679.25	24.78
Borelli	305024.35	19862.1	15.36
Martinique	334222	18499.75	18.07
Nautictrans	290657.89	18448	15.76
Paradox	166100	9756.75	17.02
Scopus	305783.18	16274.25	18.79
Total	**1567327.04**	**89520.1**	
Average liter per TEU			**18.30**

Figure 21: Barge Data

The Barges Data sheet shown on Figure 21 provides an overview of barge operations for both 2018 and 2019. It includes the total fuel consumption (in liters) for each named barge operating between Rotterdam and Hengelo, as well as the total number of TEU transported annually. Based on these figures, the liters consumed per TEU are calculated, and an average liters per TEU value is provided for each year. Although the data is aggregated annually rather than monthly, it offers a good basis for estimating the environmental impact of barge operations within the current logistics setup.

6.4. Summary and Conclusion

This chapter outlined the preparation of the datasets used for analyzing CO_2 emissions and fuel consumption in container logistics operations. The primary operational data, provided by CT and ITG, was already well-structured and required minimal cleaning before use. Key data categories included container handling, truck transport, and barge operations, with figures available for the years 2018 and 2019.

For container handling, monthly records of electricity and diesel consumption, alongside the number of container handlings, allowed for a detailed year-over-year comparison of operational efficiency. The truck data, split between ITG and CT, offered insights into both long-distance and short-distance transport patterns, providing a solid foundation for modeling emission reductions under the proposed new depot scenario in Hengelo. Finally, the barge data summarized fuel usage and transport volumes per year, supporting the evaluation of sustainability performance in inland waterway transport.

By structuring the data carefully, it was possible to align it with standard emission factors and prepare it for consistent and transparent calculation of environmental impacts. This structured approach sets the stage for the modeling and evaluation phases that follow, where the effects of introducing a local depot in Hengelo on emissions and fuel consumption will be further analyzed.

7. Modeling

This part of the research focuses on the modeling phase of the CRISP-DM methodology. It aims to calculate and compare the environmental impact of the current scenario and the new depot scenario by estimating CO_2 emissions and fuel consumption. The analysis focuses on three key areas of container transport: container handling, truck transport, and barge transport. These models help evaluate both the current situation where containers are handled through depots in Rotterdam and Antwerp and a possible future scenario where a new depot is established in Hengelo. The goal is to understand whether a depot in Hengelo could reduce emissions and fuel usage.

7.1. CO_2 Emissions Containers

To understand the emissions resulting from container handling, it is important to recognize that multiple actions can occur during a single logistics trip. For example, a container might be unloaded from a barge or truck at the terminal, transferred between different transport modes (e.g., from barge to truck), or moved into temporary storage within the terminal. Each of these activities represents a distinct handling operation that contributes to overall energy use and associated CO_2 emissions.

The number of these handling operations over a defined period, typically one year, is required to calculate the emissions accurately. These calculations rely on operational data already collected and discussed in the earlier data preparation phase, specifically total annual electricity consumption (in kWh) and total diesel usage (in liters). These energy sources correspond to the handling equipment used in the terminals, such as electrically powered cranes and diesel-powered forklifts.

Although the electricity consumption specific to handling activities in Hengelo could potentially be separated from office use, this distinction was not made. This choice was intentional to ensure consistency in calculations across all terminals and to allow the same emission formulas to be applied uniformly. As mentioned during expert interviews with CT and ITG staff (see Appendix E), the data from Hengelo is used to represent a realistic operational scenario, although the terminal itself is still in the planning phase.

Regarding diesel usage, ITG uses a fuel card system to monitor the total amount of diesel consumed per vehicle annually. However, since it is not possible to track which specific handling operation each liter of diesel was used for, the total diesel consumption is distributed evenly across all handling movements. The same approach applies to electricity consumption, as the exact allocation per container move is not recorded.

A handling operation, for the purpose of this research, refers to any single movement of a container whether it is lifted onto or off a truck, barge, or stored within the terminal. Since the total energy usage and the number of container handlings are known, average energy consumption per handling operation can be calculated. This supports the emissions analysis in the following sections by offering a consistent and scalable method for estimating environmental impact from container handling.

This formula calculates the average amount of electricity (in kWh) used per container handling operation:

$$kWh\ per\ handling = \frac{Total\ kWh\ used\ over\ the\ year}{Total\ number\ of\ \ handlling\ operations}$$

Equation 3: Electricity per Handling (Veuger, 2020)

The purpose of this formula is to determine how much electrical energy is consumed, on average, for each individual handling movement such as lifting or relocating a container using electrically powered equipment like cranes. It allows emissions related to electricity use to be fairly and consistently distributed across all handling operations, especially in cases where energy usage data is not available per specific move.

This method was chosen because the available electricity data was recorded at the terminal level (e.g., total annual usage) rather than per action. By dividing total usage by the number of container movements, the calculation provides a standardized emission estimate per handling. This supports a transparent and replicable approach in line with guidance from Veuger (2020) and Carbon Footprinting guidelines.

This formula estimates the average diesel consumption (in liters) for each container handling operation:

$$Liters\ per\ handling = \frac{Total\ liters\ of\ diesel\ used\ over\ the\ year}{Total\ number\ of\ handlling\ operations}$$

Equation 4: Diesel per Handling (liters) (Veuger, 2020)

This equation is used to assess the fuel usage associated with diesel-powered handling equipment, such as forklifts or terminal tractors. Like with electricity, detailed data per handling move was not available, so the total diesel usage is evenly distributed across all containers moves each year.

This approach ensures that emissions from diesel use can still be meaningfully incorporated into the total CO_2 emissions analysis. It provides a practical way to account for handling-related fuel consumption using available operational data. Again, this aligns with recommendations by Veuger (2020), and the emission calculation frameworks established in logistics emissions studies.

To convert the energy usage into CO_2 emissions WTW emissions factor:

- **Electricity**: 0.556 kg CO_2 per kWh (for gray electricity) (Climate Neutral Group, 2021)
- **Diesel**: 3.17 kg CO_2 per liter (*Carbon Emission Factors: More than Just a Number*, n.d.)

CO_2 from Electricity per Handling

$$CO_2\ (electricity)\ per\ handling = \ (kWh\ per\ handling) \times (0.556\ kg\ CO_2/kWh)$$

Equation 5: CO_2 from Electricity per Handling (Veuger, 2020)

This formula is used to calculate the CO_2 emissions generated from electricity consumption for each container handling operation. The emission factor of 0.556 kg CO_2 per kWh (for gray electricity) comes from the Climate Neutral Group (2021). By multiplying the average energy consumed per handling (in kWh) by this emission factor, the result represents how much CO_2 is emitted due to electricity use each time a container is moved. This approach is particularly useful when detailed energy monitoring per activity is unavailable, allowing a general yet accurate estimation of electricity-related emissions.

CO_2 from Diesel per Handling

$$CO_2\ (diesel)\ per\ handling = (Liters\ per\ handling) \times (3.17\ kg\ CO_2/liter)$$

Equation 6: CO_2 from Diesel per Handling (Veuger, 2020)

This formula calculates the CO_2 emissions caused by diesel consumption during each handling operation. The emission factor (3.17 kg CO_2 per liter) is based on standard values reported by Carbon Emission Factors: More than Just a Number (n.d.). This method converts fuel usage into a carbon equivalent by applying the WTW (Wheel-to-Wheel) factor, which accounts for both combustion and upstream emissions from diesel. Again, this allows for emission estimates even when emissions are not tracked by machine or movement.

Calculating the Total CO_2 Emissions per Handling

Adding the Two emissions

$$Total\ CO_2\ per\ handling = CO_2\ (electricity)\ per\ handling + CO_2\ (diesel)\ per\ handling$$

Equation 7: Calculating the Total CO_2 Emissions per Handling (Veuger, 2020)

This final formula sums up the emissions from both electricity and diesel consumption to determine the total CO_2 emissions per single container handling. This total represents the average environmental impact of moving one container within a terminal, regardless of the equipment used or energy source. By combining both energy types, this method provides a complete picture of emissions and supports reliable cross-terminal comparisons or future scenario modeling.

7.2. CO_2 Emissions Trucks

To accurately estimate the CO_2 emissions produced by truck transport, it is important to first calculate the emissions per kilometer. This requires two key data points: the total volume of diesel fuel consumed by trucks over a defined period (in this case, one year) and the total number of kilometers traveled during that period. Once the average liters of diesel consumed per kilometer are known, the WTW emissions factor for diesel 3.17 kg CO_2 per liter can be applied to determine emissions per kilometer (Carbon Emission Factors: More than Just a Number, n.d.).

$$Average\ liters\ of\ diesel\ per\ kilometer = \frac{total\ liters\ of\ diesel\ per\ year}{total\ of\ driven\ km\ per\ year}$$

Equation 8: Average liters of diesel per kilometer (Veuger, 2020)

This formula shows how much fuel is consumed per kilometer on average. It helps normalize the diesel usage across all truck operations, regardless of the route or load size.

$$Average\ kilograms\ of\ CO_2\ emitted\ per\ km = average\ liters\ of\ diesel\ per\ km \times 3.17\ kg\ CO_2$$

Equation 9: Average kilograms of CO_2 emitted per km (Veuger, 2020)

The result of this equation is the average amount of CO_2 (in kilograms) emitted per kilometer driven, based on diesel fuel consumption. This value provides the foundation for further emission analysis.

Once the emissions per kilometer are established, it is important to consider how load weight influences fuel consumption. Heavier loads generally result in higher emissions. Therefore, the transported cargo is categorized into different weight intervals. For each weight class, the total distance traveled, and the total tons transported are calculated.

$$Total\ CO_2\ (kg) = (Distance\ in\ km\ for\ the\ weight\ class) \times (CO_2\ per\ km\ (kg))$$

Equation 10: Total CO_2 (kg) (Veuger, 2020)

This equation calculates the total emissions for a specific weight class by multiplying the traveled distance by the CO_2 emissions per kilometer found earlier.

After calculating the emissions per kilometer and determining the ton-kilometers (ton-km) for each weight class, the next step is to relate these values in order to determine the emissions per ton of cargo per kilometer. This is important because it helps assess the emissions efficiency of transport operations based on the weight of the cargo.

$$Ton - km = (Total\ weight\ in\ tons\ for\ the\ class) \times (Distance\ in\ km)$$

Equation 11: Total ton-km (Veuger, 2020)

This formula quantifies the total amount of transport work performed by combining the transported mass (in tons) with the distance it was carried (in kilometers). It provides a standardized basis for comparing transport efficiency across weight categories.

$$CO_2\ per\ ton - km\ (kg) = \frac{Total\ CO_2\ (kg)\ for\ the\ weight\ class}{Total\ ton - km\ for\ the\ weight\ class}$$

Equation 12: CO_2 per ton-km (kg) (Veuger, 2020)

This equation calculates how much CO_2 is emitted, on average, for each ton transported over one kilometer within a given weight class (Veuger, 2020). The value allows for comparisons between light and heavy cargo and highlights which operations are less fuel-efficient and more polluting.

Once emissions per ton-km are established for each weight class, they can be used to assess individual transport movements more accurately. Each trip is evaluated based on the total cargo weight, which includes both the goods and the weight of the container (if relevant). This total weight is then used to determine which emission factor (per ton-km) should be applied based on the appropriate weight class.

For example, if a round trip consists of a full container outbound and an empty one on the return, each leg of the journey must be treated separately. Different emission values will apply due to the difference in transported mass, and the total emissions are obtained by summing both parts of the trip.

$$CO_2\ (kg) = \left(\frac{Cargo\ weight\ (kg) + Container\ weight\ (kg)}{1000}\right) \times (Trip\ distance\ in\ km) \times (CO_2\ per\ ton - km\ (kg))$$

Equation 13: CO_2 emitted for trip (Veuger, 2020)

This formula translates trip-specific data into a concrete CO_2 emission value by converting the total transported mass into tons, multiplying it by the trip distance, and then applying the relevant emission factor per ton-kilometer (Veuger, 2020). It enables detailed comparisons of emissions from different routes and cargo configurations, supporting targeted sustainability improvements in logistics.

7.3. CO_2 Emissions Barges

To assess the environmental impact of barge transport, it is essential to determine how much MDO is consumed per TEU over a specific period, such as one year. This is calculated by dividing the total annual MDO consumption by the number of TEUs transported during that time.

$$Liters\ per\ TEU = \frac{Total\ liters\ of\ MDO\ consumed}{Number\ of\ TEUs\ transported}$$

Equation 14: Liters per TEU (Veuger, 2020)

This formula provides the average amount of fuel used to transport one TEU. It standardizes fuel consumption, making it possible to estimate emissions per unit of container cargo (Veuger, 2020).

Once fuel consumption per TEU is known, the next step is to convert it into CO_2 emissions using a WTW emission factor. This gives the emissions per TEU, regardless of distance traveled.

$$CO_2\ per\ TEU\ (kg) = (Liters\ per\ TEU) \times (CO_2\ per\ liter)$$

Equation 15: CO_2 per TEU (kg) (Veuger, 2020)

With a WTW factor of 3.53 kg CO_2 per liter of MDO (Carbon Emission Factors, n.d.), this equation allows conversion of fuel data into emissions data, which is necessary for evaluating the environmental performance of barge transport (Veuger, 2020).

However, total emissions per TEU alone do not reflect the influence of route length. Moving a container over 50 km does not result in the same emissions as moving it over 500 km. Therefore, it is important to express emissions relative to distance travel by dividing the emissions per TEU by the corresponding trip distance. This results in emissions per TEU per kilometer.

$$CO_2\ per\ TEU\ per\ km\ (kg) = \frac{CO_2\ per\ TEU\ (kg)}{Distance\ (km)}$$

Equation 16: CO_2 per TEU per km (kg) (Veuger, 2020)

This equation accounts for distance variations and allows comparison between short and long barge trips (Veuger, 2020). It also supports fractional TEU loads (e.g., 0.5 TEU or 1.3 TEU), which can be scaled proportionally. For example, transporting a full 2 TEU load over 200 km differs significantly from a 0.5 TEU load over the same distance. Additionally, emissions for empty containers are typically lower, and separate factors may be applied depending on the analysis approach.

After obtaining CO_2 per TEU per kilometer, the emissions for a specific barge trip can be estimated. This requires knowing the TEU load and the distance traveled. Whether the container is 20-foot (1 TEU) or 40-foot (2 TEUs), full or empty, the total emissions are calculated by multiplying the TEU value by the emissions per kilometer and the distance.

$$CO_2\ (barge\ trip) = (Distance\ in\ km) \times (Emissions\ per\ TEU\ per\ km\ (kg))$$

Equation 17: CO_2 (barge trip) (Veuger, 2020)

This formula is used to estimate the total emissions for a given barge journey. For example, if a 1 TEU full container produces 0.2031 kg CO_2 per km, a 200 km trip would result in 40.62 kg CO_2 emissions. For an empty container at 0.1433 kg CO_2 per km, the same journey would result in only 28.66 kg CO_2 (Veuger, 2020).

This method ensures that emissions are accurately estimated based on fuel use, distance, and load, and allows for clear comparisons between barge trips and other transport modes such as trucks.

7.4. Summary and Conclusion

This chapter focused on applying emission calculations to estimate the environmental impact of logistics operations carried out by CT and ITG. Using actual company data and emission factors from sources like Veuger (2020) and the Climate Neutral Group (2021), the CO_2 emissions were calculated for three key areas: container handling, truck transport, and barge transport.

Instead of using software tools such as BigMile, EcoTransIT, or GaBi mainly due to limited access and lack of detailed input data this research used practical, emission factor-based formulas. These equations made it possible to work with the available data and still produce accurate and consistent results.

The calculated emissions per container move, per kilometer by truck, and per TEU by barge now form the basis for comparing the current logistics routes with the scenario where a depot is added in Hengelo. While the comparison itself is covered in the next chapter, the formulas used here provide all the needed values to do that analysis.

Overall, this chapter helped turn operational data into measurable emissions figures, giving a clear overview of how each part of the logistics chain contributes to CO_2 output. This sets up the next step: evaluating whether the Hengelo depot can lead to lower emissions and fuel consumption.

8. Evaluation

This chapter analyzes the environmental performance of three essential parts of container logistics: container handling, road transport by truck, and inland waterway transport by barge. The analysis uses operational data from CT and ITG for 2018 and 2019 and applies the WTW method to estimate both CO_2 emissions and fuel consumption across the logistics chain. These two indicators were chosen because they are the most measurable and directly linked to environmental impact in logistics operations.

This section helps answer Sub-Research Question 4: "Which specific sustainability and operational metrics (e.g., CO_2 emissions, fuel consumption) need to be evaluated?"

By focusing on CO_2 emissions per handling, per kilometer for trucks, and per TEU per kilometer for barges, the analysis identifies where the largest environmental impacts occur. These calculations also allow for a direct comparison between the current situation where depots are located in Rotterdam and a new scenario involving a container depot in Hengelo. Barge transport in the Hengelo scenario only covers the inland segment (e.g., from Rotterdam to Hengelo), which eliminates the need for additional truck movements between Hengelo and the western depots. This shift reduces both fuel use and emissions and demonstrates the potential environmental benefits of the local depot. The results from this comparison provide a clearer understanding of how relocating services to Hengelo can contribute to more sustainable logistics.

8.1. Container Handling

An evaluation of the 2018 and 2019 container handling data in Hengelo shows clear improvements in operational efficiency and sustainability. The available data includes electricity consumption by cranes, diesel usage by forklifts, and the total number of container handlings. To estimate the environmental impact, WTW emission factors were applied: 0.556 kg CO_2 per kWh for electricity and 3.23 kg CO_2 per liter for diesel. These factors account for the entire energy lifecycle, from production to consumption.

In 2018, total electricity consumption was 286,839 kWh, diesel usage was 65,513.95 liters, and the number of handlings was 144,679. By dividing energy and fuel consumption by the number of handlings, the average consumption per handling was determined. Multiplying this by the emission factors resulted in approximately 1.10 kg CO_2 per handling from electricity and 1.46 kg from diesel, with a total of around 2.56 kg CO_2 emissions per handling.

In 2019, electricity use increased to 377,664 kWh, diesel usage decreased to 46,517.05 liters, and handlings rose to 147,562. Using the same approach, electricity-related emissions per handling increased slightly to 1.42 kg CO_2, while diesel-related emissions dropped to 1.02 kg CO_2. This led to a reduction in total emissions per handling to 2.44 kg. These results suggest that the operations became more efficient and less dependent on diesel-powered equipment, possibly due to improved planning or increased use of electric machinery.

Overall, the data shows a positive trend toward lower emissions per handling, despite a higher total handling volume. This supports the objective of making logistics more sustainable and strengthens the case for developing a new depot in Hengelo to further reduce transport-related emissions.

Overview	2018	2019
Number of actions	144679	147562
Power consumption in kWh	286839	377664
Diesel consumption in liters	65514	46517.1

Power consumption in kWh per handling	1.9826	2.5594
Diesel consumption in liters per handling	0.4528	0.3152
Kg CO_2 emissions per kWh per handling	1.1023	1.4230
Kg CO_2 emissions from diesel per handling	1.4626	1.0182
Kg CO_2 emissions per handling	2.5649	2.4412

Table 3: Container Handling 2018-2019

8.2. Truck Emissions

8.2.1. ITG Data (Current Scenario)

The analysis of the 2019 truck transportation data gives a good overview of how much fuel the company's trucks used and how much CO_2 they emitted. The dataset includes the total kilometers driven, total fuel used, and how many liters were used per kilometer by each truck. Only the vehicles with full data were included to make sure the results are accurate. In total, the trucks drove around 3,090,674 kilometers, using about 893,537 liters of diesel. Based on this, the average diesel usage was calculated to be 0.2827 liters per kilometer, which was found by averaging the fuel consumption values of each truck.

To calculate CO_2 emissions, the WTW emission factor for diesel was used, which is 3.23 kg CO_2 per liter. This gave an average of 0.9131 kg CO_2 per kilometer, which shows how much pollution the trucks produce during transportation.

Looking more closely at the numbers, there are some clear differences in how efficient each truck is. For example, the truck BX-XX-07 used the most fuel per kilometer (0.3939 L/km), while BV-GL-24 was much more efficient, using just 0.1849 L/km. These differences could be caused by factors like how new the vehicle is, how well it's maintained, how much load it carries, or how it's driven.

Overall, this data helps to better understand how the truck fleet performs and gives a useful baseline for comparing truck transport to other methods like inland barge transport. It also shows where improvements can be made, such as switching to more efficient vehicles or using alternative transport modes to help reduce emissions and fuel use.

8.2.2. ITG Data (New Depot Scenario)

For the new depot scenario, the total truck distance was calculated to be 1,806,578 km. This distance was derived by adjusting the original truck travel distances provided in the dataset. Specifically, an assumption was made that trucks currently perform round trips to Rotterdam depot four times each week. The distance from Hengelo to Rotterdam is approximately 209 km one way. Therefore, the annual total distance associated with these specific trips was calculated as follows:

$$209\ km/trip \times 4\ trip/week \times 4 weeks/month \times 12 months/year = 40{,}128 km/year$$

Equation 18: Annual distance to be subtracting

Subtracting this annual distance from the original total provided in the dataset resulted in the adjusted figure of 1,806,578 km for the new depot scenario.

Using the provided average diesel consumption rate of 0.2827 liters per kilometer (L/km), the total diesel consumption was calculated as:

$$1{,}806{,}578\ km \times 0.2827 L/km = 511{,}006.7\ Liters$$

Equation 19: Total diesel consumption new depot

To convert fuel consumption into CO_2 emissions, the WTW emission factor of 3.23 kg CO_2 per liter of diesel was applied:

$$511{,}006.7\ L\ \times 3.23 kgCO_2/L = \ 1{,}651{,}561.6\ kgCO_2$$

Equation 20: CO2 emissions for new depot

Therefore, the total CO_2 emissions for the trucks in the new depot scenario amount to approximately 1,651,561.6 kg CO_2 annually.

8.2.3. Comparison Between Current and New Depot Scenario

A comparative summary of both scenarios is provided below:

Scenario	Distance (km)	Diesel Used (L)	CO_2 Emissions (kg CO_2)
Current	3,090,674	893,537	2,886,123.5
New Depot	1,806,578	511,006.7	1,651,561.6
Reduction	1,284,096	382,530.3	1,234,561.9

Table 4: Comparison Between Current and New Depot Scenario

By introducing the new depot in Hengelo, the total annual truck distance can be reduced by approximately 1,284,096 km, which corresponds to a reduction in diesel fuel consumption of around 382,530.3 liters. Consequently, this results in a substantial reduction in annual CO_2 emissions of approximately 1,234,561.9 kg CO_2, equivalent to roughly a 43% reduction compared to the current scenario.

This significant decrease highlights the substantial sustainability improvements achievable through the establishment of a local container depot in Hengelo.

8.2.4. Regarding the CT Data

The dataset for truck transportation in early 2019 focuses on the fuel consumption and CO_2 emissions of a specific driver over three months: January, February, and March. During this period, the average fuel consumption stayed consistent at around 25 to 26 liters per 100 kilometers. This suggests that the driving conditions, such as load weight and route type, were relatively stable. As the monthly driving distances increased from about 3,767 km in January to 6,261 km in March, both fuel usage and CO_2 emissions increased as well.

To calculate the CO_2 emissions, the WTW method was used. This involves multiplying the total amount of diesel used by the emission factor for diesel fuel, which is 3.23 kg of CO_2 per liter (Climate Neutral Group, 2021). For example, in March, the total fuel used was 1,583.97 liters. The CO_2 emissions for that month were calculated as:

$$1{,}583.97\ liters \times 3.23\ kgCO_2/L = 5{,}116.22\ kg\ CO_2$$

Equation 21: CO_2 emissions in March

To understand how efficient the truck was environmentally, the emissions per kilometer were also calculated by dividing the total CO_2 emissions by the distance driven. For March, that would be:

$$\frac{5{,}116.22kg\ CO_2}{6{,}261.25km} = 0.8171kg\ CO_2/km$$

Equation 22: CO2 emissions per km in March

The results across all three months show CO_2 per kilometer values ranging between 0.816 and 0.838 kg. These figures provide a useful basis for comparing environmental performance and support the evaluation of how changes in transport routes or depot locations influence emissions.

Month	January	February	March
$\boldsymbol{CO_2}$ emission (kg)	3,159.86	4,510.08	5,114.23
$\boldsymbol{CO_2}$ emission per km (kg/km)	0.839	0.816	0.817

Table 5: CO_2 emissions for Trucks for CT

8.3. Barges Emissions

The data from barge transportation in 2018 and 2019 provides useful insight into fuel consumption and CO_2 emissions performance over time. For both years, the total liters of fuel used, the number of TEUs transported, and the average fuel consumption per TEU were analyzed. This helps to assess how efficiently the barges operated and what impact this had on the environment.

In 2018, six barges were used, with a total fuel consumption of 1,296,368.8 liters and 81,388.3 TEUs transported. This results in an average of 17.33 liters per TEU. In 2019, one new barge ("Paradox") was added mid-year, and total fuel consumption increased to 1,567,327.04 liters, with 89,520.1 TEUs moved. However, the average fuel consumption per TEU also increased to 18.30 liters, meaning the barges used slightly more fuel per container compared to the previous year.

To estimate the CO_2 emissions, the WTW emission factor for MDO was used, which is 3.53 kg CO_2 per liter. This factor was multiplied by the average liters per TEU to calculate emissions for each year using the formula:

$$CO_2\ emissions\ per\ TEU = Average\ liters\ per\ TEU \times 3.53$$

Equation 23: CO_2 emissions per TEU

From this calculation, the CO_2 emissions per TEU in 2018 were approximately 61.16 kg, while in 2019, it increased to around 64.59 kg. This rise in emissions suggests that although more TEUs were transported in 2019, the operations were slightly less fuel-efficient and more environmentally impactful.

Several factors might explain this increase, such as changes in the operating period of the barges. For example, "Argus" only operated until June 2019, while "Paradox" only started mid-year, which may have influenced the average fuel usage. Overall, while barge transportation increased in scale, the higher emissions per TEU indicate that there is still potential for improving sustainability, for instance by optimizing fuel efficiency or minimizing empty trips.

8.3.1. Comparison between Current and New Depot Scenario

A detailed quantitative calculation of the barge transport scenario could not be performed due to the absence of comprehensive data. Nevertheless, a qualitative analysis can illustrate potential sustainability improvements associated with the new depot scenario.

Under the current logistics arrangement, barges transport loaded containers from Rotterdam to Hengelo. After delivering the containers, these barges typically return empty to Rotterdam, covering an additional distance of approximately 238 km. This return trip significantly contributes to unnecessary fuel consumption, operational costs, and CO_2 emissions.

In the proposed scenario, establishing a container depot in Hengelo would enable containers to remain locally stored after unloading, eliminating the need for immediate return transport of empty containers to Rotterdam. Consequently, barges would no longer have to cover the unnecessary 238 km return trip empty. This reduction in transport distance would directly decrease fuel usage, operational expenses, and CO_2 emissions, thus contributing positively to the overall sustainability and efficiency of the container logistics chain.

For future studies, performing a detailed quantitative analysis with more comprehensive barge-related data is recommended to accurately measure these sustainability benefits.

8.4. Summary and Conclusion

This chapter analyzed the environmental performance of container handling, truck transport, and barge transport, using operational data from CT and ITG for the years 2018 and 2019. The WTW method was applied to estimate CO_2 emissions and fuel consumption for each part of the logistics chain.

For container handling at the Hengelo terminal, the results showed a slight improvement between 2018 and 2019. Emissions per handling operation decreased from approximately 2.56 kg CO_2 to 2.44 kg CO_2, suggesting increased operational efficiency, possibly due to a greater reliance on electric equipment and improved logistics planning.

For truck transport, the emissions in the current scenario were found to be around 0.816–0.913 kg CO_2 per kilometer, depending on the fuel efficiency of individual trucks. A comparison between the current situation and a future scenario with a new depot in Hengelo revealed that annual truck distances could be reduced by approximately 1.28 million kilometers. This would lead to a diesel fuel savings of around 382,530 liters and a CO_2 reduction of roughly 1,234,562 kilograms per year an improvement of approximately 43%.

Regarding barge transport, although a detailed quantitative comparison for the new depot scenario was not possible due to limited data, a qualitative analysis showed clear sustainability benefits. Under the new depot arrangement, the elimination of unnecessary empty return trips of barges to Rotterdam (approximately 238 km each trip) would significantly reduce fuel consumption and emissions. This change would contribute to making inland waterway transport even more sustainable.

In conclusion, three major sustainability and operational metrics CO_2 emissions per container handling, CO_2 emissions per truck kilometer, and CO_2 emissions per TEU for barge transport were identified and evaluated. The findings show that relocating operations to a local depot in Hengelo could substantially reduce emissions, improve fuel efficiency, and enhance the overall environmental performance of the container logistics chain.

9. Deployment Plan

In the deployment phase of the CRISP-DM method, the focus is on how the results of the research can be used by the company. In this thesis, the research looks at CO_2 emissions and fuel consumption for different transport routes and container activities between Rotterdam–Hengelo and Antwerp–Hengelo. These results are important for ITG and CT as they are considering building a new depot in Hengelo and want to understand the sustainability benefits of doing so.

Although the research was done for a university project, the results can still be useful in practice. The company can use the CO_2 emissions per container, per kilometer, or per handling to compare their current logistics setup to what it would look like with a local depot. This helps them make better decisions based on actual numbers.

The models and methods used like WTW, TTW, and emission factor-based calculations can also be applied by the company in future projects. These methods can support them in tracking their emissions or reporting under regulations like the CSRD. Since the data used in the research came from real company records, it's reliable and gives a good starting point for planning improvements.

The results can also help the company when talking to stakeholders or preparing internal reports. Showing how much CO_2 or fuel could be saved with a depot in Hengelo makes it easier to support the decision with clear data. While the project only focuses on two routes and two years, the method used can be applied to other routes as well, making this a flexible tool for future use.

Everything in the research, from the data sources to the calculation steps, has been explained clearly, so the company can use it again or build on it. This way, the project can really help ITG and CT make their transport more efficient and environmentally friendly.

10. Conclusion

This research project investigated whether establishing a new container depot in Hengelo could reduce CO_2 emissions and fuel consumption across the container logistics chain. The study compared the current situation, where containers are transported mainly through depots in Rotterdam and Antwerp, with a future scenario involving a new local depot in Hengelo. By applying the WTW method and analyzing operational data from CT and ITG for 2018 and 2019, the research provided insight into how this shift could contribute to more sustainable logistics operations.

10.1. Main Results and Findings

The results of the analysis highlighted several important findings. In terms of container handling at the Hengelo terminal, emissions per handling operation decreased from approximately 2.56 kg CO_2 in 2018 to 2.44 kg CO_2 in 2019. This reduction was mainly driven by lower diesel consumption and possibly greater use of electric handling equipment. For truck transport, the 2019 data showed that the average diesel consumption was 0.2827 liters per kilometer, corresponding to approximately 0.913 kg CO_2 per kilometer. A further comparison between the current and new depot scenarios showed that implementing the new depot would reduce total truck distance by about 1,284,096 kilometers annually. This would lead to a decrease in diesel consumption of around 382,530 liters and a reduction in CO_2 emissions of approximately 1,234,561.9 kilograms, representing a 43% reduction compared to the current setup.

Regarding barge transport, a detailed calculation for the new depot scenario could not be carried out due to data limitations. However, a qualitative analysis revealed that the elimination of empty return trips from Hengelo to Rotterdam would significantly improve the sustainability of barge operations. Currently, barges return empty after deliveries, unnecessarily covering an extra 238 kilometers per trip. The new depot would allow containers to remain in Hengelo, cutting out this inefficient leg and thus reducing fuel consumption and emissions.

10.2. Contribution

In terms of contributions, this study provides practical value by offering CT and ITG a clear, data-supported evaluation of how a new depot could improve sustainability. It also contributes academically by demonstrating how the CRISP-DM framework, combined with WTW and emission factor-based methods, can be applied effectively in logistics research. By using real operational data, the study shows that structured data modeling can provide meaningful insights into environmental performance in container transport.

10.3. Limitations

There were some limitations to this research that need to be considered. One major issue was that not all the needed data was provided by the company, which meant that the analysis had to be done using the available data only. For example, certain trip-specific details, exact fuel usage per route, or container weights were not available, which limited the level of accuracy.

Another limitation was the scope of the project, which only looked at data from 2018 and 2019, and just two main routes. Including more recent years or more transport paths would have made the results more complete. Also, this research focused only on environmental impact, without looking at the financial costs of opening a new depot, which is something the company will still need to consider separately.

Lastly, even though standardized methods like WTW, TTW, and emission factor-based approaches were used, they can't always fully reflect real-life conditions such as traffic, route variations, or driver behavior.

10.4. Recommendation for CT/ITG

Based on the findings, several recommendations can be made for CT and ITG. Establishing the Hengelo depot should be seriously considered, given the clear potential for emission and fuel savings. Further investments in electric handling equipment would build on the positive trend already observed at Hengelo. In addition, improving emissions tracking systems, such as separately monitoring office and operational energy usage, would help further optimize sustainability efforts. Although this study relied on manual modeling, in the future, more advanced tools such as BigMile, EcoTransIT, or GaBi could support scenario analysis and reporting once more detailed operational data become available. Finally, it would be valuable for the companies to apply the methods used here to a wider range of routes and terminals to maximize environmental benefits across their entire logistics network.

10.5. Future Research

For future research, it would be beneficial to perform a full LCA that covers the entire logistics process, including both environmental and financial dimensions. Using specialized software such as GaBi would allow for a deeper and more precise evaluation. Future studies should also consider extending the scope to include more recent data and additional transport routes. Moreover, scenario-based simulations and cost-benefit analyses could offer valuable insights into the long-term impact of different logistics strategies, ensuring that sustainability and operational efficiency are both taken into account when making investment decisions.

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Appendices

Appendix A – Carbon Dioxide (CO_2)

A.1. Describing Carbon Dioxide CO_2

CO_2 is a natural gas that plays a main role in the earth's carbon cycle which is produced and absorbed through biological and earth-based phenomena (Goel & Agarwal, 2014). Although, human activities in particular the burning of fossil fuels have a significant increase in the CO_2 levels in earth, which impact to environment problems. Therefore, the impact of CO_2 emissions on the environment will be explored more.

A.2. Impact on Greenhouse Gas

CO_2 is one of the primary greenhouse gases which is responsible for trapping the heat in the atmosphere (Goel & Agarwal, 2014). Normally the earth absorbs solar energy and releases it back into space, however, since the CO_2 is main part of the greenhouse gases then it holds the heat which leads to increasing in the temperature (Goel & Agarwal, 2014). The expansion of the CO_2 emissions make it fundamental to find ways or solutions to reduce the CO_2 emissions especially in the fossil fuels sector. Since a significant amount of CO_2 emissions come from the burning of fossil fuels, such as oil and natural gas, for energy production and transportation. Therefore, the logistics industry, particularly road transport, is one of the biggest contributions to these emissions (Goel & Agarwal, 2014). It does not only discharge CO_2 emissions but also harmful gases which negatively impact the air quality.

A.3. Relevance to Research

In the current situation, the empty or needs to be cleaned containers, would be transported to Rotterdam or Antwerp from Hengelo for repairs or cleaning, which increase the traveling distance and fuel consumption during this process and the main important increase in the CO_2 emissions. Therefore, optimizing logistical operation throughout a new depot could benefit both environmental and financial since there will be reduction on the transported distance which would lead to lower fuel usage.

Appendix B - Study Design

B.1 Knowledge Question

The systematic literature review (SLR) addresses the following knowledge question:

"What tools or software are capable of modeling emissions and fuel consumptions for the current and future situation?"

This question is essential as it provides insights into the most suitable methods for evaluating CO_2 emissions and fuel consumption related to the establishment of a new container depot in Hengelo. Various methodologies exist, such as WTW, TTW, Emission Factor-Based Approaches, and LCA. Conducting this review ensures that the most applicable and scientifically validated methods are selected.

B.2 Key Concepts and Sources

The key concepts relevant to this research are outlined in Table A.1. These concepts define the scope of the literature review and guide the search terms used in academic databases.

Key concepts	
1	**CO_2 emissions**
2	**Fuel consumption**
3	**Models and tools**

Table B.6: Key Concepts

To refine search queries, related terms and synonyms were used, as presented in Table A.2.

Key Concept	Related Terms	Narrower Terms	Broader Terms
CO_2 emissions	GHG emissions, carbon footprint, transportation emissions	Wheel-to-Wheel (WTW), Tank-to-Wheel (TTW)	Environmental impact
Fuel consumption	Fuel efficiency, energy usage, transport energy	Emissions per ton-km, Load Performance Indicator (LPI)	Transport and energy optimization
Models and Tools	LCA, emissions calculator, CO_2 modeling	COFRET, CPI, GaBi software	Supply chain sustainability

Table B.7: Search Terms

B.3 Database Selection

The databases selected for this review include:

Scopus – Covers engineering, sustainability, and logistics research.

Web of Science – A highly reputable database for peer-reviewed journal articles.

GreenFile – Focuses on environmental and sustainability research.

ScienceDirect – Contains studies related to logistics, transport modeling, and environmental impact.

These databases were chosen to ensure comprehensive and high-quality research findings.

B.4 Inclusion and Exclusion Criteria

The selection criteria were refined to ensure the inclusion of relevant and high-quality articles.

Criteria	Reasoning
Must contain CO_2 emissions modeling and fuel consumption calculations	Ensures relevance to the research question.
Must be peer-reviewed journal articles	Ensures scientific credibility.
Must be published within the last 10 years (2014–2024)	Ensures use of recent methodologies.
Must focus on logistics, freight transport, and container handling	Aligns with the research scope.

Table B.8: Inclusion Criteria

Criteria	Reasoning
Studies focused on aviation, passenger transport, or unrelated industries	Keeps focus on container logistics.
Studies older than 10 years	Older methods may be outdated or irrelevant.
Non-peer-reviewed sources (blogs, white papers)	Ensures reliability of findings.
Studies without CO_2 emissions or fuel consumption methodologies	Removes qualitative-only studies.

Table B.9: Exclusion Criteria

B.5 Search Log and Results

The search strategy was applied consistently across databases using Boolean operators for improved accuracy.

Example Search Query:

("CO_2 emissions" OR "GHG emissions" OR "carbon footprint") AND ("fuel consumption" OR "energy usage") AND ("logistics" OR "transport sector")
AND ("WTW" OR "TTW" OR "LCA" OR "Emission Factor-Based Approach")

Date	Database	Search String	# of Results	Notes
27/11	Scopus	("CO_2 emissions" AND "fuel consumption")	3400	Filtered results to the most relevant 10 papers.
27/11	Web of Science	("CO_2 emissions AND fuel consumption AND inland transportation")	1	Highly relevant study, included in final selection.
19/01	GreenFile	("LCA AND CO_2 emissions")	87	Found relevant sources on GaBi and carbon footprinting.

21/01	ScienceDirect	("Emission Factor-Based approach AND logistics")	53	Selected articles focusing on emissions estimation models.
29/11	Scopus	("Wheel-to-Wheel AND Tank-to-Wheel")	295	Found comparative analyses of WTW and TTW.

Table B.10: Search Log

Appendix C – Included Research Papers

	Article	Author	Year	Term	Key finding	Source
1	Integrated Emission and Fuel Consumption Calculation Model for Green Supply Chain Management	- Aslı Aksoy -İlker Küçükoğlu - Seval Ene - Nursel Öztürk	2014	- Calculation CO_2 emissions - Fuel consumption	It explains how to calculate the CO_2 emissions and fuel consumption using the fuel type and the distance taken	Web of science
2	Carbon footprinting methodology	_	np	_	Found a lot of relevant things related to calculation of the CO_2 emissions and the inland transportation	_
3	Carbon Dioxide	- S. Goel - D. Agarwal	2014	- CO_2	The explanation of CO_2 and how it affects the environment	Science Direct
4	Wheel-to-wheels scenarios for 2050 carbon-neutral road transport in the EU	- Georgios Fontaras - Roland Dauphin - Peter Prenninger - Stephan Neugebauer	2024	- WTW - TTW	Found the explanation of the WHW and TTW and for what they are use	Scopus
5	Economic and emission assessment of LNG-fuelled ships for inland waterway transportation	- De-Chang Li - Hua-Long Yang - Yu-Wei Xing	2023	- Calculation CO_2 emissions - Fuel consumption - Inland transportation	Found a tool/way that can calculate fuel consumption	Web of science
6	Carbon Emission Analysis and Reporting in Urban Emissions: An Analysis of the Greenhouse Gas Inventories and Climate Action Plans in Sarıçam Municipality	- Orkun Davutluoğlu - Abdurrahman Yavuzdeğer - Burak Esenboğa - Özge Demirdelen - Kübra Tümay Ateş - Tuğçe Demirdelen	2024	- CO_2 emissions - Fuel consumption - Sustainability calculation	Understood that there are different scopes of emissions and needs to take them into consideration	Web of science
7	Does It Matter Which LCA Tool You Use? – A Comparative Assessment of SimaPro and GaBi	- Ivan T. Herrmann - Andreas Moltesen	2015	-LCA (GaBi vs. SimaPro)	Explains the tool Gabi	Web of Science
8	The Influence of Route Choice and	- Prpić-Oršić et al - Roberto Vettor	2016	- Fuel Consumption Model	The article examines how route choice, ship speed, and	Scopus

	Operating Conditions on Fuel Consumption and CO_2 Emission of Ships	- Odd Magnus Faltinsen - Carlos Guedes Soares			operating conditions impact fuel consumption and CO_2 emissions, providing useful methodologies for optimizing transport efficiency and sustainability in your research.	
9	Fitting Analysis of Inland Ship Fuel Consumption Considering Navigation Status and Environmental Factors	- Zhi Yuan - Jingxian Liu - Yi Liu - Yuan Yuan - Qian Zhang - Zongzhi Li	2020	- Calculation CO_2 emissions - Fuel consumption - Inland transportation		Scopus
10	Modest Method for Estimating CO2 Emissions from Container Handling Equipment at Ports	- Muhammad Arif Budiyanto - Faril Ichfari - Takeshi Shinoda	2024	- Calculation CO_2 emissions - Fuel consumption - Inland transportation	It explains the method to know the CO_2 emissions from the container handling.	Scopus
11	Review of Wheel-to-Wheel lifecycle emissions of liquefied natural gas heavy goods vehicles	- Marc E.J. Stettler - Mino Woo - Daniel Ainalis - Pablo Achurra-Gonzalez - Jamie Speirs - Jasmin Cooper - Dong-Ha Lim - Nigel Brandon - Adam Hawkes	2023	- WTW - TTW	Explaining the WTW lifecycle	Scopus
12	Het visualiseren van CO2 en NOx uitstoot op klantniveau	- Floor Veuger	2020	_	It explains how to calculate the CO_2 emissions for the container handling, trucks, and barges.	_
13	Carbon Footprint tools	-	np	-	It explains different tools on how to calculate the CO_2 emissions	-

Table C.11: Research Papers

Appendix D – Prisma Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	p.9
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	NP
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	p.9
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	p.5
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	p.36
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	p.36-37
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	p.36
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	p.9-10
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	p.9-10
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	p.11-12
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	NP
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	NP
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	NP
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	p.20
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	NP

Section and Topic	Item #	Checklist item	Location where item is reported
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	p.19-20
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	p.18-21
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	NP
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	NP
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	NP
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	NP
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	p.10-11
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	p.10-11
Study characteristics	17	Cite each included study and present its characteristics.	p.11-14
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	NP
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	NP
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	p.18-21
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	NP
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	NP
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	NP
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	NP
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	NP
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	p.27-29
	23b	Discuss any limitations of the evidence included in the review.	p.32
	23c	Discuss any limitations of the review processes used.	p.32

Section and Topic	Item #	Checklist item	Location where item is reported
	23d	Discuss implications of the results for practice, policy, and future research.	p.33
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	NP
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	NP
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NP
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	NP
Competing interests	26	Declare any competing interests of review authors.	NP
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	p.35-39

Table 12: Prisma Checklist

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

Appendix E – Interview Summary 1

Interview 1: Project Introduction and Understanding the Assignment
Date: 19/11/2024
Participants: Representatives from CT and ITG
Location: Hengelo Facility (on-site)
Interview Type: Semi-structured interview and facility tour

Purpose:

The purpose of this first interview was to gain a clear understanding of the project's objectives and the expectations from CT and ITG. It was essential to learn how container logistics and cleaning are currently organized and to explore the potential benefits of establishing a new container depot in Hengelo.

Topics Discussed:

During the interview, several key topics were addressed related to container transport, handling processes, and current challenges faced by the companies. Questions were asked to deepen the understanding of logistics operations and future plans:

- **Barge Capacity:** It was explained that the barges operating between Rotterdam and Hengelo can typically carry between 60 and 100 TEUs, depending on the specific vessel and waterway conditions.
- **Ownership of Containers:** The transported containers are not exclusively ITG's containers. Barges generally carry containers from multiple clients to maximize load capacity and reduce empty sailing. However, ITG's cargo represents a significant share on the routes relevant to this project.
- **Container Cleaning at CT:** Not all containers are brought to CT for cleaning. Containers requiring cleaning are selected based on customer requirements and the type of previous cargo. Containers that do not need cleaning are either stored directly or transported further without being processed at CT.
- **Transport Methods:** Three types of transportation methods are currently used:
    - Truck Transport is used for flexible short- to medium-distance deliveries.
    - Barge Transport is preferred for bulk movements between seaports and inland terminals.
    - Combined Transport uses barges for the main leg of the journey and trucks for final delivery, optimizing environmental and operational efficiency.
- **Current Challenges:** Both companies highlighted that long-distance transport, particularly empty container movements back to Rotterdam and Antwerp, causes high fuel consumption, increased CO_2 emissions, and operational inefficiencies. Empty returns are especially costly and environmentally damaging.

Additional Activity:

Following the interview, a guided tour of the CT facility was provided. This tour offered valuable insights into the cleaning operations, equipment used, and the general workflow of container handling at the site. It gave a better practical understanding of how energy and fuel are consumed during container cleaning and handling activities.

Main Takeaways:

The companies strongly emphasized their goal to make logistics operations more sustainable by reducing unnecessary transport movements. Establishing a new depot in Hengelo would allow containers to be stored, cleaned, and repaired locally, significantly decreasing truck kilometers driven to and from the western ports. This change is expected to lower both fuel consumption and CO_2 emissions, align with long-term sustainability goals, and improve overall logistics efficiency for both CT and ITG.

Appendix F – Interview Summary 2

Interview 2: Data Requirements for Emission Calculations
Date: 28-02-2025
Participants: Representatives from CT and ITG
Location: Hengelo facility (on-site)
Interview Type: Semi-structured interview

Purpose:

The purpose of this second interview was to discuss in detail the data requirements necessary for accurately calculating CO_2 emissions and fuel consumption within the project. The meeting aimed to confirm what specific data was available, explain why each data element was needed, and agree on the data delivery timeline.

Topics Covered:

During the interview, the required datasets were discussed for each part of the logistics chain:

- **Container Handling:**
  It was explained that for accurate emission calculations, total electricity consumption (kWh), diesel consumption for handling equipment (liters), and the total number of container handling operations were necessary. It was also clarified that electricity consumption would include crane operations and, where separate metering was not available, also the office consumption, to maintain consistency across terminals.
- **Truck Transport:**
  The discussion highlighted the need for total diesel consumption and kilometers driven to calculate average liters per kilometer. Additionally, weight or cargo data, especially information on full and empty containers, was requested to enable emissions per ton-kilometer calculations for more detailed analysis.
- **Barge Transport:**
  For the barge operations, it was requested to provide the total liters of MDO consumed, the number of TEUs transported, and distances covered per route. Clarification was given that distinguishing between full and empty containers would further improve the accuracy of emissions calculations.

For each part, the importance of applying WTW emission factors was emphasized to ensure that the full lifecycle emissions, including both fuel production and consumption phases, were considered. The interviewees were also informed about the specific emission factors that would be applied (e.g., 0.556 kg CO_2/kWh for electricity, 3.23 kg CO_2/liter for diesel, and 3.53 kg CO_2/liter for MDO).

Main Takeaways:
The companies confirmed that most of the requested data was available in their records or could be made available soon. It was agreed that operational data, including fuel and energy usage, would be shared to enable a complete emission analysis for container handling, trucking, and barge transport activities. The interview also helped ensure that CT and ITG understood how the data would be used in the emission models, further aligning expectations between the research team and the companies. As a result, this session provided the foundation needed to move forward with the environmental impact calculations.