A Sustainability Assessment for Transport Routes in Container Transport

Master Thesis

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MASTER THESIS

Sustainability assessment for transport routes in container transport

A research project at Cofano Software Solutions B.V. concerning the investigation, design and validation of an artifact that treats the problem of the sustainability assessment in container transport.

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ABSTRACT

The container transport sector faces significant issues when it comes to the sustainability of its operations. The transport volume of containers is rising every year, and with that the contribution to global emissions and pollution. To combat this, both governmental and non-governmental institutions have set goals to reduce emissions from transport. As container transport usually involves many modalities, each with its specific emission impact factors it is difficult to assess the sustainability of container transport routes. This study aims to design and validate an artifact for logistics service providers and their customers that treats the problem of the assessment of sustainability for container transport routes. Specifically, it investigates the applicability of the life cycle assessment methodology for the sustainability assessment of container transport routes.

In order to achieve this goal a design science research methodology was chosen. A problem investigation is done through a systematic literature review together with expert interviews. In the systematic literature review, as well as in the expert interviews, relevant environmental sustainability categories are identified for container transport and factors that impact the sustainability of container transport. Additionally, data requirements and functional requirements for the artifact are defined. Based on the results of the problem investigation an artifact is designed and implemented in a software tool. Finally, the artifact is validated using a perception-based evaluation. Results of this validation indicate that the artifact is useful and helps the practitioners achieve their goals. Next to this, practitioners are inclined to want to use the artifact in the near future.

The results of this research indicate that the life cycle assessment model can be adapted to container transport and that the artifact provides a way to assess the sustainability of transport routes in container transport. By adapting the life cycle inventory and choosing relevant impact categories for container transport the method can aid practitioners in choosing more sustainable container transport options.

LIST OF ACRONYMS

AIS	Automatic Identification System
API	Application Programming Interface
CEMT	Conférence Européenne des Ministres de Transport
CSR	Corporate Social Responsibility
ECA	Enterprise Carbon Accounting
EEA	European Environment Agency
EMSA	European Marine Safety Agency
GHG	Greenhouse Gas
GWP	Global Warming Potential
IMO	International Maritime Organization
IPCC	International Panel on Climate Change
ISO	International Standards Organization
IVP	Intermodal Voyage Planner
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MRV	Monitoring Reporting and Verification
NGO	Non-Government Organization
PM	Particulate Matter
SaaS	Software as a Service
SLR	Systematic Literature Review
STREAM	Study on Transport Emissions for All Modes
TBL or 3BL	Triple Bottom Line
TEU	Twenty-foot Equivalent Unit
TRACI	Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts
UN	United Nations
UTAUT	Unified Theory of Acceptance and Use of Technology

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Part I

Background

1 INTRODUCTION

Container transport has been a crucial part of logistics worldwide for decades, and is growing everyday [1]. However, with this comes an increase in pollution and emissions. To combat this, both government and non-governmental organizations (NGOs) set out goals in order to decrease the carbon footprint and pollution of the industry. Many of these goals have associated legislation that is slowly put in place by governments across the world.

Worldwide there have been many initiatives with goals to reduce the environmental impacts of human activities. One important current plan of action is the Paris Agreement [2], in which the United Nations (UN) and several other nations declared their dedication to the reduction of greenhouse gas (GHG) emissions. In order to reach these goals, climate action is needed. National governments have to increase their climate efforts and find ways to achieve these goals. Currently, if business-as-usual continues, emissions from maritime transport are expected to grow 150-250% due to world trade tripling between now and 2050 [3]. On top of the GHG emissions, the pollution of air and water are a top-priority of both governments and NGOs. Therefore, transport companies might need to comply with stricter standards on these topics in the near future.

Besides increasing pressure from governments to comply with stricter emissions standards, there is an increase in calls from stakeholders to pay more attention to the environmental impacts of operations [4]. In an example by Zadek [5], Nike is described to have changed its stance on their Corporate Social Responsibility (CSR). Many stakeholders, including consumers, criticized Nike for their user of sweatshops in their supply chains. As a result of this pressure, Nike now follows a strict set of supplier labor codes to ensure a higher level of social well-being throughout the supply chain.

In Figure 1.1 the global trade volume in TEU (Twenty-foot equivalent unit) is depicted. A TEU is a common way of indicating volumes of container transport. Volumes of trade are ever-increasing, as well as the significant share of emissions and pollution coming from transport (see Figure 1.2). This makes it imperative to find new ways to create cleaner transport.

Because of the aims to lower the emissions drastically over time, depicted in Figure 1.2, the pressure on governments to tighten the law increases. In this figure the ambition to significantly reduce the carbon emissions of several modalities is shown.

The increase in pressure and the increasing awareness of consumers is motivating companies to assess the sustainability of their operations.

This chapter will give an introduction of the topic at hand, as well as describe the goals of this master thesis. Section 1.1 provides a definition of sustainability for container transport which will be used throughout this research. In section 1.2 a context is given to which the research goals and outcomes apply. A set of research goals and research questions is defined in section 1.3 and section 1.4 and an outline of the coming chapters is given in section 1.5.

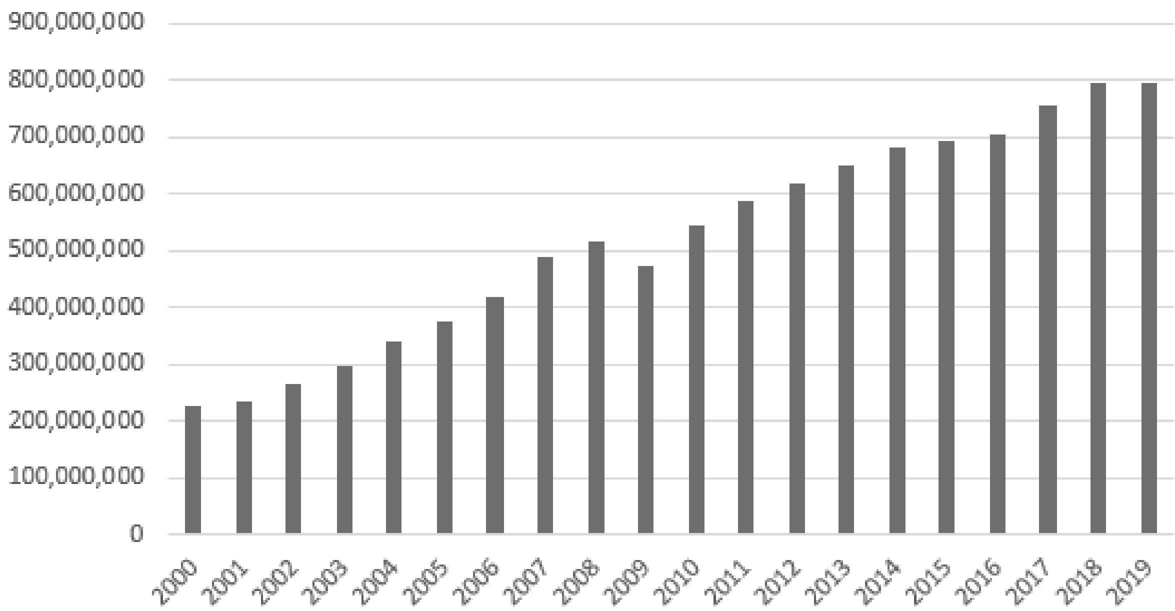

Figure 1.1: Global trade volume in TEU over time, source: [1].

1.1 Sustainability Definition

Sustainability is a very broad concept. It became a more apparent subject in the late 20th century as more and more sustainability issues started to arise. Now, it is a topic most companies cannot ignore. Especially in transport, sustainability has become important. The transportation sector is one of the more polluting industries worldwide [7], and still growing every year [1].

In a systematic literature review (SLR) conducted in January 2021, the author found that environmental issues are most prevalent in scientific literature about sustainability in container transport. The factors that impact sustainability usually are considered to be emissions, pollution of air and pollution of water. However, several more are identified. For detailed results of the SLR, see section 3.1. In line with these findings, this master thesis will use the environmental aspect of sustainability as the running definition of sustainability within container transport.

A common view on sustainability is that next to economic performance, there are two other aspects of importance to organisational practices: the environmental and social performance. This model is called the triple bottom line (TBL or 3BL) [8]. There are currently no real implementations for this model, as the social and environmental aspects are often very hard to quantify in a meaningful and comparable manner.

Even though social and economic issues are also a part of what's commonly seen as the triple bottom line, social and economic issues are not discussed in most scientific literature on sustainability in container transport. This is reasonable as companies need to be inherently profitable to be economically sustainable. The main economic issue found in the systematic literature review is increased costs that might come with choosing sustainable alternatives [9], [10]. The primary social issues are mostly related to environmental issues, such as health concerns caused by poor air and water quality.

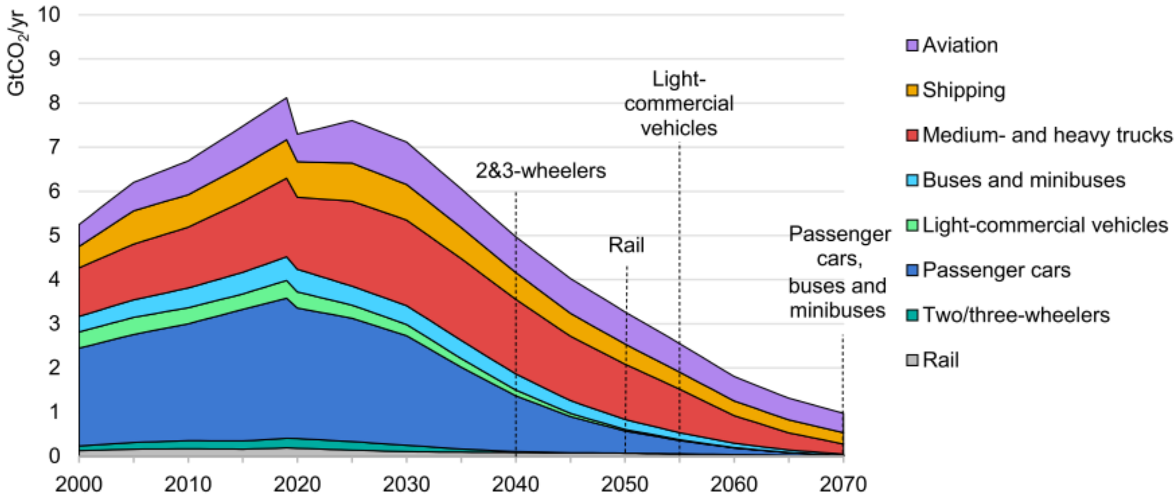

Figure 1.2: Global transport emissions and future predictions [6].

1.2 Transport Routes

In this thesis when a transport route is discussed, it is always an executable transport that has vehicles linked to its execution that are known during planning. In Figure 1.3, an example of a transport route from Rotterdam to Hamburg is shown. This transport route can be planned and executed, it is not a theoretical route. In this research when we are discussing transport routes, we are always referring to individual instances of a transport, not a transport route in general. The research is about the assessment of individually planned transport routes in order to evaluate the environmental performance in practice.

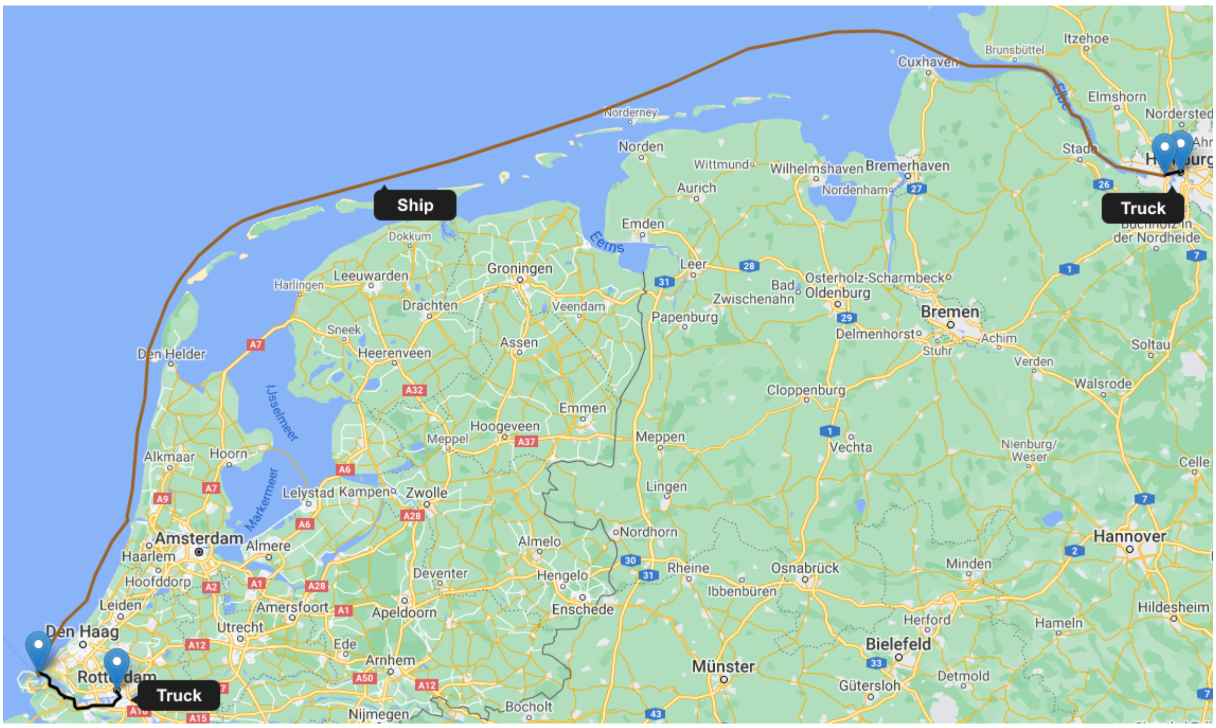

Figure 1.3: An example transport route with multiple modalities involved, from Rotterdam to Hamburg.

A container transport route usually consists of multiple modalities such as trucks, ships and trains. The intervals of transport carried out by these modalities will be referred to as legs. Since container transport typically consists of several of these legs. Because each of these legs has its own emission impacts, such as load percentage, fuel type or empty miles, it is a challenging task to assess the sustainability.

1.3 Life Cycle Assessment

The life cycle assessment is a standardized method to assess the environmental impacts of a product or process throughout its lifetime [11]. Hence the name Life Cycle Assessment (LCA). Originally, the LCA method is a so-called cradle-to-grave method, as it assesses the environmental impacts from the very resources of a product (cradle) to its disposal (grave).

At its core, LCA consists of four phases:

1. Goal definition
2. Life cycle inventory
3. Life cycle impact assessment
4. Interpretation

The most important phases are the life cycle inventory and the life cycle impact assessment, as these phases create the results used to decide on sustainability issues.

Normally, LCA is applied to a product or service. While a transport is not a product or service, it is possible to use the methodology to get to environmental impacts of container transports. In order to apply LCA to a container transport instance, we can treat a transport as a process. One could even argue that the actual transport itself is a service. The legs within the transport route will be steps in this process that can be assessed. Then, the total assessment is the aggregation of the assessments of the legs.

1.4 Project Context

Cofano Software Solutions B.V. is a software company that offers software systems (Software as a Service (SaaS)) to the logistics sector. One of the software tools they provide is the Intermodal Voyage Planner (IVP). This software tool can provide transport routes based on a network of all possible routes. Cofano is getting more and more requests from customers to incorporate sustainability metrics in some form. Therefore, Cofano desires a software tool that provides the user with sustainability metrics on shipping routes provided by the IVP.

1.5 Research Goals

This study aims to improve sustainability in container transport by creating an objective sustainability assessment tool for transport routes in order for suppliers to make more informed decisions on sustainability in container transport. It aims to do this by (re)designing an artifact for the sustainability assessment of transport routes and answer several research questions, or knowledge questions. Then, the study explores how this new model can be automated within the existing systems of Cofano.

1.6 Research Questions

The main research question of this project is:

How can the sustainability of transport routes in container transport be assessed?

The following research questions (RQs) are outlined in order to answer the main research question:

RQ1 What is the motivation for choosing more sustainable container transport routes?

RQ2 What identified categories from the literature review (Emissions, Air pollution, Water pollution, Resource use, Waste disposal) are relevant for the sustainability assessment of container transport routes?

RQ3 What type of analysis is desired? Forecasting or analysis of container transport history?

RQ4 What other methods exist for the sustainability assessment of container transport routes? If other methods exist, what are the shortcomings of these methods?

RQ5 What steps of the LCA method are necessary for the assessment of environmental sustainability of container transport routes?

RQ6 How can the model be integrated in logistics software systems?

RQ7 Is the adapted model useful?

1.7 Outline

The remaining parts of the document are outlined as follows: Chapter 2 describes the method and approach used in this master thesis. Chapter 3 discusses the results of the problem investigation step in the design cycle, this includes results from a systematic literature review and expert interviews. Chapter 4, 5 and 6 describe the treatment design, where solution requirements are outlined in chapter 4 and the life cycle assessment implementation is discussed in chapter 5. In chapter 6 the proposed treatment is discussed. Outlined is how the process of life cycle assessment is used, as well as the implementation process. The last step of the design cycle is outlined in chapter 7 which corresponds to treatment validation. Finally a reflection on the research project is done by means of a discussion in chapter 8 and the conclusion in chapter 9. The conclusion will also provide implications for practitioners and possibilities for future research in the field of sustainability in container transport.

Part II

Method

2 APPROACH AND METHODOLOGY

This chapter describes the approach and methods of this research project. In section 2.1 the method that is used to design a new artifact is discussed. Then, the approach for the problem investigation is outlined in section 2.2. In the same fashion, sections 2.3 and 2.4 consecutively present the approach for the treatment design and treatment validation.

2.1 Method

This study follows a design science approach in order to develop a software tool for the assessment of sustainability in container transport. It follows the design cycle described in the design science methodology by Wieringa [12]. The methodology relies heavily on the design cycle, which is a three-step cycle that can be iterated over multiple times. The methodology also describes an implementation step, but this is not included in this research. With this 4th step included the cycle is called the engineering cycle, depicted in Figure 2.1.

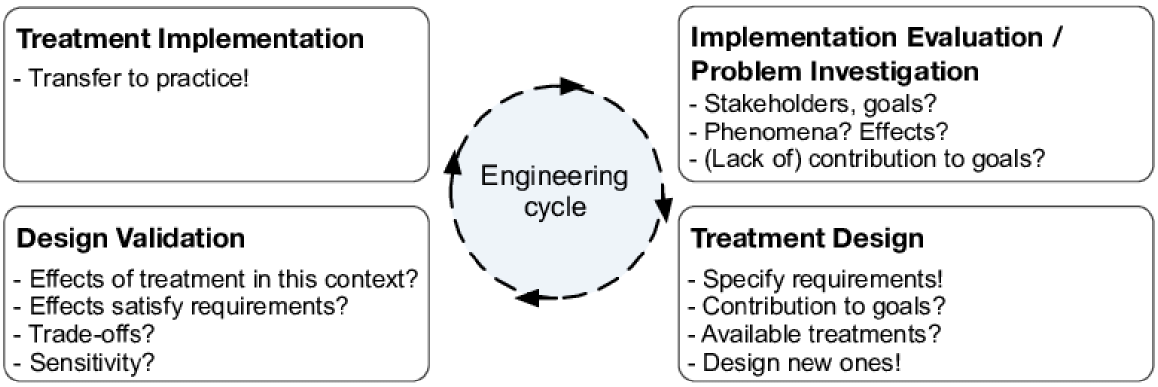

Figure 2.1: The engineering cycle as described by Wieringa [12].

The three steps from the engineering cycle that form the design cycle are used: problem investigation, treatment design and treatment validation, shown in Figure 2.2. In the problem investigation the problem context is defined and stakeholders are identified. Then, an expert panel is created consisting of experts in the field of container transport. The expert panel is interviewed through semi-structured interviews. The answers provided by this expert panel help answer several research questions, primarily RQ1, RQ2 and RQ3.

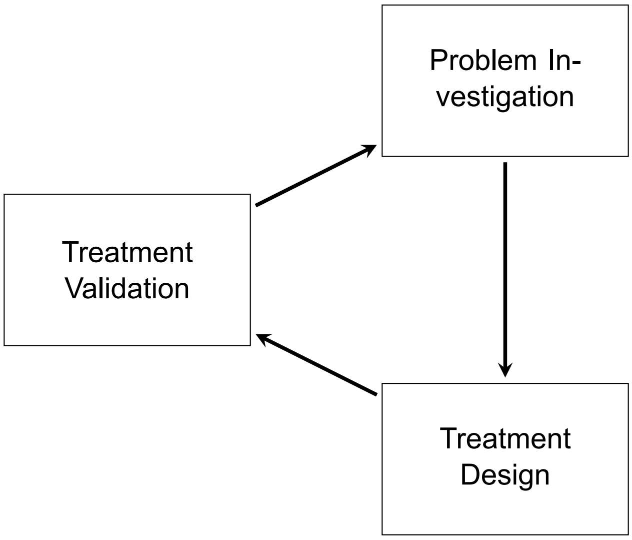

Figure 2.2: Design cycle, as described by Wieringa [12].

2.2 Problem investigation

2.2.1 Stakeholder analysis

For this research it is important to identify the stakeholders of the problem and its context. These stakeholders can influence the problem treatment through their answers in interviews. Wieringa [12] defines a stakeholder as a person or legal person (organization or government etc.) that is affected by treatment of the problem. This can be both a negative or a positive effect. Ultimately the goal is to produce a positive effect for the main stakeholders.

The stakeholders in this research project are described in Table 2.1.

Table 2.1: Research problem stakeholders and their stakeholder type according to Wieringa.

Stakeholder	**Type**
Cofano	Sponsor
Shippers, shipping companies or other logistics companies	End user

Cofano is the sponsor of this research project. They provide a budget for the development of the artifact proposed in this project.

The end users of the developed artifact are shippers or shipping companies that may want to use the sustainability assessment provided by the artifact. This is the most important stakeholder group. The expert panel consists of people in the field who are considered experts on the topic of sustainable transport and members of the end user stakeholder group.

2.2.2 Systematic literature review

A systematic literature review is conducted prior to the qualitative interviews to find out how sustainability is defined in selected scientific literature on sustainability in container transport. Additionally, sustainability impact factors and the quantification of these factors is investigated.

To conduct the research, a research method is proposed that implements the guidelines of a Systematic Literature Review(SLR) [13]. This article provides guidelines on how to conduct a systematic literature review. There are three phases to the SLR. First, a set of research questions is formulated together with a review protocol. Then, exclusion and inclusion rules are defined and the search is performed. Finally, all selected literature is listed and assessed on quality.

For conducting the queries the Scopus is used. Scopus is an online database of scientific literature (Accessed through: https://www.scopus.com).

Literature review research questions

A set of research questions (SLR RQs) is formulated:

SLR RQ1: How are the three pillars of sustainability [14] represented in container transport according to scientific literature?

SLR RQ2: What factors influence the sustainability of container transport according to scientific literature?

SLR RQ3: How can these factors be quantified?

Database queries

The three research questions all serve to answer a different question, so each question has a different database query. A query consists of keywords and logical operators (such as **AND** or **OR**). Then there are some wildcard characters (such as *****) which represents zero-or-more characters. The search is focused on retrieving items based on keywords in the title, abstract and/or keywords of the papers.

SLR RQ1: TITLE-ABS-KEY("sustainability" OR "sustainable") AND TITLE-ABS-KEY("container transport" OR "maritime transport")

SLR RQ2: TITLE-ABS-KEY ("sustainability" OR "sustainable") TITLE-ABS-KEY ("container transport" OR "maritime transport") AND TITLE-ABS-KEY ("factor*" OR "influence*" OR "impact*")

SLR RQ3: TITLE-ABS-KEY ("sustainability" OR "sustainable") AND TITLE-ABS-KEY ("container transport" OR "maritime transport") AND TITLE-ABS-KEY ("assess*" OR "metric*" OR "quantif*" OR "measur*")

The selection process consists of three phases. These three phases will be the same for each query. First, the papers will be subject to inclusion and exclusion criteria. These are properties of the paper such as the language it is written in, the type of publication and what journal they are from. Second, based on reading the title and abstract of the paper the relevancy of the paper will be decided. Finally, a quality assessment will be done on the remaining papers with the criteria listed below.

Inclusion and exclusion criteria

As proposed by the guidelines from [13], a set of criteria is defined to select relevant papers for the review. Any paper directly discussing the sustainability within container transport or maritime transport is considered relevant. The following additional inclusion criteria have been defined:

- Studies should be in English.
- Articles should be journal publications, as they are subject to a more thorough peer-review process. Included journals are:
  - Applied Energy
  - Atmospheric Environment
  - Energy
  - International Journal of Logistics Research and Applications
  - Journal of Cleaner Production
  - Marine Pollution Bulletin
  - Naturwissenschaften
  - Procedia CIRP
  - Resources, Conservation and Recycling
  - Sustainability
  - Transportation Research
  - Transport Policy
  - WMU Journal of Maritime Affairs
  - World Review of Intermodal Transportation Research

Relevancy criteria

243 papers were retrieved from the database. However, to find papers that answer the RQs the results need to be filtered first. Many results aren't directly discussing the topics they were filtered on. The first selection phase therefore categorizes all papers into 'yes', 'no' and 'maybe' categories based on reading the title and the abstract. These are based on the answer on the question: 'Does the paper at hand directly discuss the topic it was filtered on?' Three criteria are considered for relevance, each linked to a research question. These criteria are respectively:

- **SLR RQ1:** Sustainability in container transport or maritime transport.
- **SLR RQ2:** Influences or factors of sustainability in container transport or maritime transport.
- **SLR RQ3:** The measurement, assessment or quantification of one of the factors from SLR RQ2 in container transport or maritime transport.

The papers retrieved for SLR RQ1 will be subject to the criteria for SLR RQ1, the papers retrieved for SLR RQ2 will be subject to the criteria for SLR RQ2, etc. The papers in the 'yes'- and 'maybe'-category are evaluated based on a full-text read.

Data extraction form

Table 2.2 is designed to give an overview of the data that is extracted from the literature and how it relates to the SLR RQs.

Table 2.2: Data extraction form used in the SLR

No.	Extracted Data	Description	Type
1	Bibliographic reference	Authors, year of publication, title, source of publication, funding source	General
2	Representation of the three pillars of sustainability	Common issues of sustainability on the economic, social and environmental dimension	SLR RQ1
3	Factors that influence sustainability	Collection of factors that influence sustainability of container transport	SLR RQ2
4	Metrics and/or formulas	Collection of metrics or formulas to quantify the factors that influence sustainability of container transport	SLR RQ3

Selected papers

Table 2.3 shows the total number of papers found per SLR RQ and the total number of papers that are selected. The search was conducted in April 2021 and resulted in a total of 243 papers. After the selection process 46 papers were left. Of these papers 18 were duplicates, therefore the final number of papers selected is 28 of all SLR RQs combined. Of these papers, 18 are included for multiple SLR RQs. In this review the papers aren't bound to just one research question. One paper can help answer multiple research questions.

Table 2.3: Selected papers by SLR RQ

Source	SLR RQ1	SLR RQ2	SLR RQ3	Total
Scopus	128	65	50	243
Papers Selected	**24**	**15**	**7**	**28**

2.2.3 Qualitative interviews

An expert panel is interviewed through semi-structured interviews based on the process of conducting in-depth interviews by Boyce and Neale [15]. This is done as part of the problem investigation to gain insights in several topics:

- The motivation behind going for more sustainable options in container transport.
- What aspects of sustainability in container transport are important to the end user.
- As part of requirements engineering, the needs and wants are documented.

The answers provided by the expert interviews, together with the literature review conducted in January, guide us in creating a treatment for the research problem.

The interviews consist of 3 parts:

- Part I - General Information
- Part II - Motivation
- Part III - Requirements

In the first part, general information is written down about the interviewee. This includes information such as their name, the organisation they work at, their role at this organisation and their level of expertise in this field.

Part II of the interview consists of several questions about the motivation of the interviewee behind sustainable transport or choosing for more sustainable options for transport. Aspects of sustainable transport that the interviewee deems important are noted. Another item in this part is what the interviewee thinks will happen when organizations do not ever choose for more sustainable options in container transport (leaving the problem untreated).

The final part, Part III, consists of questions regarding the requirements for a software tool that does the assessment of sustainability for transport routes. Additionally, it is determined how the interviewee would use such a tool if it existed.

2.3 Treatment design

In the systematic literature review several existing methods and metrics were identified, but none of the methods can be mapped to the assessment of transport routes. However, a strong focus on the environmental side of sustainability was found in container transport. Greenhouse gasses and air pollution were the two top issues identified in scientific literature. For this reason the life cycle assessment method is explored as a way of assessing the sustainability of container transport since it has a strong focus on the environmental side of sustainability, especially on emissions.

For the life cycle inventory, data requirements are defined based on the input from the expert interviews. Emission sources within container transport are identified as well as important factors that influence these emissions and a layered emission estimation system is designed which uses fall back default emission estimations.

The life cycle impact categories for the sustainability assessment of transport routes are selected based on input from the expert interviews conducted in the problem investigation together with the systematic literature review.

Finally, a solution is proposed in which the steps in the life cycle assessment model are worked out in detail. The proposed solution is implemented in a demo environment.

2.4 Treatment validation

As suggested by Wieringa [12], a validation by expert opinion is carried out. Interviews with a panel of experts are conducted in which the experts give their opinion on the proposed treatment. The expert panel consists of (part of) the stakeholders interviewed for the problem investigation and requirements engineering. The validation interview questions is based on the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh et al. [16], see Figure 2.3 on the next page.

UTAUT is a technology acceptance model based on multiple other models, such as the Technology Acceptance Model by Davis et al. [17]. In total it unifies components from eight different technology acceptance models. The UTAUT model is adapted to fit the context of the artifact.

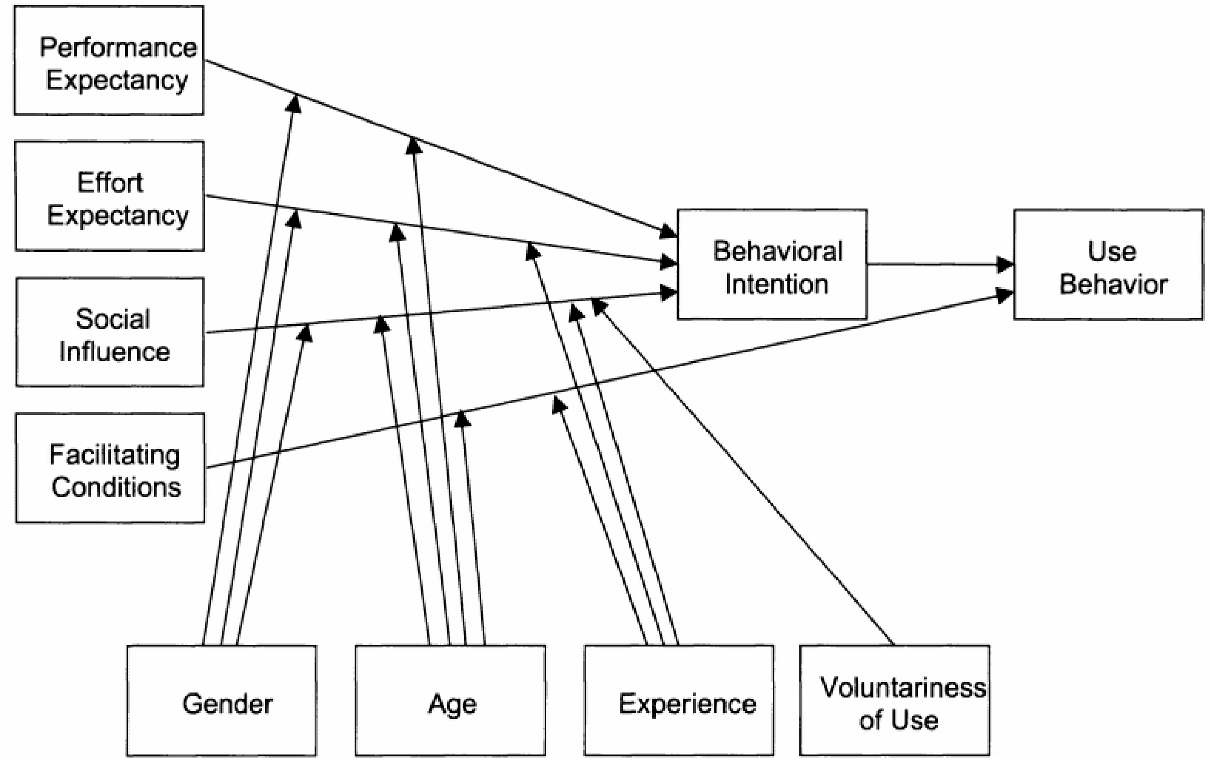

Figure 2.3: Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh et al. [16].

2.5 Method overview

Table 2.4: An overview of what methods are used in this research project.

Research question	Methods	Chapter
Main	Design cycle [12]	2
RQ1	Semi-structured interviews	3
RQ2	Semi-structured interviews, Systematic literature review	3
RQ3	Semi-structured interviews	3
RQ4	Systematic literature review	5
RQ5	Semi-structured interviews	6
RQ6	Treatment design [12]	6
RQ7	Design Validation [12] (based on UTAUT [16])	7

Part III

Results

3 LITERATURE REVIEW & QUALITATIVE INTERVIEWS

This chapter describes the results of the systematic literature review conducted in January 2021, together with the outcomes of the qualitative expert interviews conducted in May 2021. The analysis of these results serves as the problem analysis of the design cycle [12].

The literature review discusses the pillars of sustainability, which are three distinct aspects of sustainability and sustainable development: social, economic and environmental. It discusses how these pillars are represented in scientific literature on sustainability in container transport. Additionally, the literature review investigated what factors influence the sustainability in container transport and how these factors can be measured.

The topics discussed in the qualitative expert interviews are the motivation behind the decision of choosing more sustainable transport routes, the consequences of not making these decisions and the requirements for a software tool that does a sustainability assessment of transport routes.

Finally, a small section covers general remarks and other findings from the interviews that do not belong to any specific category.

3.1 Systematic literature review

As mentioned before, in January 2021 a systematic literature review was conducted to investigate the current state-of-the-art on sustainability in container transport. The literature review found that sustainability in container transport is getting more and more relevant each year, a trend can be viewed in Figure 3.1.

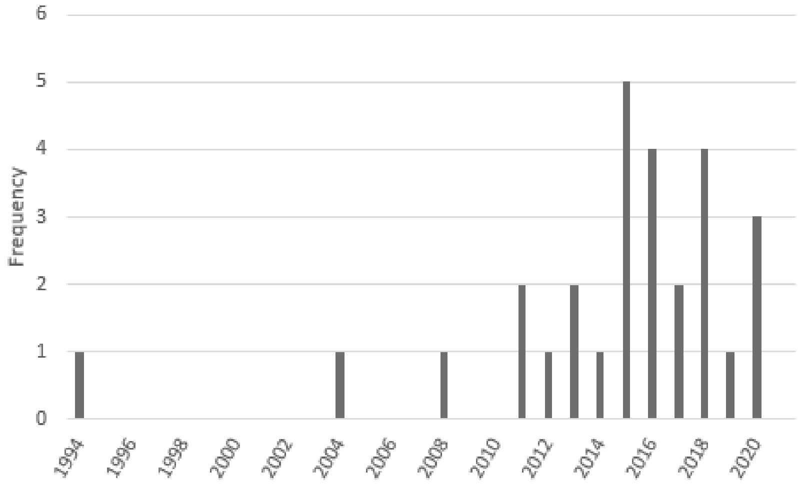

Figure 3.1: The number of included scientific papers over time.

3.1.1 Sustainability categories in container transport

According to scientific literature select for the literature review, the environmental pillar is the main pillar of sustainability for container transport. Research on sustainability in container transport is mostly concerned with greenhouse gas emissions and pollution of air and water, and not with social aspects like health and human rights. Environmental categories were distilled from literature (see Table 3.1 for a small overview of sources):

- Emissions
- Air pollution
- Water pollution
- Waste disposal
- Resource usage

Table 3.1: Overview of results for SLR RQ1 - Sustainability issues in container transport.

Pillar of Sustainability	Issue	Sources
Economic	Delays	[9], [10], [18], [19]
	Air pollution	[10]
Social	Traffic mortality	[20]
	Human health	[21], [22]
	Noise	[23]
	Unfair treatment of employees	[24]
Environmental	Greenhouse gas (GHG) emissions	[9], [10], [20]–[23], [25]–[34]
	Air pollution	[9], [10], [21]–[28], [32], [33], [35]–[38]
	Water pollution	[20], [22]–[24], [26]–[28], [35], [36], [39]
	Waste disposal	[23], [28], [35]
	Energy consumption	[22], [28], [32], [35]
	Land and resource usage	[24], [35], [36]
	Protection of wildlife	[36]

The papers that discuss emissions are largely concerned with CO_2 emissions. CO_2 in general is seen as a priority risk in container transport. It is a great contributor to global warming and climate change (emissions perspective). Additionally, around 30-40% of CO_2 emitted since the beginning of the industrialization has been dissolved into the oceans [40]. This process is called ocean acidification, as the reaction of dissolving CO_2 in water lowers the pH-level and therefore making the water more acidic. Acidification has many negative impacts on ocean ecosystems, and the primary solution for this problem is CO_2-emission reduction.

Besides acidification, another important water pollution source from container transport is eutrophication. Eutrophication is the process of adding chemical nutrients to a water ecosystem to the point that it leads to oxygen depletion and/or a severe loss of water quality. NO_x emissions from container transport contribute to eutrophication, albeit to a limited extend. It is important to reduce both CO_2 and NO_x emissions.

3.1.2 Sustainability factors in container transport

In order to accurately measure sustainability performance, accurate input data is needed. In the literature review, several factors are identified that influence the sustainability of container transport operations. For the environmental side of sustainability, a distinction can be made between transport operations and port operations. In general for transport operations, the factors are mostly concerned with emissions and air pollution. In Table 3.2 an overview of the results from the SLR can be seen.

Table 3.2: Overview of results for SLR RQ2 - Sustainability factors in container transport.

Pillar of Sustainability	Factor	Sources
Economic	**Port**	
	Gross Domestic Product (GDP) per capita & GDP growth	[36]
	Port throughput & port throughout growth	[19], [36]
Social	**Port**	
	Noise levels of ports	[33], [36]
	Accident frequency in ports	[36]
Environmental	**Transport**	
	Transport energy intensity	[20], [33]
	Switch from road to rail transport	[20], [30], [31], [35]
	Use of alternative fuels	[20], [22], [25], [35]
	Use of renewable energy	[35], [41]
	Ship specific	
	Age of engine, engine power, fuel type	[21]
	Ship speed	[21], [31], [41], [42]
	Gross tonnage of ship	[21], [42]
	Shipping route design	[31]
	Just-in-time (JIT) implementation	[43]
	Oil spill frequency	[39]
	Port	
	Ballast water disposal	[33], [35], [41]
	Waste disposal	[35], [36]
	Reuse & Recycling of material	[35]
	Emissions during container handling	[37]

For ships, it is important to incorporate engine properties and operational properties. Engine properties include fuel type and total power of the engine. Operational properties include operational speed and just-in-time implementation. The operational speed, especially for large ships can be significantly lower than their maximum operational speed to reduce emissions. This process is called slow-steaming and has a large effect on total emissions. Just-in-time implementations is a relatively new method to reduce the idle time in ports by better timing arrival based on port schedules. However, this technique is very hard to implement due to a high level of uncertainty and lack of information on port availability.

3.1.3 Assessment models & frameworks

In the selected scientific literature, no assessment models were found specifically for container transport that encompass all categories of environmental sustainability. However, individually, these categories can be objectively measured. CO_2 can be measured in $g \cdot kWh^{-1}$ or $mg \cdot tonne\, km^{-1}$. This could even be standardized to $mg \cdot TEU\, km^{-1}$ where a TEU is a twenty-foot-equivalent unit, which is commonly used in container transport to denote volume. Similarly, air pollutants such as Particulate Matter (PM10 and PM2.5), ozone gas (O_3) etc. can also be quantified by this metric.

Additionally, emissions could be measured by using CO_2-equivalent for emissions other than CO_2, known as the global warming potential (GWP). The GWP can be calculated for many emission gases, for which a conversion table is made available by the Intergovernmental Panel on Climate Change (IPCC) [44]. These tables contain detailed information on many gases and other pollutants, and can be used to convert all emission data into one metric. This is useful, as for example N_2O gas has a much higher global warming potential than CO_2 (298, IPCC [44]) [45]. By converting emissions like N_2O we can compare and add up emissions to come to one total GWP metric.

3.2 Expert interviews

In this section the results of the interviews are presented. The interviewed organizations are discussed together with the interview questions and answers. The main goal of the interviews is to first find out the motivation behind choosing more sustainable transport options (RQ1), and second to determine what information is needed to make this decision (RQ3). The answers to these research questions, together with the information from the literature review will provide the answer on what impact categories are relevant for container transport (RQ2).

The method is based on the process for conducting in-depth interviews by Boyce and Neale [15]. This process consists of six steps:

1. Plan (found in section 2.2.3)
2. Develop instruments (found in section 3.2)
3. Train data collectors
4. Collect data
5. Analyze data (found in sections 3.2.1 – 3.2.4)
6. Disseminate findings (found in section 3.2.6)

Training data collectors was not necessary as the author was the only person conducting interviews. Collecting data is done while conducting the interviews. This is not specified any further in this research.

The expert interviews consist of three parts. In the first part, some general information is collected about the interviewees' function and organisation. Secondly, a part of the interview is dedicated to determining the motivation behind sustainable transport. Finally, the last part of the interview is dedicated to defining functional requirements for the treatment. A total of three experts are interviewed within the period of the 30th of June to the 14th of July. The same set of questions is used for each expert interview, these questions can be found in appendix A (in Dutch).

3.2.1 Part I - General information

In Table 3.3 an overview of the interviewees is presented, their roles and a brief description of the organisation they work at is given.

Table 3.3: Interviewees and their roles

ID	Role	Description of company
1	Logistics Consultant	Independent logistics consultancy company for inland shipping
2	Business Development Manager	Co-operation of shippers and shipping companies
3	Logistics Analyst	Large producer of steel

Interviewee 1

Interviewee 1 is a logistics consultant at an independent logistics consultancy company. She has a masters degree in business economics. The company is specialized in the modal shift from truck transport to multi-modal transport, mainly inland shipping. Most of the times the reason for this shift is to reduce emissions of either NO_x or CO_2. She has been working in this field for over ten years.

Interviewee 2

Interviewee 2 is a business development manager at an organization that is a co-operation of shippers and shipping companies. He has a bachelors degree of applied science in economics. The organization connects the shippers with the shipping companies to create long lasting business relationships. He has more than ten years of experience in the field of more sustainable shipping. The organization consists of both shippers and customers of logistics service providers and both of these parties would benefit from having a tool such as the one discussed in this research.

Interviewee 3

Interviewee 3 is a logistics analyst at a large producer of steel in The Netherlands. She has a PhD in logistics and supply chain management. As the company is large producer of goods, it already has to deal with the European carbon trading system. Within the company there is a drive to optimize the logistics networks and reduce the carbon footprint of their transportation.

Interviewee 3 has been working at this company for three years focused specifically on emissions and carbon intensity of logistics. Next to this she has more than ten years of experience in the logistics sector. As the organization is interested in the carbon footprint of their logistics the tool discussed in this research would be beneficial.

3.2.2 Part II - Motivation

This section outlines the information retrieved from the interviews that provide the motivation for sustainable transport options.

Interview 1

One of the main drivers for shifting road transport to the more sustainable multi-modal transport is to alleviate road traffic by removing trucks. This in turn facilitates traffic flow in cities and on highways. Interestingly, interviewee 1 mentions that for governmental institutions most of the times this also is a financial incentive. Roads cost a lot of money to maintain, and trucks have a large impact on road wear and tear. When shifting from road to rail or from road to water the lifetime of roads can be drastically increased. Interviewee 1 mentions that most projects are with local governments in order to increase mobility and improve sustainability.

When these local governments do not attend to the increasing issues from transport, human health conditions will decrease and road maintenance costs will increase. Interviewee 1 mentions that CO_2 is not the only problem within transport, even though most companies focus mostly on CO_2. The emissions of particulate matter and NO_x have adverse effects on human health through air pollution.

Most companies that are interested in choosing more sustainable transport aim to reduce their CO_2 emissions. Interviewee 1 mentions that in order for companies to focus more on sustainable operations there needs to be an incentive to do so. The interviewee refers to recent news that companies such as Tata Steel are now forced to drastically reduce their CO_2 emissions, and how this can also be achieved by making the logistics operations more sustainable.

A big hurdle in the transition to more sustainable transport is that companies or logistics partners of companies are used to doing business in a certain way. It is relatively easy to transport with a truck, as they are easily arranged and usually very affordable. Transitioning to a multi-modal transport system takes many steps and some planning. This takes time and effort. However, interviewee 1 states that part of being sustainable is being cost-effective. Most of the times more sustainable alternatives cost the same. This is needed according the the interviewee, as most of the times in transport tendering mainly the costs are important.

Interview 2

Interviewee 2 mentions that due to lack of legislation there is a lack of awareness, resulting in a lack of motivation to ask sustainability questions to inland shippers. However, in specific sectors there is a larger awareness to produce and transport in a more sustainable manner.

In addition, interviewee 2 pointed out that, even though awareness right now is still low on average, there are larger organizations the interviewee refers to as “front runners” that are actively looking into sustainability. Interviewee 2 states that sooner or later legislation on sustainability will follow for logistics as well, as it exists for production today. Mentioned is the CO_2 trading system or carbon tax, applied to logistics someday.

Interview 3

Interviewee 3 mentions that mostly the drivers for "decarbonization" of operations for the company she works at is legislative pressure. Next to this, there is also the prospect of legislation. Mentioned is a proposal by the European Commission to also introduce a carbon emission tax in logistics. This prospect is also a driver to measure the CO_2 emissions and find ways to reduce them.

Furthermore, within the department where interviewee 3 works, the drive to reduce CO_2 emissions is proposed as a competitive strategy. If they move fast and have the right skill set for the future, they can provide a better and cleaner logistics service than their competition. The organisation uses sustainability themselves as a prerequisite in order to do business with logistics service providers.

3.2.3 Part III - Requirements

This section describes the information retrieved from the interviews that provide the requirements for the artifact of this research project.

Interview 1

Interviewee 1 explains the load of the vehicle during transport as a factor for the emissions. For more precision, instead of using estimates of emissions they use estimates of diesel consumption during transport. Based on these diesel estimations, the emissions are estimated.

Emissions other than CO_2 such as NO_x and SO_2 are of less importance, especially to shippers, according to interviewee 1. However, for local governments this is more important, as said before, because NO_x and particulate matter impact the air quality. CO_2 has no direct impacts on human health, but many indirect effects. Some specific sectors are also very much interested in NO_x due to limits imposed by the government on how much NO_x can be emitted.

Interviewee 1 mentions that for inland shipping the two factors that influence emissions most are direction of shipping (upstream or downstream) and load percentage. When looking at shipping direction the type of river impacts the effect of shipping direction. A large river flows at a faster rate than a canal does. Another factor is the size of the ship. A larger ship has relative larger load to weight ratio, therefore reducing the emissions per load.

Regarding the presentation of the data and the type of analysis, according to interviewee 1 it depends on the type of organization. Organizations that are pioneers in sustainable transport will probably want to have forecasts on the sustainability of their transports. Other organizations might only want to have an inventory of their emissions from logistics operations and therefore an analysis of their transport history.

Interview 2

The company of interviewee 2 has implemented a CO_2 monitoring system as a pilot project. This monitoring system measures the actual fuel consumption for the emissions calculation. Interviewee 2 states that the emissions they found were about 10% less on average than found in a study by CE Delft [46] which includes emission factors for all kinds of vessels/vehicles.

As the study of CE Delft is being discussed, the different emissions measured in the study are discussed. Interviewee 2 states that most companies are not interested in any other emissions but CO_2 with the reason being that there is less regulation on other emissions. The only other emission that could be relevant for some companies would be NO_x as there are limits for this emission. The interviewee suggest to only present CO_2 and have an advanced view for other emissions.

Interviewee 2 says that for inland shipping the type of waterway matters together with if transport is going upstream or downstream. On a river such as the Waal river, going upstream will take 100% of the engine power, while going downstream might only take 40% of the engine power. This has a large effect on fuel consumption and therefore on emissions as well.

As for transfers of goods in terminals, interviewee 2 states that this might be relevant to include as the cranes in the terminals usually run on diesel as well. In the case that they run on electricity it matters how this electricity is generated. Hypothetically, a transport with equal emissions but one more terminal transfer is worse than a transport with less terminal transfers.

Interviewee 2 mentions that they employ as strategy of "seeing, understanding, optimizing". This means that they analyze the history (seeing) of emissions, then try to gain insights in what options are more polluting than others (understanding) and finally determine how to make shipping more sustainable (optimizing).

Interview 3

Interviewee 3 states, just like the other interviewees, that the main focus is on CO_2 emissions and that they first aim to map out their logistics network. This can be seen as an analysis of the current state. When inquired about the importance of NO_x emissions in their sector the interviewee mentions that it is indeed important in some cases to also look at NO_x. But mainly because the company works on a NO_x budget, and in order to open up new factory locations they need to be able to prove a reduction in NO_x elsewhere.

Whenever the analysis of history is done and a current state of emissions in logistics is accomplished, the network can be optimized. However, the optimization according to interviewee 3 is more about removing trucks from the road. In any case, the differences between two alternatives can then be shown through the difference in emissions.

3.2.4 Other remarks from the interviews

During the interviews, many other useful pieces of information came to light. A small overview of these remarks can be found below.

Interview 1

Interviewee 1 mentions that modifications to trucks are easier to make than modifications for ships since the lifespan of a truck is about 10 years while that of a ships engine is usually 30 years or more.

Interviewee 1 also mentions that initially it would make more sense to only look at CO_2 emissions as for most companies other emissions would be confusing.

Another remark by interviewee 1 is that in order to get the fairest emissions inventory one would have to look at the actual fuel consumption during the transport. Based on this fuel consumption one could deduct the actual emissions. Added to this one would need to include the fuel consumed by getting to the location of the transport (empty transport kilometers) as this is technically part of the transport. This ensures that all emissions are accounted for.

Interview 2

Interviewee 2 mentions that the reason behind the focus solely on CO_2 emissions is that the pressure on companies is applied by governments based on the Paris Agreement. The Paris Agreement does not mention any other emissions besides CO_2.

Interviewee 2 also says that local governments might be interested in measuring NO_x and particulate matter. Because it has health impacts for residents of the local area. However, commercial organizations have no reason to worry about these impacts because there are no repercussions for this type of pollution yet.

3.2.5 Limitations

The number of experts who are interviewed in this analysis is limited. In total, three experts are interviewed. The qualitative analysis of the interviews is therefore limited to the knowledge of these three experts. However, for this research project three interviewees is considered sufficient as the knowledge of these three experts is expected to cover most of sustainability in transport. From the results can be concluded that all interviewees gave similar answers to the questions in the interviews. According to Boyce and Neale [15] this is a sign that a sufficient sample size has been reached. This process can be repeated with a larger sample size in order to substantiate this claim.

3.2.6 Conclusions

As the main conclusion from the interviews, the drivers for choosing more sustainable transport can be outlined to be to reduce carbon emissions or improve human health, depending on the type of organization. The reason for this reduction is mostly due to legislative pressure from governments. Governmental organizations such as local governments are more concerned with local impacts and therefore value NO_x emissions and particulate matter as well as carbon emissions. However, commercial organizations are mostly interested in their carbon footprint. In a select number of cases, when an organization has NO_x limits, an interest in these emissions arises.

There is a distinction between data requirements and functional requirements. For data requirements, a set of factors that influence emissions is extracted from the interviews. According to the interviewees, the quality of emission estimations will improve if these factors are taken into account. Factors include the direction of shipping (upstream or downstream), load percentage and vessel size (when looking at inland shipping). From one of the interviews can be concluded that terminal transfers are an important factor to take into account, cranes in these terminals run on diesel or electricity and therefore contribute to the total emissions during transport.

For functional requirements, it depends on the type of organization what information they are interested in. As mentioned before, local governments are more interested in NO_x emissions as well as particulate matter. Most other organizations, when they are not a front-runner in sustainable transport, are mostly interested in their carbon emissions. Therefore, a switch is needed in the tool to go from one view (simplified) to another view (advanced, more emissions). Another requirement based on whether an organization is a front-runner in sustainable transport or not is the type of analysis, front-runners may probably want to plan their transport based on the carbon emissions, while companies that want to do the bare minimum only want to see their history of emissions from transport.

4 SOLUTION REQUIREMENTS

This chapter will elaborate and analyze the information retrieved by the expert interviews. Specifically, what is expected to be presented by the software tool for the assessment of transport routes and what focus areas are of interest for the end-users of the tool. This will be fundamental for the treatment design as described in the design cycle by Wieringa [12].

First, the focus areas are discussed. The expert interviews have exposed the important focus areas for sustainability in container transport. These areas will be compared with the categories that scientific literature deems important.

Second, the data requirements are discussed. The life cycle assessment is as accurate as the estimation data in the life cycle inventory. Therefore, a well constructed estimation of emissions and other inputs is imperative for the success of the model.

Furthermore, the functional requirements for the sustainability assessment tool will be discussed, along with their feasibility and how they can be implemented in a software tool. These are mostly user experience requirements on how and what information needs to be presented in the tool.

4.1 Sustainability focus areas

4.1.1 From expert interviews

From the expert interviews only some focus areas in sustainability were found important: emissions and air pollution. Of course there is an overlap between emissions and air pollution. If we look at the categorization by Bare et al. [47] the only categories that were deemed important are climate change and human health with a strong focus on climate change (CO_2). From the interviews is found that it depends on the type of company what information is desired. Companies that have restrictions on certain emissions (like on NO_x) will be interested in the amount of those emissions emitted during transport as well. However, most companies will only be interested in CO_2. Therefore it is necessary to be able to switch from a simplified view (CO_2 only) to a more advanced view which contains all kinds of emissions.

4.1.2 From scientific literature

As discussed in section 3.1.1, five categories of sustainability issues were distilled in a literature review conducted prior to this research. In this review the following categories were found: Emissions, Air pollution, Water pollution, Waste disposal, and Resource usage.

In scientific literature from other fields, the categorization is based more on the type of emission issue instead of the type of emission/pollution. Bare et al. came up with this categorization [47]: Ozone depletion, Climate change, Acidification, Eutrophication, Smog formation, Human health impacts, and Ecotoxicity.

4.2 Data requirements

For the life cycle inventory it is imperative that the properties discussed in section 3.1.2 are taken into account. The life cycle assessment is as good as the quality of input data, so when the input data from the inventory is inaccurate the assessment will be highly inaccurate too. The requirements defined down below are contribute to the highest emission estimation quality. For the assessment the transport routes are cut into legs of the different modalities used in the voyage. This way we can do an inventory and assessment on each leg individually and aggregate the results for the complete transport route. Therefore, data requirements are specified for each modality.

4.2.1 Maritime transport

Important factors for maritime transport emissions are:

- Use of slow steaming (operational speed)
- Fuel type
- Engine power
- Load percentage

In order to track the slow steaming aspect of shipping, the operational speed of the vessel needs to be known. With this information we can determine the power of the engine needed to achieve this operational speed. For this information some data about the engine type and fuel type is needed. Additionally, the fuel type also affects the emissions. For example, bio-diesel will emit almost no CO_2 emissions, while the difference between euro5 and euro6 diesel emissions is mostly the NO_x emissions [46]. In shipping, the use of LNG instead of fuel-oil also mostly impacts emissions other than CO_2. If the ship is loaded full versus half-full will also impact the fuel consumption, and therefore the emissions.

4.2.2 Inland shipping

Important factors for inland shipping are:

- Shipping direction (upstream or downstream)
- Waterway water level
- Fuel type
- Engine power
- Load percentage

For inland shipping, in contrast to maritime transport, the operational speed is not linearly correlated to fuel consumption. Inland shipping is done mostly over large inland waterways. These waterways have a flow rate and, depending if the direction of transport is upstream or downstream this affects the fuel consumption significantly. From the interviews an example was made that downstream transport only uses 40% - 50% of the fuel it takes to go upstream.

The water level in the waterway also affect the maximum load capacity of vessels, increasing the emissions per TEU per kilometer.

4.2.3 Road transport

Important factors for road transport are:

- Congestion
- Engine power
- Fuel type
- Load percentage

For road transport, most factors are straightforward. One unique factor that is not as prevalent in other modalities is congestion. The road modality is by far the most polluting modality when it comes to emissions per TEU per kilometer, due to the relative fuel consumption per container transported. A good way to reduces emissions from transport is by moving away from the road modality as much as possible.

4.2.4 Railway transport

Important factors for railway transport are:

- Engine type (electric, fossil fuel)
- Energy mix of the country when the train operates on electricity
- Load percentage

For railway transport, the emissions heavily depend on the type of train. Electric trains do not emit anything. However, depending on the country the electricity might be generated from non-renewable resources. So, the energy sources of the country needs to be known in order to account for the emissions of the electricity. For example, the trains in The Netherlands are all powered from 100% renewable energy, therefore no emissions are linked to electric railway transport. Diesel trains however do have emissions. Again, the load affects the emissions.

4.2.5 Terminal transfer emissions

Important factors for terminal transfers are:

- Type of transfer (this impacts what types of cranes are used)
- Total number of container moves within the terminal
- Energy mix of the country when a crane is electrically operated

From the interviews can be concluded that there terminal transfers also have emission that need to be taken into account. For different modalities this requires a different set of cranes, which can be electrically operated or operated on diesel. In the case they operate on electricity, once again the energy sources of the country can be used.

4.3 Functional requirements

4.3.1 Types of analysis

From the interviews can be concluded that both forms of analysis, forecasting emissions and analysis of transport history, are desired. It depends on the type of organization what type of analysis would be preferred. However, it is presumed that most organizations start by analyzing their transport history for total emissions and total impacts. After all, you cannot improve something that is not measured. When a baseline is created, the sustainability performance can be benchmarked.

Feasibility

The two types of analysis can both be implemented in the same tool. By being able to search for transports and save them, a history of transports (a portfolio in a way) is created that can be analyzed. In order to analyze a transport history, it needs to be possible to save a transport so it can be analyzed together with the other transports in the history. This is done by saving transport routes and legs to a database. To enable saving a transport, the user needs to be able to specify the amount being transported. Therefore, a user needs to be able to specify the number of TEU for the transport in the tool.

4.3.2 Simple versus advanced view

The interviews also showed that in practice many organizations are not interested in emissions other than CO_2. If the artifact shows six types of emissions, but only one is desired, this can lead to confusion and affect the ease of use. Therefore, a functional requirement is that the data is presented in a simplified mode, with the option to toggle a detailed mode that shows all the information. This ensures that all parties can access the information they desire while maintaining simplicity.

Feasibility

By default the advanced view will also be created, with a switch to toggle the advanced view. This ensures that the advanced view shows all possible emissions for those interested, while the simplified view shows a subset. By default, the simplified view will be shown.

5 LIFE CYCLE ASSESSMENT IMPLEMENTATIONS

The following chapter describes LCA methods and provides an analysis of their functionality and shortcomings for the design problem in this research. The analysis is part of the problem investigation and treatment design as described in [12].

First, the standard LCA method is explained. Phases of the LCA are described and evaluated on their use for the assessment of transport routes in container transport. Two different models for the life cycle impact assessment are discussed.

Next, an alternative LCA method is discussed: Enterprise Carbon Accounting (ECA). This is a process LCA that has a single focus on carbon emissions. The impacts can be directly linked to financial data.

Finally, current solutions with implementations of LCA that could be used to assess the environmental sustainability of container transport routes are discussed.

5.1 Life cycle assessment

The life cycle assessment (LCA) is used to determine the environmental impacts of a product, process or service during its so-called "lifetime". Normally the LCA targets a whole supply chain, where the goal is to document the cumulative environmental impacts of the assessed product throughout the chain up to the end of life stage of the product. This is called cradle-to-grave.

5.1.1 ISO steps in the LCA

A normal LCA consists of four main steps [11]:

1. Goal Definition
2. Life cycle inventory (LCI)
3. Life cycle impact assessment (LCIA)
4. Interpretation

Of these steps, the LCI and LCIA are most important as they form the basis for the decision regarding sustainability issues.

Goal definition

In the goal definition of the assessment some general information must be disclosed, such as the reasoning behind carrying out the LCA. After specifying the goal of the assessment, the scope of the assessment is defined. Here a process system is defined, which is a series of processes that are in the life cycle. Next, functional units are defined, which are units of a service that can be quantified in terms of input/output during the life cycle of the product. Then, reference flows are defined, which is the amount of energy needed to realize the functional units.

An important step in the scoping is defining the system boundary, what is included in the assessment and what is not. Besides this, there are some other steps in the scope that are defined in the ISO standard for the LCA. These mostly involve data quality assurance and documentation. A last step, however is to give an outline of the identified impact categories used in the assessment. These can be kg CO_2 for example, or a more complex metric such as eutrophication. The impact categories are discussed more in-depth later in the LCA.

Life cycle inventory

The LCI is used to create an inventory of inputs and outputs from and to the environment. This includes any emissions to the atmosphere, land or bodies of water, but also resource use (energy or materials). According to the ISO standard this is done in several steps with a bottom-up approach. Again, there are several steps just for data quality assurance.

Life cycle impact assessment

In the impact assessment step within the life cycle assessment, impact categories are selected based on their relevancy. Again, a justification for choosing specific impact categories is needed and needs to be documented. Then an analysis is done on the inventory of inputs and outputs identified in the LCI. Usually for the LCIA, an already existing method is chosen. Models for LCIA include TRACI [48] or ReCiPe [49]. These methods are discussed later on.

Interpretation

The interpretation should contain three items: significant issues, study evaluation and a conclusion with limitations and recommendations.

5.1.2 LCIA methods

As discussed in the sections above, there are existing methods for the impact assessment of the life cycle inventory. Two are discussed in this research are TRACI and ReCiPe.

The TRACI tool

The Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) is a tool developed by Bare et al. [48] to determine the environmental impact of many chemicals. The categories that the TRACI LCIA uses are [47]:

- Ozone depletion
- Climate change
- Acidification
- Eutrophication
- Smog formation
- Human health impacts, and

- Ecotoxicity

All categories have quantifiable equivalence units, such as the CO_2-equivalent unit (CO_2-eq) for climate change. The impacts are determined per category, by summing over each chemical, medium and site. A medium in this model can be air, water, land or a more specific instance of these. The formula is as follows:

$$I^i = \sum_s \sum_x \sum_m F^i_{xms} \cdot P^i_{xms} \cdot M_{xms},$$

where I^i is a specific category of impacts (i) of a chemical (x), e.g. eutrophication. F^i_{xms} and P^i_{xms} are site-specific factors that can be used to determine the relative impact for a site (s) and medium (m). After all, sometimes the location of the emission matters [47]. M_{xms} is the mass of the chemical that is released.

For impact categories that do not use the relative impact for different sites, a more simple formula is used:

$$I^i = \sum_x \sum_m CF^i_{xm} \cdot M_{xm},$$

where, instead of site-specific calculations, a characterization factor CF^i_{xm} is used to estimate the impact of the chemical (x), released to medium (m). TRACI provides tables for these characterization factors.

In order to facilitate these calculations, the TRACI tool has extensive data sheets with equivalence unit conversions for every impact category.

It should be noted for the TRACI model that outcomes cannot be compared due to different impact units. The units for ozone depletion are different from eutrophication and their impacts cannot be compared.

It is still advised to do an extensive interpretation before drawing conclusions, as there may be high uncertainty in data collection and estimation of impacts. A normalization can be done when the impacts are within a certain region, for example per capita in Europe.

The ReCiPe method

ReCiPe is a life-cycle impact assessment method originally developed by the Dutch National Institute for Public Health and the Environment (RIVM) together with consultants and universities [49]. In 2016 the method was revised to what it is today.

The ReCiPe method uses a slightly different model than TRACI, shown in Figure 5.1. ReCiPe defines midpoints and endpoints, and relationships between mid- and endpoints, so-called damage pathways [49]. Through this method of mid- and endpoints and damage pathways, it introduces an abstraction layer to enable more global goal-setting. However, as can be seen in the model, the midpoints and damage pathways are heavily interconnected. This makes it hard to

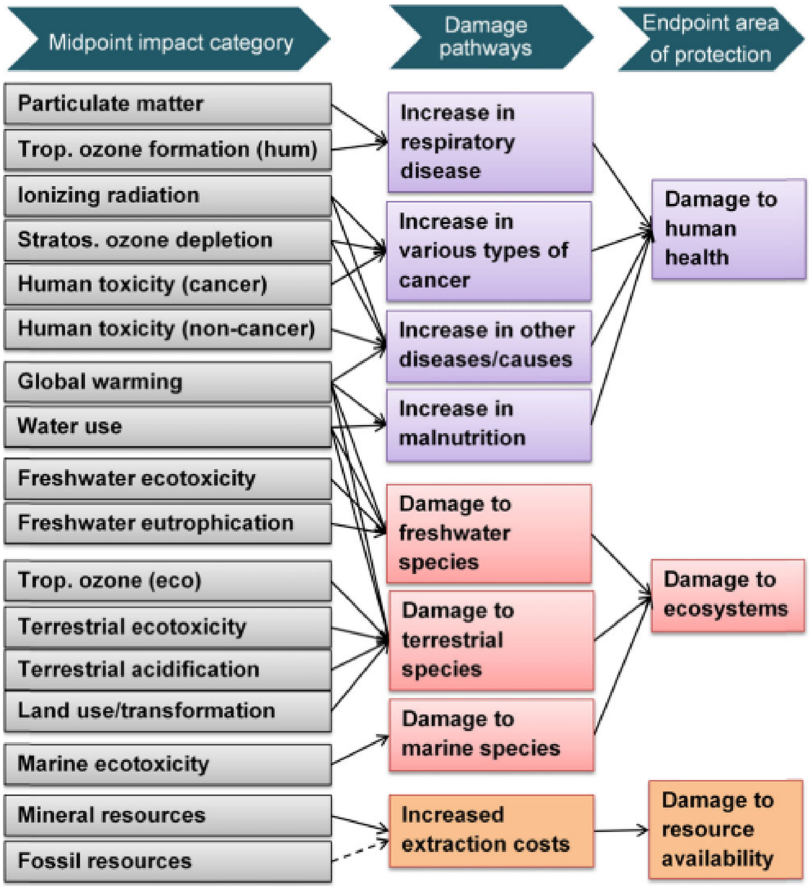

Figure 5.1: The ReCiPe model, from [49].

isolate issues.

The impact scores in the ReCiPe method are calculated as follows:

$$CFe_{x,a} = CFm_x \cdot F_{M \longrightarrow E,a},$$

where CFe and CFm are the characterization factors of the endpoints and midpoints respectively and a the area of concern. The chemical or stressor is denoted by x. $F_{M \longrightarrow E,a}$ is the conversion factor from mid- to endpoint, which is provided by the ReCiPe model.

5.1.3 Applicability of LCA

The LCA method, specifically the Life-cycle inventory and the life-cycle impact assessment are applicable to transport routes in container transport. As mentioned earlier, the LCI and LCIA are the two most important steps in the LCA. The TRACI model for the impact assessment contains all categories identified in scientific literature on sustainability in container transport, be it defined a little bit different.

5.1.4 Shortcomings

Even though the LCA is defined through an ISO standard, the standard still leaves many things open to interpretation of the practitioner [11]. This enables the introduction of bias and makes the method inconsistent. This could be prevented by creating a solid goal definition and interpretation for the LCA, but remains difficult to do.

The two LCIA methods discussed in the sections above both have advantages and disadvantages. The TRACI method is straightforward, and includes most of the categories distilled from the literature review. However, resource usage is not included in the method.

On the contrary, ReCiPe is a more complex model, which does include resource usage. The resource usage is included in the top level category (endpoint) “Damage to resource availability”. However, the endpoint categories are not as applicable to transport routes as the TRACI impact categories.

Both models fail to accurately assess fossil fuel resource usage. TRACI has a very general conversion factor table for fossil fuels.

5.2 Enterprise Carbon Accounting

Enterprise Carbon Accounting (ECA) is a hybrid form of LCA, where there is a strong focus on CO_2-equivalent units and carbon emissions. The goal is to create and report a full inventory of all carbon emissions within the supply chains of an organization [50]. This can facilitate the creation of carbon credit, which is carbon emission credit that can be sold to other organizations.

5.2.1 Applicability of ECA

In the same way as the normal LCA is applicable to container transport, the ECA is also applicable to container transport. However, ECA is not suitable for the sustainability assessment of container transport. CO_2-equivalent units are important for the sustainability assessment, but it is not limited to this. ECA only looks at the global warming potential (in CO_2-eq), therefore not taking into account the other impact categories identified in the systematic literature review (Section 3.1) and qualitative interviews (Section 3.2).

Additionally, carbon accounting has inconsistencies in demands for accuracy, consistency and certainty between different organizational fields. Scientists that are responsible for counting carbon value accuracy most, accounting professionals value certainty the most and in the economic market where carbon credit is traded consistency is valued most [50]. LCA accounts better for these issues by documenting data quality, However, one could argue that these inconsistencies are also present in communicating LCA results.

5.3 Current solutions

This section discusses some of the implementations of LCA in current applications and their shortcomings. In general, these implementations are very similar. Therefore, they share a lot of advantages and disadvantages.

5.3.1 GaBi life cycle assessment

GaBi is a downloadable software tool that contains many data sources that can be used in a classical LCA [51]. It should be possible to model all kinds of transport in this tool. However, the GaBi tool is focused on modeling a product or a service. This is what the life cycle assessment is for, so the tool is not bad. But for container transport we are mainly interested in modelling the emissions from transport. Creating flows of inputs and outputs is mainly important for the production of some product. If a user wants to use the GaBi software to model their transport emissions they will have a hard time as the GaBi software is able to do many other things. This makes it hard to navigate the tool and find what you are looking for. When the user wants to model the transportation process, the user needs to create an inventory of emissions from transport first. Then, after the inventory is done they can input all the emissions in the software. This again requires a large effort, while the main interest is emissions from transport. Additionally, the resolution of the inventory is small because the analysis is very abstract and top-level. The tool does not take into account the many factors that impact the emissions from transport.

Similar software tools exist, be it web-based or a downloadable application. However, in these applications similar issues also arise regarding complexity of the software resulting in high learning effort.

6 PROPOSED SOLUTION

This chapter will go into detail about the treatment design as described by Wieringa [12]. The steps of LCA will be discussed and which ones are necessary for conducting a LCA for transport routes. Each of the steps that are relevant will be discussed.

In the life cycle inventory step, an overview is made of how the artifact determines the emissions and what information is taken into account. An overview is presented on the factors that influence the emissions and how these can be taken into account.

A small section goes into the emissions linked to container transfers, which have corresponding emissions that need to be taken into account.

Finally, the implementation of the artifact is discussed.

6.1 Necessary steps from the LCA method

The automated LCA will always assess the same type of item: transport routes. Therefore, defining the steps for the automated LCA once is sufficient. These steps will be the same each time an transport route assessment takes place. All steps from the LCA are necessary to be a valid LCA according to the ISO standard.

6.1.1 Goal definition

The goal definition, as well as the interpretation for each transport route sustainability assessment will be the same each time. Therefore these are defined or written down once and shown in the application in the “Goal definition” and “Interpretation” tab under Life Cycle Analysis.

Reasoning

The reasoning for carrying out an LCA on a transport route is to determine the emission impacts of a specific transport and its alternatives, in order to have a comparison between different options and make an informed decision on what option to execute.

Goals

Usually the primary goal of LCA is to choose the option that has the least effects on human health and the environment. However, the decision makers in this process have other factors to consider such as costs and transport duration. Therefore the goal of the LCA is to present the environmental impact factors. This way the environmental impacts can be integrated in the decision making in container transport. A secondary goal is to highlight the differences in environmental impacts between different segments within a transport. Certain modalities are more polluting than others and this can be supported with data by LCA. This in turn informs the decision makers and enables them to choose more sustainable options.

Required information

The primary questions stakeholders have are:

1. Are there more sustainable alternative transport routes we can take?
2. How sustainable was our organization the past year?

Alternatives - The information needed to answer this question is emission data and impacts from all options for a given transport route in order to compare them.

Overall sustainability - The information needed for this question is a history of all routes that are executed in a certain time period and their corresponding emissions and impacts.

Specificity

The specificity of the automated LCA is should be as specific as possible. Meaning that the more specific the emission data is, the better. In this case where emissions are determined from transport emissions, knowing the actual emissions from the vehicle is the optimal specificity. However, this is almost impossible to do. Therefore in many cases an estimation of emissions is used. This is less optimal, but will still be sufficient. The quality of the LCA is as good as the specificity of the vehicle emission data.

Functional unit

The functional unit used in this LCA is the unit Twenty-foot Equivalent Unit (TEU). This is a suitable unit as all transport is done with containers and they have a standardized unit (TEU). Per kilometer is not included as this normalizes the distance traveled. Usually a boat would travel more kilometers than a train would, as the train can go over land. However, if this is normalized the total emissions are not relevant anymore. Therefore for comparing two routes the distance traveled impacts total emissions and hence total emissions are not normalized to distance.

Scope

The scope of the assessment is the transport process. This only includes the transportation part of the ”Raw Materials Acquisition“ phase. Emissions of the production of the products is excluded, as well as emissions of the production of the vehicles that are used during the transport. The scope is purely emissions of transporting the containers itself. Any activities outside the transport of containers are out of scope. In Figure 6.1 this process is depicted. From the interviews can be concluded that measuring the fuel consumption directly will always be a better way to calculate emissions than estimation based on vehicle type and distance traveled. This is in line with recommendations from the LCA method to measure directly at the source. However, this requires all vehicles to accurately report their fuel consumption and would take a rather large effort to do. Estimating the emissions will be less accurate, but it is cheaper and requires less effort.

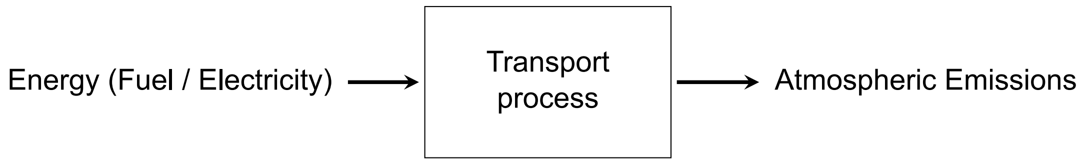

Figure 6.1: Transport process with its input and output according to the LCA Scope.

Assumptions

To document the assumptions made within this implementation of the life cycle assessment, a list of assumptions is kept below.

- Assumed is that the energy mix of the electricity used by the rail modality is 100% renewable energy and therefore carbon neutral.
- Assumed is that, when the load is not known, an average load is used during transport for emission estimations.
- Similarly is assumed for trucks that when the type of road is unknown, the average road type is travelled.
- Assumed is that there is no difference in emissions between going upstream in contrast to transporting goods downstream. In many cases there is a difference, this is discussed in more detail in the discussion in section 8.1.
- Assumed is for container transfers that a total of three container moves is executed per container transfer. See section 8.4 for more on this.

Data quality assurance

Recommended is that, when the LCA is used internally, an internal reviewer who is familiar with LCA practices and not associated with the study reviews the report. For internal use this is sufficient according to the ISO standard.

Impact categories

The impact categories that are used in this implementation of LCA for transport routes in container transport are climate change, acidification, eutrophication, smog and human health (particulate matter). However, according to the information gathered in the interviews, most organizations are only interested in the climate change category.

6.1.2 Life cycle inventory

The life cycle inventory is one of the most important steps in the LCA process, as the accuracy of the model is dependent on the accuracy of estimations of emissions.

Normally, a life cycle inventory returns a diagram with the final product with flows of inputs and outputs of the system. This diagram then includes all processes that are included in the scope of the assessment [11]. However, the method is adjusted to fit the context of container transport. The final product is always the transport of goods, while the sub processes are modelled by the different legs of the same modality. An example can be viewed in Figure 6.2. In this figure the process of transport 1 TEU is depicted. In the center the transport process is built up from (possibly) multiple transport segments of a specific modality. The number of kilometers travelled for each segment is linked to some emission estimation to calculate the used energy (in MJ) and the chemical emissions shown in the figure. In a LCI, the inputs are always quantifiable elements, for example 1 kg of steel. However, in this application we use quantifiable distances of the same modality travelled, for example 1000 km of a container ship with IMO 9299032. The reason for this adaptation is that in this application it is impossible to measure at the source. This means estimation data is used, which is based on the distance travelled and vehicle/modality properties.

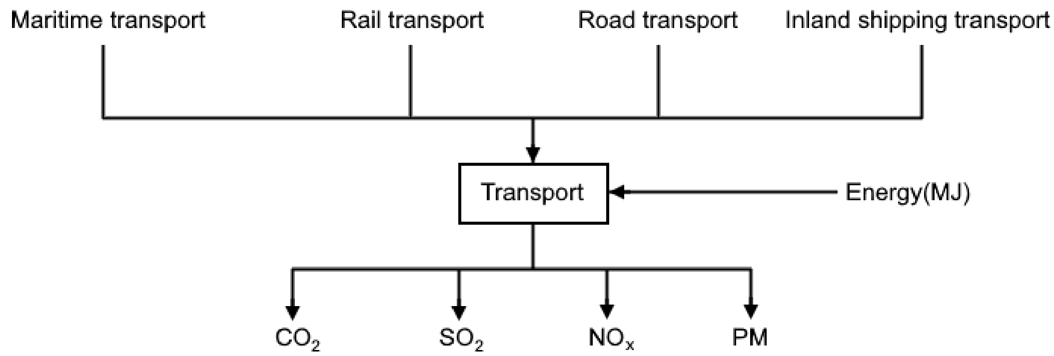

Figure 6.2: Adapted life cycle inventory diagram for the transport of 1 TEU.

In order to enable high level of accuracy in the estimations, a division is made in the transport route based on modality type. The transport route is cut up into legs of the same modality. For each of the segments in the route we have a modality type that contains information necessary for accurate emission estimations. The atmospheric emissions for the life cycle inventory will be CO_2-equivalent emissions, NO_x, SO_2 and particulate matter (PM). Inputs would be energy (in MJ) and fuel consumption. However, in this LCI estimations of emissions are used. The next steps will be discussed in the life cycle impact assessment (section 6.1.4).

6.1.3 Emission estimations for LCI

In this section and its subsections, the emission estimation process for each of the modalities will be described in detail. For each of the modalities that are used in container transport emissions estimations are created based on a set of impact factors and modality properties. In this research project some of the modalities have more accurate emissions estimations than others, mainly due to time constraints, but also due to the difficulty of increasing the accuracy. The issues are discussed in more detail in section 8.1 and section 8.2. In this research project maritime transport is prioritized, as this is usually the largest contributor to the emissions in container transport. The largest part of container transport is usually done by deep sea, short sea, or inland shipping. This prioritization resulted in the maritime transport modality emission estimations usually being based on the specific vessel that is used in the transport, while the other modalities use a default modality emissions estimation.

Maritime transport emission estimation

In case of maritime transport, a IMO number (a unique identifier for a ship) is linked to a specific vessel of which we can retrieve accurate CO_2 emissions from the Thetis MRV dataset. The

Thetis MRV dataset is a dataset from the Thetis system that contains ship-specific emission data developed by the European Maritime Safety Agency (EMSA). The emission data is validated and contains no outliers. An example item from this data set can be seen in Table 6.1. In this example the ship Maersk Douala (IMO Nr: 9299032) is analyzed.

Table 6.1: Example emission data from the Thetis MRV dataset for IMO nr: 9299032

IMO number	**Ship type**	**CO_2 emissions**
9299032	Container ship	20.68 g CO_2 per metric tonne per nautical mile

Then, based on the CO_2 emission data we extrapolate the energy usage, SO_2, NO_x and particulate matter emissions. We do this by mapping the CO_2 emissions on the data provided by the Study on Transport Emissions for All Modes (STREAM) [46]. The container ship type (5.000-7.999 TEU) from this study can be seen in Table 6.2.

Table 6.2: Example emission data from the STREAM study for Container ship type (5.000-7.999 TEU)

Ship type	**Energy usage**	**CO_2-eq**	**NO_x**	**SO_2**	**PM**
Container ship	0.15	11.7	0.29	0.022	0.0061

The ratios of emissions in the data provided by the STREAM study are used to estimate the other emissions of the ship. The study offers many other modalities such as road, rail and aviation. An example of a conversion done for maritime transport can be seen in Table 6.3, 6.4 and 6.5.

Table 6.3: Emission : CO_2-eq ratios derived from STREAM data for Container ship type (5.000-7.999 TEU)

Energy usage : CO_2-eq	**NO_x : CO_2-eq**	**SO_2 : CO_2-eq**	**PM : CO_2-eq**
0.012821	0.024786	0.001880	0.000521

Because the STREAM study uses the CO_2-equivalent unit instead of CO_2, it includes the CO_2-equivalent of other emissions such as CH_4 and N_2O. For this research study we are also interested in these two emission gases, therefore we try to estimate the emissions based on the CO_2-equivalent provided by STREAM and the average composition of the CO_2-equivalent unit per transport unit. These are provided by the European Environment Agency (EEA) [52]:

Table 6.4: CO_2-equivalent emission composition per sector in CO_2-equivalent % (2019) [52]

Sector	**CO_2**	**CH_4**	**N_2O**
Domestic transport	98.8%	0.14%	1.04%
International shipping	98.88%	0.18%	0.96%

The CO_2-equivalent percentages for CH_4 and N_2O emissions can be converted to the $g \cdot TEU^{-1} \cdot km^{-1}$ unit through the TRACI model. This model provides a conversion to the CO_2-equivalent unit, but we can also use this in reverse.

Due to the fact that the resulting emissions for CH_4 and N_2O are very low and only impact the CO_2-equivalent (global warming potential in TRACI), they are left out of the inventory as they serve no purpose other than their contribution to the CO_2-equivalent unit. However, to convert

Table 6.5: Emission estimation based on Emission : CO_2-eq ratios and CO_2-eq composition for Maersk Douala (IMO Nr: 9299032) in $g \cdot TEU^{-1} \cdot km^{-1}$

CO_2	CH_4	N_2O	MJ	NO_x	SO_2	PM
156.328	0.015	0.008	2.027	3.918	0.297	0.082

the CO_2 emissions from the Thetis MRV dataset we multiply the CO_2 emissions by (1 / 0.9888) to get the CO_2-equivalent based on the EEA data. The number 0.9888 is the percentage of CO_2 in the CO_2-eq composition provided by the EEA, see Table 6.4. For the Maersk Douala this would be $156.328 \longrightarrow 158.067$ CO_2-eq.

An overview of all converted emissions can be seen in Figure 6.3. On the x axis the CO_2-eq emissions are shown and on the y axis the frequency of this emission category is shown. For clarity purposes the histogram has category boxes of 40 in size. Note that even though the average is $170 g \cdot TEU^{-1} \cdot km^{-1}$, there are many ships with significantly higher or lower emissions. For example the ship Blue Star Myconos (Imo 9208679) has a CO_2 emission of $623.52 g \cdot mtonne^{-1} \cdot nmiles^{-1}$. This is roughly $4765 g \cdot TEU^{-1} \cdot km^{-1}$. Even though this seems very high, it is verified in the MRV dataset.

The resulting table with all processed ship emissions contains 10161 items as 2154 items had missing data. This means that from the total of 12315 items in the dataset, 82.5% of the Thetis MRV dataset can be used for emission estimations for the inventory of the LCA.

The measured CO_2 emissions are converted to match the unit of $g \cdot TEU^{-1} \cdot km^{-1}$. Because the conversion from CO_2-eq to other emissions is done through conversion factors, this unit will translate over to the estimated emissions. A data point in the resulting data set has the following attributes:

- IMO number

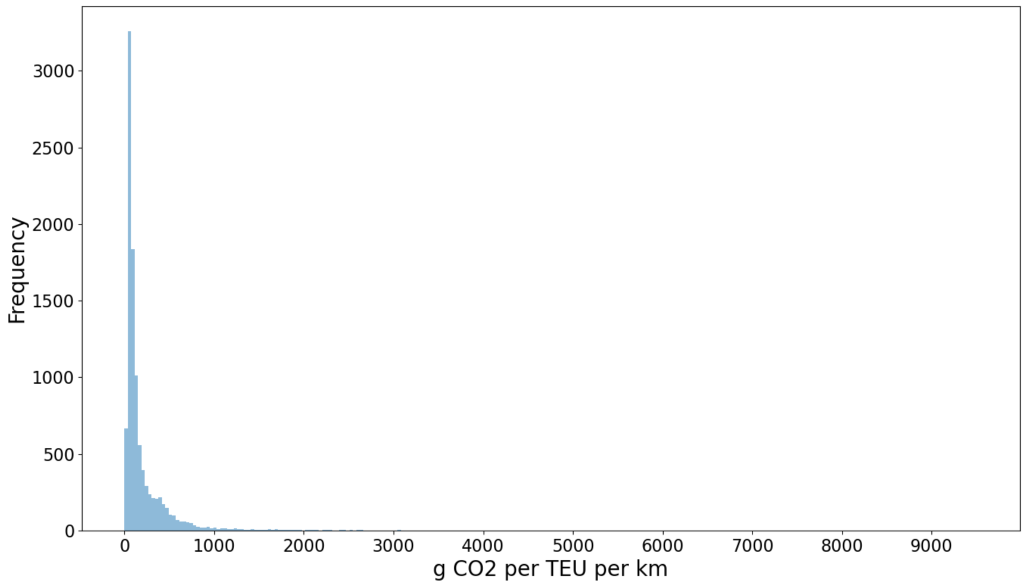

Figure 6.3: Frequency histogram of all converted CO_2 emissions from the MRV dataset.

- Ship type
- Ship name
- CO_2-equivalent (in $g \cdot TEU^{-1} \cdot km^{-1}$)
- Enery usage (in $MJ \cdot TEU^{-1} \cdot km^{-1}$)
- SO_2 emissions (in $g \cdot TEU^{-1} \cdot km^{-1}$)
- NO_x emisisons (in $g \cdot TEU^{-1} \cdot km^{-1}$)
- Particulate matter (PM) (in $g \cdot TEU^{-1} \cdot km^{-1}$)

To get to these data points, the complete process has the following steps:

1. Acquiring the CO_2 emissions of the vessel present in the Thetis MRV dataset.
2. Converting the unit of $g \cdot mtonne^{-1} \cdot nmiles^{-1}$ to the unit used in the tool $g \cdot TEU^{-1} \cdot km^{-1}$.
3. Convert the CO_2 emissions to CO_2-equivalent units by using the EEA data [52].
4. Determine the vessel type of the Thetis MRV item. Based on this and the CO_2-eq data, estimate MJ, NO_x, SO_2, and PM. If fuel type is known, the conversion table for the emissions can be applied in this step as well.

Important to note is that the Thetis MRV data set only contains ships that call European ports. This means a number of ships do not report their CO_2 emissions in a standardized way. For these ships a set of default modality emissions is selected from the STREAM study. Again, the emissions are converted to match the $g \cdot TEU^{-1} \cdot km^{-1}$ unit.

If the fuel type information also is available, the estimations can be multiplied with a conversion table for that specific fuel type. However, most ships do not use alternative fuels and therefore if the fuel type is unknown assumed is fuel oil is used.

Other transport emission estimations

For the other transport modalities, such as road (truck), rail and aviation, the life cycle inventory process relies on the estimation data provided by the STREAM study. For the estimation data assumed is that an average load weight is transported. The emission data is converted to the $g \cdot TEU^{-1} \cdot km^{-1}$ unit. The default modalities used in this study are shown in Table 6.6.
For the truck default modality, assumed is that the truck transports 2 TEU. A load capacity of 2 TEU is the most common load capacity found in trucks. In general, for the default modalities the average cargo load is assumed and average type of road (city, country, highway) is assumed.
If the IMO number of a ship is not present in the estimated emissions data constructed from the Thetis MRV data set, there are fallback default modality emissions ranging from a large container ship (DEEPSEA modality) to a specific CEMT class. A CEMT class refers to a ships size in order to restrict ship access to inland waterways based on ship size. These CEMT classes have corresponding average emissions. If more default modality emissions are needed, they can be extracted accordingly.

Table 6.6: Default modalities extracted from the STREAM study.

Modality type	**Name**
Road	TRUCK
Rail	TRAIN_ELECTRIC TRAIN
Sea	DEEPSEA
Inland waterways	CEMT III CEMT IV CEMT Va CEMT VIb CEMT Vb

Emissions from container transfers

As discussed in chapter 4, including the emissions of container transfers is relevant for the total amount of emissions during a transport. To account for these transfers, a constant factor for a container move is introduced. A container move is defined as a move from the container yard to a vehicle for transport or from the vehicle back to the container yard. According to a study by Van Duin and Geerlings [53], this is equal 10.6kg CO_2 as the average emissions per container move. The study identifies many ways a container can be moved, distinguishing between types of cranes and their relative energy consumption. For this study, the average of the container move emissions for moves from yard to ship and yard to truck are taken as a base estimate. The reasoning behind this assumption is that most of the transfers in container transport are between these yard and ship or yard and truck. When comparing two similar transports, the one with significantly less container transfers is generally the more sustainable option.

A difficult problem in estimating container transfer emissions is estimating the total number of container moves within the terminal. This depends on the way the terminal operates, but usually a container moves from an incoming section to an outgoing section. This move, together with loading and unloading the container will add up to three total moves. However, in the case of trucks, sometimes an empty container is brought back to the terminal. In this case, an extra container move is executed. For this project, a total of three container moves is assumed.

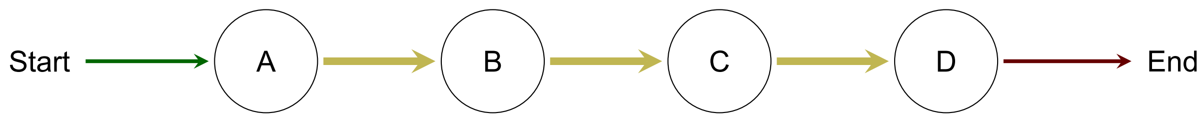

Figure 6.4: Typical network of terminals on a multi-modal transport route. This is an abstract representation of Figure 1.3. The green arrow indicates the start and contains only one container move: loading the container on the vehicle. The red arrow indicates the end and consists of only one container move: loading the container off the vehicle. The yellow arrows indicate a transfer, which consists of two container moves: off the first vehicle and on the next vehicle.

Figure 6.4 shows a typical transport containing four transfers, the rule for determining how many container moves are executed is $3n$ where n is the number of terminals in the transport route. For the example in Figure 6.4 this means that there are $3 \times 4 = 12$ container moves.

6.1.4 Life cycle impact assessment

For the LCIA step in the life cycle assessment the TRACI model will be adapted to fit the needs of container transport specifically. The reason for choosing to adapt the TRACI model and not the ReCiPe model is because the TRACI model is easier to adapt to fit the needs of container transport. The ReCiPe model endpoints are less easily mapped to the relevant environmental impact categories for container transport. This does not mean that the ReCiPe model cannot be used for the impact assessment in container transport. The process is depicted in Figure 6.5.

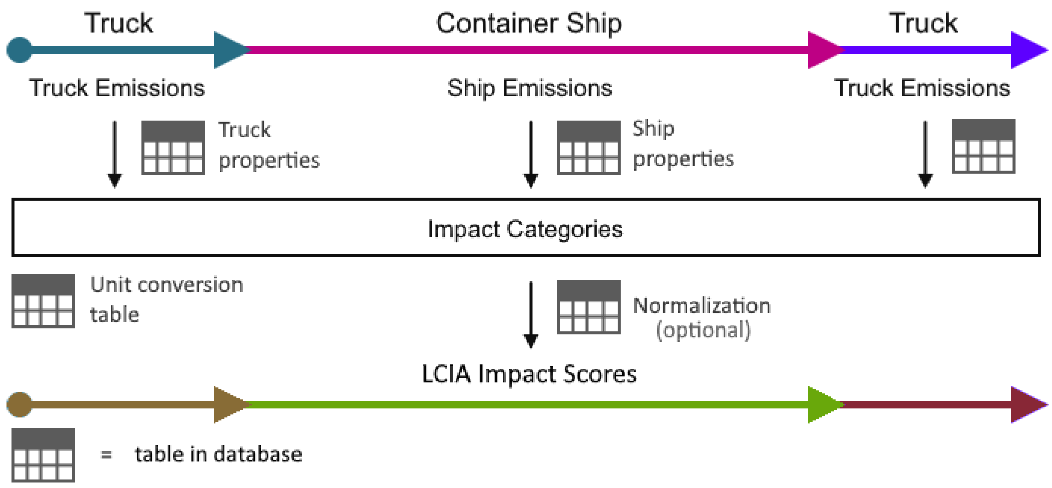

Figure 6.5: Proposed application of LCIA for container transport routes.

The chemicals identified and counted in the life cycle inventory step will be converted to comparable units. An example of such a unit is the Global Warming Potential unit. To convert the chemical emissions to these units, the conversion tables of the TRACI model are used. However, since the estimation data source of the STREAM study [46] already provides the CO_2-equivalent unit, the Global Warming Potential unit is equal to this value as the conversion has been done already. For the particulate matter impact category, the aggregation is also done in the estimation data. For the other relevant impact category units, the conversion still needs to be applied.

The process of splitting a transport into legs of the same modality, then aggregating their emissions can be seen in Figure 6.5. Because the model does the impact assessment for each leg in the transport route, a label for each leg is possible based on the assessment score. This label can be projected onto a map to visualize the scores.

Selected impact categories from TRACI

From the interviews, literature study and background information is found that the main focus for sustainability in container transport is emissions and pollution of air and waterways. Therefore, the selected impact categories for container transport in the TRACI model are limited to:

- Global warming
- Acidification
- Human Health particulate air
- Eutrophication of air
- Eutrophication of Water

- Smog formation

The ozone depletion impact category is omitted as the emissions per vehicle do not contain any fluorinated gases (f-gases). The f-gases are the main cause of ozone depletion.

The human health and ecotoxicity impact categories are also omitted for the container transport life cycle impact assessment as no emissions in the life cycle inventory contribute to any of these categories. These categories are mainly concerned with carcinogenic chemicals. The same holds for ecotoxicity. However, for human health there is one impact category selected: particulate matter. From the interviews can be concluded that particulate matter emissions are relevant for some organizations, mainly local governments.

6.1.5 Interpretation

The interpretation of the LCA is mostly done by the end users of the application. One of the requirements of a good interpretation is that results are presented in a readily understandable and complete manner. Note that LCA does not take into account performance (duration of transport) or costs. These factors are to be considered by the decision makers, together with the LCA results.

6.2 Implementation

The model is implemented in an application, see Figure 6.6 for an example. More screenshots can be found in the Appendix. The application will use the data provided by another application from Cofano: the Intermodal Voyage Planner. The application will consist of a front-end (React), a back-end (Java, Spring Boot) and a database (PostgreSQL), as this technology stack is used commonly within Cofano.

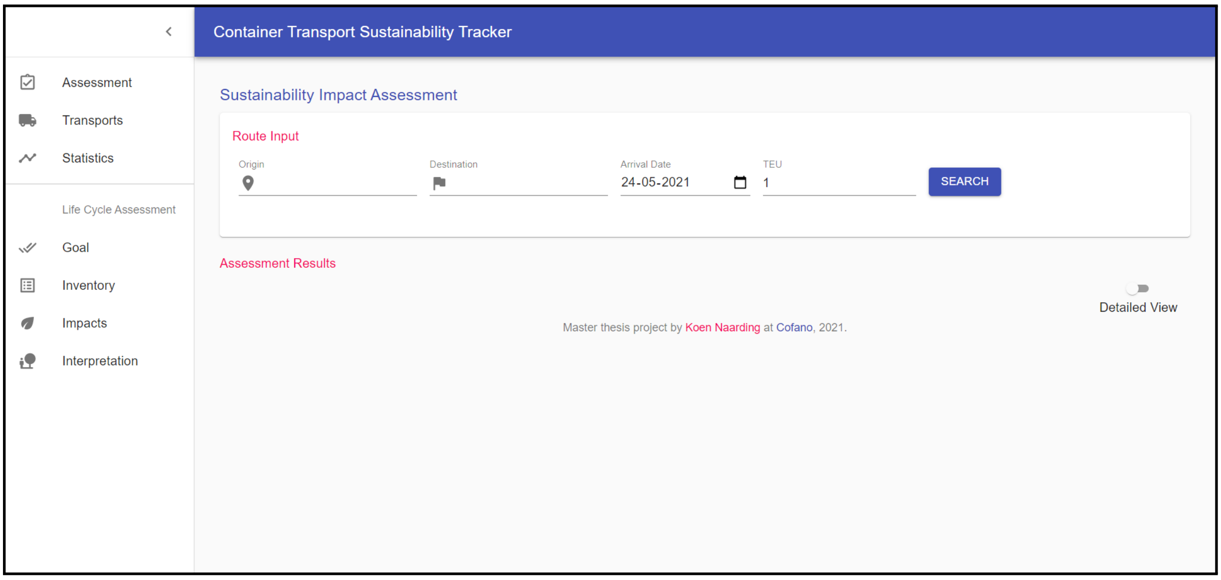

Figure 6.6: The main page of the tool. A collection of screenshots of the tool is present in appendix C.

6.2.1 Querying the IVP

The front-end allows a user to query the IVP API through a simple interface. The user provides an origin and a destination, a planned time of arrival or departure and the load that needs to be transport in TEU. If the IVP returns any possible transport routes, these will be sent to the application back-end to be assessed.

The routes of the IVP will contain information about the legs of the transport and what modalities or vehicles are linked to those legs. If no specific vehicle is linked to a leg, the default modality type used in the leg is used as a fallback. However, to optimally estimate the emissions for a leg knowing the specific vehicle that is used is necessary. For ship vessels that have an IMO, the IVP will provide the IMO in the vehicle data. The back-end of the application will check if a vehicle is specified and if that is a ship with an IMO number. If not, the application will fall back to default modality emissions.

To deduct the number of terminal stops during a voyage, the data provided by the IVP is used. As mentioned in section 6.1.3, the amount of container moves can be calculated by multiplying the number of stops by 2, then multiplying it by the number of containers in the transport. The number of stops can be deducted by taking the number of legs in the voyage and subtracting 1. In Figure 6.4 can be observed that indeed there are 5 legs, but only 4 terminals (A, B, C & D). The number of terminals is then used to calculate the emissions for container moves during the voyage.

6.2.2 Applying the model

The logic at the core of the back-end is triggered when the user posts a request for transport assessment. Per transport route the assessment is executed as described in section 6.1. Each segment will have a corresponding vehicle or fallback modality, which has corresponding emission estimations. The emission inventory for each segment of the transport route is then put through the TRACI impact categories identified for container transport. Next, the segment inventories and impacts are aggregated to route-level. Finally, the result will be returned to the user in the form of a list of assessed transport routes. These steps are visualized in screenshots found in appendix C.

6.2.3 Presenting the result

The returned assessed transport routes will be presented to the user in a list, just like the IVP presents the results. In the assessed routes there is the option to toggle a more detailed view, which shows all the emissions from that transport. In the simplified (default) view, however, only CO_2 emissions are shown. This is because of the conclusions from the expert interviews, most organizations are interested in CO_2 emissions and impacts only. The same holds for the impacts in the TRACI model, where in the detailed view everything is shown and in the simplified view only the global warming potential is shown. Again, visual examples of how this is implemented can be found in appendix C.

When the user has saved several routes over time, an overview of them can be retrieved from the “All Transports” tab. This displays a list of routes that have been saved, and can be used as a portfolio or history of executed transports.

On the statistics page, once some transports have been saved, an overview is presented of how many transports are executed, how much is transported and the total corresponding emissions.

Some other metrics include the total distance traveled, but also the total TEU km traveled. This is is the sum of the distance each TEU has been transported. Then there is the emissions per TEU km, averaged over all transports. This is a good indicator of the sustainability performance when only looking at carbon emissions. When transporting mainly by truck this value will be higher (values range north of $1500g \cdot TEU^{-1} \cdot km^{-1}$ CO_2-eq) while multi-modal transport or maritime transport is more efficient (Maersk Duala has $158.067g \cdot TEU^{-1} \cdot km^{-1}$ CO_2-eq). Finally, a total CO_2-eq metric is presented that is the sum of all CO_2-eq emissions for all saved transports. This can be useful when building an inventory of carbon emissions for a companies logistics operations.

6.2.4 Goal definition and interpretation

The other two steps of the LCA, goal definition and interpretation of the results are necessary for a valid LCA. Because these two steps are always the same, they are presented on the front-end of the application in an information screen that describes the automated LCA process in detail.

7 EVALUATION

The following chapter discusses the evaluation of the artifact based on the UTAUT model [16]. The evaluation is also the last step in the design cycle by Wieringa [12].

First, the goal of the evaluation is discussed. Then, the customization of the UTAUT model is discussed and which constructs are used for each variable in the model. Then, for each variable in the model a set of questionnaire items is defined. Then the results of the questionnaire are analyzed. Next, a reflection is done on the evaluation in the discussion (section 7.5) and limitations (section 7.5.1). Finally, conclusions are drawn in section 7.6.

7.1 Goals

In this evaluation no hypotheses are tested or statistical generalizations are made. The goal of this first evaluation is to gather insights in the performance expectancy and effort expectancy for the artifact, as well as the intention to use the artifact, by collecting thoughts and perceptions of the domain experts.

7.2 Adapted UTAUT model

For this research project, the focus lies on the Behavioral Intention to use the artifact. The Use Behavior itself can be measured as soon as the artifact is deployed, but the focus of this study is to assess the intention to use. This also eliminates the Facilitating Conditions variable from the adapted model. The adapted model can be seen in Figure 7.1. Another variable that is eliminated from the model is Social Influence. Even though this variable might play a role in voluntary use of a system, in this research it is assumed that the artifact will be of mandatory use. This eliminates Social Influences as a factor. The reason for this assumption is that due to stricter regulation around emissions organizations will be forced to monitor their emissions more closely. At this point it is not a voluntary choice of the organisation to use such an application. The organisation will impose the use of the application on its employees.

7.2.1 UTAUT variables and constructs

In the following section, an overview of the variables and constructs in the adapted UTAUT model will be presented together with a brief explanation. For the full overview of variables and constructs and corresponding questionnaire items, see Appendix B.

Performance Expectancy

For the performance expectancy variable, this study focuses mostly on the perceived usefulness, relative advantage and job-fit constructs. The validation aims to evaluate if requirements defined by literature and interviews are satisfied. The point scale that is used here is a 5-point

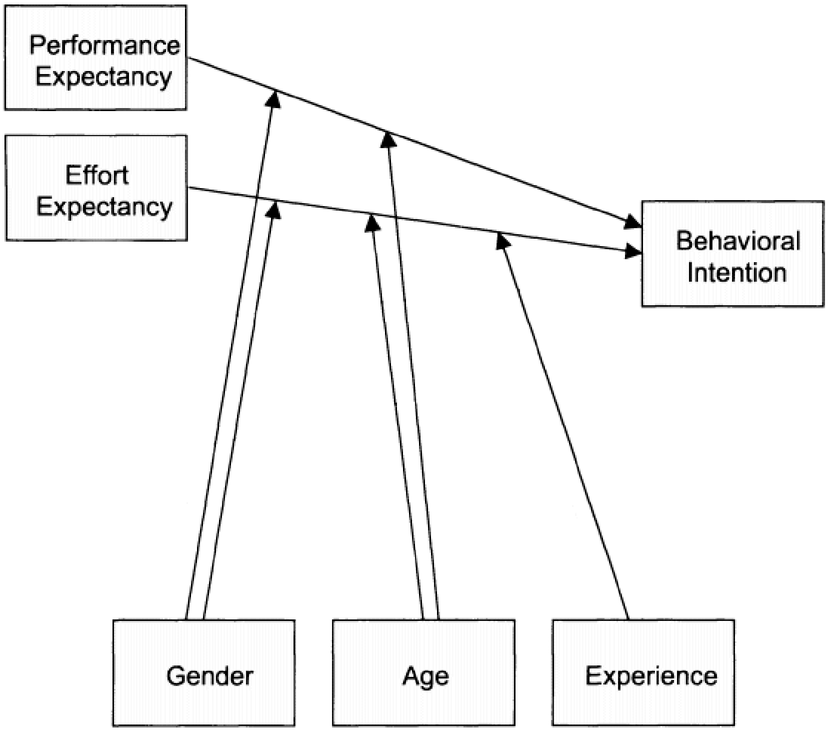

Figure 7.1: The adapted UTAUT model.

Likert scale. The options include: Strongly disagree, Disagree, Neither agree nor disagree, Agree, Strongly agree.

Table 7.1: Selected set of questionnaire items for the Performance Expectancy variable.

Construct	Items
Perceived Usefulness	Using the system would make it easier to do my job. I would find the system useful in my job.
Job-fit	Use of the system can significantly increase the quality of output on my job.
Relative Advantage	Using the system enhances my effectiveness on the job.

Effort Expectancy

This variable focuses on the ease with which end-users use the system. There is a lot of overlap between the constructs within this variable. In this study a small mix of items is used including at least one of every construct. The point scale that is used here is a 5-point Likert scale. The options include: Strongly disagree, Disagree, Neither agree nor disagree, Agree, Strongly agree. Note that the complexity construct item is reversely rated, the rating goes from 1-5 starting at Strongly agree.

Behavioral Intention

The dependent variable, Behavioral Intention, is measured through two items listed below. The point scale that is used here is a 4-point forced choice. The options include: Strongly disagree, Disagree, Agree, Strongly agree.

Table 7.2: Selected set of questionnaire items for the Effort Expectancy variable.

Construct	Items
Perceived Ease of Use	Learning to operate the system would be easy for me. My interaction with the system would be clear and understandable.
Complexity	It takes too long to learn how to use the system to make it worth the effort.
Ease of Use	Overall, I believe that the system is easy to use.

Table 7.3: Selected set of questionnaire items for the Behavioral Intention dependent variable.

Construct	Items
Behavioral Intention	I intend to use the system within the next 6 months. I predict I would use the system in the next 12 months.

7.3 Questionnaire

The questionnaire is made with Google Forms and sent to the experts through email. The respondents were insisted on completing the questionnaire. In Google Forms, besides adding all the questionnaire items, it is also possible to add sections with explanation. This feature is used to include the screenshots of the artifact together with a description of what can be seen in each screenshot. The included screenshots can be seen in the appendix (Appendix C). The reason that the respondents are informed about the tool through screenshots and descriptions is because at the time of evaluation the artifact was not yet deployed in a demo environment for the respondents to try out.

7.4 Results

In this section the results of the questionnaire are outlined. Due to time constraints, only one of the respondents has filled in the questionnaire. Therefore, results are limited to thoughts and perceptions from earlier interviews and the results of one respondent. In the limitations (section 7.5.1) this issue is discussed in-depth.

7.4.1 Performance Expectancy

The effort performance questions are constructed using a five point Likert scale. The average score for performance expectancy is 3,5.

7.4.2 Effort Expectancy

The effort expectancy questions are constructed using a five point Likert scale. The average score for effort expectancy is 3,75.

7.4.3 Behavioral Intention

As mentioned in the sections above, the behavioral intention questions are a forced-choice four point scale. The average score for behavioral intention is 3.

Table 7.4: Selected set of questionnaire items for the Performance Expectancy variable.

Construct	Items	Answers
Perceived Usefulness	Using the system would make it easier to do my job. I would find the system useful in my job.	1: Neither agree or disagree 1: Disagree
Job-fit	Use of the system can significantly increase the quality of output on my job.	1: Agree
Relative Advantage	Using the system enhances my effectiveness on the job.	1: Strongly agree

Table 7.5: Selected set of questionnaire items for the Effort Expectancy variable.

Construct	Items	Answers
Perceived Ease of Use	Learning to operate the system would be easy for me. My interaction with the system would be clear and understandable.	1: Strongly agree 1: Agree
Complexity	It takes too long to learn how to use the system to make it worth the effort.	1: Disagree
Ease of Use	Overall, I believe that the system is easy to use.	1: Agree

Table 7.6: Selected set of questionnaire items for the Behavioral Intention dependent variable.

Construct	Items	Answers
Behavioral Intention	I intend to use the system within the next 6 months.	1: Agree
	I predict I would use the system in the next 12 months.	1: Agree

7.5 Discussion

This section discusses the results based on the perceptions and thoughts of the respondents as well as the limitations of this evaluation.

The perceived usefulness construct turned out lower than expected (see section 7.4.1). Beforehand, expected was that the interviewees would find the artifact useful in their job. However, the only interviewee that responded to the questionnaire was interviewee 2 (see section 3.2.1). This interviewee is not involved in the planning of transport or emissions calculations. So, it can be expected that in his day-to-day work the tool is not useful. However, as can be seen in the job-fit construct and relative advantage construct, overall interviewee 2 believes the artifact is useful.

It was expected that the behavioral intention of the interviewees would be on the low side. And since the items are forced choice it was expected that most interviewees would fill in “Disagree”. The reason for this expectation was that most interviewees mentioned in the interviews that they already use some form of automated emission calculations in their work. So, it was assumed that the threshold for the behavioral intention to use another system would be high. However, as can be seen in section 7.4.3, the behavioral intention is mostly positively rated.

7.5.1 Limitations

The experts are not randomly selected. This is limiting the generalizability of this evaluation in most cases [15]. However, a key characteristic of sound generalizations is the representativeness of the interviewees [54]. The interviewees are representative for the sustainable transport domain, as described in section 3.2.1. So, even if there were only three experts chosen for this evaluation, we could assume that similar observations and perceptions will be observed if experts are picked from other organizations similar to the organizations of the selected experts. Expected is that similar but different organizations that share characteristics with the organizations from the currently selected experts share the same goals, interests, way of thinking, creating similar experiences and perceptions as the ones the selected experts have [54], [55]. Of course, more empirical research is needed to substantiate this claim.

Additionally, only one of the three selected experts has responded to the questionnaire, adding to the limitation mentioned above. On top of this, the expert that has responded also does not do any transport planning or emissions calculations himself in his day-to-day job.

Because the demo version of the artifact was not yet deployed to a demo environment at the time of conducting the evaluation, the experts were provided a set of screenshots together with a description of each screenshot as supplementary material. As this is not the real artifact, the experts are giving their thoughts and perceptions of what they think the artifact is like to use. Because they cannot use it in a demo environment, this limits the evaluation of the actual artifact. Of course, this can be easily mitigated by re-evaluating after the demo is deployed.

7.6 Conclusions

This section outlines the main findings from the evaluation.

Both the performance expectancy and effort expectancy are relatively high. The interviewee agrees on the usefulness of the system, helping him substantiate claims on sustainable transport and visualizing emissions from transport.

As the second variable, effort expectancy (3.75) is considered relatively high in this evaluation. This implies that the interviewee expects that the artifact is not too complex and perceived to be easy to use. The interviewee agrees on all effort expectancy constructs (except for the complexity construct which is reversely rate).

The behavioral intention variable is rated 3 out of 4 points, relatively weighted against the other variables this equates to 3.75 out of 5. This implies the interviewee is interested in using the artifact in the near future.

Part IV

Reflection

8 DISCUSSION

This chapter will go into detail about results and possible reasons why they were or were not as expected. The focus of the discussion is mostly on the emission estimations as this is a large part of the project.

First, the fallback modality emissions and their shortcomings are discussed in section 8.1. A comparison is made between two container ships and how using the fallback modality emissions would impact the quality of the emission data.

Next, for each modality the emission estimation impact factors are discussed in section 8.2. Outlined is which factors are taken into account and which ones are not taken into account in this model. For the factors that could be taken into account in the future, a reference to future research is provided.

Next, the emissions from terminal transfers are discussed in section 8.4.

Finally, the life cycle impact assessment categories are discussed and their applicability to be used as a sustainability assessment in container transport.

8.1 Default modality emissions

As stated in the background and results of this project, having accurate emission estimations for the inventory of emissions within the life-cycle assessment is imperative for the quality of the assessment. In most cases the real life measurement of CO_2 emissions are close to the fallback modality estimated emissions. An example is shown in Table 8.1 and the fallback DEEPSEA modality emissions in Table 8.2.

Table 8.1: Emission estimation for Maersk Douala (IMO Nr: 9299032) in $g \cdot TEU^{-1} \cdot km^{-1}$

CO_2-eq	**MJ**	**NO_x**	**SO_2**	**PM**
158.067	2.027	3.918	0.297	0.082

Table 8.2: Emission estimation for the DEEPSEA modality in $g \cdot TEU^{-1} \cdot km^{-1}$

CO_2-eq	**MJ**	**NO_x**	**SO_2**	**PM**
163.8	2.1	4.06	0.308	0.0854

As can be seen in Table 8.1 and Table 8.2, the fallback value is very close to the ship specific estimated emissions. However, the differences vary per ship. In Figure 6.3 can be seen that most emissions are around the $100g \cdot TEU^{-1} \cdot km^{-1}$. In this figure we can also observe that there are instances that would profit heavily from falling back to the default modality because their actual emissions are much higher than the fallback estimations. In the same way this can cause a disadvantages for lower emission vessels.

Some examples are shown in Table 8.3 (Maersk Hoheweg) and Table 8.4 (Maersk Gudrun). Maersk Hoheweg is a container ship built in 2007 with a carrying capacity of 11807 deadweight tonnage (DWT) and a length of 139m. Maersk Gudrun is a container ship built in 2005 with a carrying capacity of 115700 deadweight tonnage and a length of 366m. The carrying capacity in TEU varies based on the weight of the cargo. However, it is around 800 TEU for Hoheweg and 8000 TEU for Gudrun (based on 14 tonnes per TEU).

Table 8.3: Emission estimation for Maersk Hoheweg (IMO Nr: 9362956) in $g \cdot TEU^{-1} \cdot km^{-1}$

CO_2-eq	**MJ**	**NO_x**	**SO_2**	**PM**
575.134814	7.373803	14.255291	1.081253	0.299645

Maersk Hoheweg (9362956) would profit heavily from a fallback emission estimation based on the DEEPSEA modality as their real emissions is as much as three times the fallback value. However, for Maersk Gudrun (9302877) the opposite is true.

Table 8.4: Emission estimation for Maersk Gudrun (IMO Nr: 9302877) in $g \cdot TEU^{-1} \cdot km^{-1}$

CO_2-eq	**MJ**	**NO_x**	**SO_2**	**PM**
69.799028	0.894893	1.730039	0.131222	0.036365

This vessels real emissions are almost three times as low as the fallback modality. If the emissions of these ships was unknown during the emissions inventory phase, they would both have the same emission estimations based on the fallback value of the DEEPSEA modality. This would mean that they would be treated as equally polluting options, while in reality the Maersk Hoheweg is almost ten times as polluting as the Maersk Gudrun. The reason for this difference might be the difference in load capacity.

8.2 Emission impact factors

As can be seen in the tables above, the emissions estimation is very important for the overall outcomes of the assessment. In chapter 4 the requirements for the data on which the emissions estimations are based are defined. Different factors that influence emissions per modality are highlighted. For maritime transport one important thing that is not taken into account in the current implementation is fuel type. However, the model does support this information if it is provided. In the current implementation no fuel type information is fed into the application, but if it was the emissions would be converted accordingly. The STREAM study [46] offers conversion factors for each emission type based on the fuel type.

For road transport traffic is not taken into account. However, one could argue that because the default modality emissions for road transport are based on a large amount of data points traffic is taken into account on average. Again for the fuel type of road transport, for example the difference between euro5 and euro6 emissions matter. However, this information is not provided in the current implementation. If is was provided, emission factors are provided by [46] to account for this.

Another point of interest is the total load a vehicle is carrying. This has impacts on the total emissions during transport as heavier vehicles emit more than lighter vehicles. The default modalities could take into account the emissions based on weight, however, this information is not available to the model in the current implementation so it is not taken into account.

Lastly for road transport, the type of road is also not taken into account. Assumed in this project is that the road modality uses the “average” type of road (highway, country, city). Therefore, the resolution of emission estimations is not very high.

For the rail transport modality two types are defined: fossil fuel trains and electric trains. In the case of the electric train it is assumed that it uses 100% renewable energy, but in theory different modalities could be created to use a country-specific energy mix. However, the feasibility of this solution is debatable. In many instances, a train crosses the border to another country. In this case there will be two countries providing the electricity to the train. It would be needed to find the relative number of kilometers the train is in country A versus the kilometers the train is in country B or even more countries. Then for each of the countries the relative energy mix needs to be determined. Finally, the inventory of emissions for the electric train can be determined.

For inland shipping specifically, it is important to take the direction of transportation into account. As mentioned by interviewees, the difference in fuel consumption (and therefore emissions) between downstream and upstream transport can be as much as 50%. This is not supported in the current model. It would require an analysis of direction of transport and the type of waterway to determine the impact of the shipping direction.

8.3 Well to Wheel versus Tank to Wheel

The estimation data from the STREAM study [46] provides both well to wheel (WTW) as well as tank to wheel (TTW) emission data. The difference between WTW and TTW is that in the emission data from WTW the emissions from fuel production and transport is also taken into account. TTW only takes the use phase of the fuel into account. While it would be beneficial to use the WTW emission data, as this is a fairer representation of total emissions related to the fuel usage, the emission data from the Thetis MRV dataset used in this study is TTW. To avoid inconsistencies in the type of data used in this tool, it is decided that TTW data is used for every estimation in the assessment. This consequently means that emission estimations do not take into account the emissions from fuel production and is therefore less complete.

8.4 Emissions from transfers

The estimation of emissions from transfers is very general, like the default modality emissions that are used as fallback for when more accurate emissions are unavailable. Theoretically an analysis is possible on the transport route to determine what type of container moves are going to be executed and the specific cost of those container moves. The study by Van Duin et al. [53] provides CO_2 emissions in kg per container move and also per modality type. This in theory enables better emission estimates for container transfers when the modality switch is known.

Additionally, based on the terminal structure and operations it might be possible to better estimate the total number of container moves executed based on the terminal data and transfer data.

8.5 Life cycle impact assessment categories

The used model for the life cycle impact assessment, TRACI, contains several impact categories of which 5 are selected for the sustainability of container transport. Each of the selected categories is scored according to its impact. However, this means that in total 5 scores are generated. One for each of the impact categories. These scores cannot be combined into one score without using some weighing of the impact categories. This is a problem, as weighing the importance of each impact category involves opinions and this could introduce a bias into the model. This is not done in this research project as it would limit the objectivity of the model significantly.

9 CONCLUSION

This chapter will provide a short summary of findings in this study and conclude the project. In the summary of findings the relevancy of the topic will be outlined, as well as answers to the research questions. Then, implications for practitioners will be discussed together with ideas for further research. Finally, some closing statements are provided by the author to conclude the project.

9.1 Summary of findings

In this section the relevancy of the topic is discussed, as well as the outcomes of each step in the design cycle.

Sustainability in container transport is becoming a more relevant topic each year, in scientific literature as well as in practice. The reason largely being that global trade is ever-increasing and governments all over the world want to reduce the environmental impacts of the increasing emissions associated with container transport. The increase in legislative pressure is a key driver for many organizations to gain insights in the environmental footprint of their logistics operations.

In order to gain insights in container transport operations, methods to assess the sustainability of container transport are needed. In this study, the applicability of the life cycle assessment model for container transport is explored.

In qualitative interviews with a carefully selected panel of experts in the field of sustainable transport as well as an extensive literature review of the state of the art of sustainability in container transport the problem is investigated.

Based on the knowledge from the interviews and literature review, a treatment to the problem is designed. The artifact uses emission estimations from every aspect of container transport that is found important in the problem investigation. The most specific and most accurate emission estimations are used, unless information is missing. In this case, the artifact falls back to a more general emission estimation.

The artifact is finally evaluated based on the thoughts and perceptions of the expert panel. Found was that the artifact is deemed useful and would be relatively easy to use and easy to learn. However, the behavioral intention to use the artifact remained low.

9.2 Implications for research

In the following section the research questions are outlined once more and answers are provided when possible. Then, new questions that have emerged from this research project are discussed for future research.

9.2.1 Research questions

RQ 1

What is the motivation for choosing more environmentally sustainable transport routes?
From the literature study and interviews with expert in the field can be concluded that the biggest driver for choosing more sustainable options in transport is reducing CO_2 emissions. This is largely because of current regulation and the prospect of future regulation of CO_2 emissions. As can be read in this thesis, there are more dimensions to environmental sustainability than just CO_2. These other areas of impact are of far less concern in practice.

It depends on the end user what motivates them to watch emissions. From the interviews can be found that local governments are more interested in NO_x and particulate matter (PM) because their area of concern is the health and well being of the people that live there. Governmental bodies in general have a different goal as health and well being is their top priority. For commercial entities, the main priority remains profit. This means that if they do not have to watch their emissions, they usually will not do it. However, when forced by legal repercussions due to crossing their emission limits commercial entities will immediately be interested and motivated to lower their emissions.

RQ 2

What identified categories from the literature review (Emissions, Air pollution, Water pollution, Resource use, Waste disposal) are relevant for the sustainability assessment of transport routes?
From the interviews can be concluded that it depends on the type of organisation just like the motivation. Governmental bodies are interested in emissions (CO_2) as well as air pollution (NO_x and PM) while commercial organizations are mostly interested in their CO_2 emissions. This leaves water pollution, resource use and waste disposal unattended.

RQ 3

What type of analysis is desired? Forecasting or analysis of transport history?
Prior to the interviews it was found that two types of analysis are possible when it comes to the assessment of transport routes. A comparative analysis between transport alternatives, in the planning phase of transport, and the assessment of the transport history in a certain period. From the interviews can be concluded that both are relevant, but it depends on the type of organisation. Front runners in field of sustainable transport likely want to use forecasting (the comparative analysis) while they plan their transport, while most companies are mostly interested in their total emissions over a period of time (history analysis).

In one of the interviews mentioned was that there is a specific order in which the awareness of sustainable transport develops. This starts with measuring the current situation, as you need to have a base emission performance to compare future emission performances with. The current situation can be measured by the history analysis. Then, when an organisation decides it wants to improve on sustainability within their logistics operations they can employ the comparative analysis to forecast their emissions and decide based on the emissions of a transport.

RQ 4

What other methods exist for the sustainability assessment of transport routes?
No assessment models were found specifically for container transport in the selected scientific literature that encompass all categories of environmental sustainability. However, individually these categories could be measured. For environmental sustainability, there are implementations of life cycle assessment that could be used for container transport such as GaBi.

What are the shortcomings of these methods?
GaBi is a downloadable software tool in which on can model a life cycle assessment. Similar implementations to GaBi exist, some web-based and others downloadable tools. However, for container transport specifically, the most relevant item is not the modeling of different flows in or out of the system. This is because in this application of LCA there is no product or service being assessed. The most important part is the life cycle impact assessment model where the emissions from transport are modeled on the impact categories. Doing this in the GaBi software is possible, but it would take a large effort to do so. Learning how to work with a system such as GaBi takes time and expertise in the field of life cycle assessments. This in turn would take time and effort from companies.

RQ 5

What steps of the LCA method are necessary for the assessment of environmental sustainability of transport routes?
If an organization is interested in incorporating the sustainability impacts assessment of the transport routes in another life cycle assessment then they need all the steps. This is because in order to create a valid life cycle assessment all steps need to be present. However, if this is deemed unimportant, an end user can simply ignore the life cycle assessment documentation pages in the tool and use the assessment data directly.

RQ 6

How can the model be integrated in logistics software systems?
The artifact was successfully implemented in an application developed for this project. An integration with an existing logistics planning system was made, the IVP at Cofano. When the user requests transport alternatives on the artifact, the artifact sends the request to the IVP API. Based on the response of the IVP API the artifact will provide the assessed routes to the user or, if no routes are found, inform the user that there were no routes found for the request. If a company has a similar system to the IVP developed by Cofano, the integration could be made within a week time. The requirements for such a system is that it provides routes with simple information such as distance and vehicle information. Preferably, the vehicle information is as detailed as possible so that the artifact can make the assessment based on the most detailed emission estimation data.

RQ 7

Is the adapted model useful?
In a first evaluation based on the UTAUT model the thoughts and perceptions of experts are collected. This is done through a questionnaire with questions from the variables performance expectancy, effort expectancy and behavior intention. The goal of the evaluation was to get insights in these variables. From this evaluation can be concluded that the artifact is indeed useful and perceived easy to use. Additionally, the evaluation showed that there is behavioral intention to use the artifact in the near future.

Main research question

How can sustainability of transport routes in container transport be assessed?
The answer to this question depends on what a company values as sustainability performance. If we take the TRACI impact categories as the sustainability performance, it will be difficult to compare results with each other. This is due to the fact that the individual impact categories cannot be compared. However, from expert interviews can be concluded that most companies see their carbon emissions as a sustainability performance indicator. When this is the case, the adapted LCA model can be used to assess the environmental sustainability of transport routes in container transport. For companies that value the NO_x emissions most, or any other type of emissions, the same model can be applied. However, whenever multiple impact categories are deemed important it will be harder to assign sustainability scores. If one alternative has a high global warming impact score and another has a high smog impact score, there is no clear-cut method to determine which one is the better alternative. So, the adapted LCA model is fit for the sustainability assessment of transport routes in container transport. However, there is a lot of room for improvement.

9.2.2 Further research

Estimations of emissions is a big field of research. There are a lot of factors that play a role in the emissions as mentioned in this research. Creating methods that accurately estimate the emissions will improve the artifact discussed in this study as it relies on the estimation quality of emissions. One example of a research project is to use real time Automatic Identification System (AIS) data to estimate real time emissions. The AIS is a tracking system in which parties can track the real time location, speed, etc. of any ship. Based on the engine type, fuel type, speed and load one is able to make very accurate estimations of real time emissions.

The emissions estimations from container transfers could be optimized by conducting an analysis on the order of modalities in the container transport. Based on this order can be inferred what types of container transfers are happening between the legs in the transport. With the information provided by Van Duin et al. [53] the accuracy of emission estimations can be improved significantly.

Another area of interest within emission estimations is for trucks. In the artifact created in this research a limitation is the accuracy of emission estimations for trucks. One of the factors that influence the actual emissions for trucks is traffic. A way to improve the emissions for trucks is to factor in the average traffic density during transport. This again would involve real time data and therefore be more accurate than the estimations used in this research.

The type of estimation data used in this study, tank to wheel instead of well to wheel, has consequently made the estimation data less complete. In future research it could be explored how to convert the TTW data into WTW data. This would enable a more complete analysis of total emissions related to fuel usage within container transport.

One of the takeaways from the interviews conducted in this research project was that it is usually more accurate to measure the actual usage of diesel during transport. A system like this will almost certainly outperform the artifact in this project. However, it also requires a substantial effort to acquire data from every vehicle continuously. Researching the feasibility of measuring diesel usage versus estimating emissions might be an interesting research project itself.

As pointed out in the limitations of the evaluation, more research can be done to substantiate the claims made in the evaluation by getting a higher number of interviewees from different, similar organizations. Similarly, the bias introduced by interpretation of the interviewees thoughts and perceptions can be minimized by conducting a follow-up study with a statistical analysis.

One problem still present in the current implementation is that there are still several sustainability impact categories. These cannot be compared with each other as they use entirely different units. Global warming potential (in CO_2-eq units) cannot be compared to smog formation (in O_3-eq units). However, in practice it is generally desirable to be able to reduce all impacts into one sustainability performance score. This solves the comparability issues. In order to achieve this, weights need to be objectively assigned to each impact category to create a weighted impact score.

9.3 Implications for practitioners

Sustainability in container transport is becoming more relevant every day. However, for this reason getting insights in emissions tied to container transport operations and reducing them is imperative in order to survive as a company. Large companies are taking action today in order to be ahead tomorrow. By seeing sustainable transport as a competitive opportunity rather than a set of rules, an organization can stand out from the rest.
By automating the LCA inventory for container transport the results can be seamlessly incorporated in existing LCA processes, therefore improving the overall accuracy of emission inventories in that process. If an organization is not creating a life cycle assessment, the emissions inventory and its impacts can still be used elsewhere. This is because all the metrics are standardized units, making them usable anywhere.

Instead of working from Excel spreadsheets or going through a lot of effort to model container transport in existing life cycle assessment software, practitioners can now use an application that provides the information they use to make informed decisions on sustainability in container transport automatically.

In order to get the highest quality measurements for the sustainability assessment, measuring fuel consumption is the best option. However, this requires a significant effort. This effort is also significantly higher than the effort needed to work with emission estimations. With the right vehicle data the emission estimations become very accurate and can be a good substitute for having to measure all of the emissions.

9.3.1 Implications for teaching

This research project can be used as an example of how to apply sustainability and sustainable development theory into practice. Sustainability is a very broad concept and its meaning is different for every application. This research project applies the theory of sustainability to container transport. Additionally, the relevant concepts within environmental sustainability are operationalized in the adapted LCA model in order to bring business value to end users.

9.4 Final takeaways

While sustainability in container transport is becoming more relevant each year, the environmental impact of container transport is still increasing. Because change takes time, a significant switch from current practices to more sustainable practices will not be happening. However, a gradual increase in awareness on sustainable logistics operations will eventually happen due to increasing pressure of stakeholders and legislation on sustainability. By creating and improving the tools that are needed we help put in the work needed to facilitate this change. Even though a lot of improvements can still be made, a few first steps are made.

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Part V

Appendix

A EXPERT INTERVIEW (IN DUTCH)

Deel I - Algemene Informatie

1. Wat is je naam?
2. Bij welk bedrijf / organisatie werk je?
3. Wat is je functie?
4. Hoeveel ervaring heb je in je functie?

Deel II - Motivatie

Onderdelen die ter sprake moeten komen:

1. Wat betekent duurzaam transport? – welke aspecten van transport zijn onderhevig aan duurzaamheidsmaatregelen?
2. Waarom is duurzaamheid in transport belangrijk?
3. Wat zou er gebeuren als duurzaamheid in transport genegeerd zou worden?
4. Doet het bedrijf al iets aan duurzamer transport?
   (a) Zo ja, wat?
   (b) Zijn hier eventueel tools voor?

Deel II - Requirements

Onderdelen die ter sprake moeten komen:

1. Als een tool zou bestaan om de duurzaamheid te bepalen van transport, wat voor informatie zou deze tool moeten leveren?
2. Hoe zou je deze informatie kunnen gebruiken? (Voorspellen van duurzaamheid in gepland transport / analyzes achteraf)

B TREATMENT VALIDATION QUESTIONNAIRE

Performance Expectancy

1. Using the system would make it easier to do my job.
2. I would find the system useful in my job.
3. Use of the system can significantly increase the quality of output on my job.
4. Using the system enhances my effectiveness on the job.

Effort Expectancy

5. Learning to operate the system would be easy for me.
6. My interaction with the system would be clear and understandable.
7. It takes too long to learn how to use the system to make it worth the effort.
8. Overall, I believe that the system is easy to use.

Intention to Use

9. I intend to use the system within the next 6 months.
10. I predict I would use the system in the next 12 months.

C COLLECTION OF SCREENSHOTS OF THE TOOL

The following pages contain a collection of screenshots of the implementation of the artifact that is at the heart of this research project. This serves to give an impression of the look and feel of the tool, as well as provide a visual representation of the functionality present in the tool.

The transport network in this implementation is a real life transport network, the demo of this tool is similar to what a production version would look like.

In the following sections a brief descriptions of the screenshots, the functionality in the screenshots and other implementation details are outlined.

The home screen (Figure C.1)

In the home screen the user can input an origin and destination, as well as the load of the transport and an arrival date. Please note that, for security reasons, a basic authentication mechanism is in place. It is not shown here as it part of basic functionality every web-based application needs.

Submitting a request (Figure C.2)

When the user submits the request, the results will be presented in a list as seen in the figure. By default, the simplified view will be presented to the user as this is the view that most organizations want according to the expert interviews (see section 3.2). In this view, only the number of stops, the CO_2-eq, and the load is presented. For the sustainability impact categories, only the global warming impact category is shown.

Advanced view (Figure C.3)

When the user wants to see more emission details, the toggle in the top right can be pressed. This enables the advanced view, containing more emission data. Do note that this example is from Shanghai to London (different from C.2). In the advanced view, additionally, SO_2, NO_x, particulate matter (PM) and the energy consumption (MJ) are also shown. Additionally, in the sustainability impact categories, many more categories relevant for container transport are shown.

Saving transports (Figure C.4)

The user can save a transport alternative and its assessment to a database. It does not matter in which view the user presses save; all emission data for that alternative is saved and can be accessed at a later point if desired. Not only is the transport route data saved, it is saved per leg as well. This means that the resolution of emission information remains high.

Portfolio of transports (Figure C.5)

An overview of all saved transports can be seen on this page, together with all the assessment impacts. This is also shown per leg in the transport. As mentioned before, on this page it is also possible to switch between simplified view and advanced view.

Portfolio statistics (Figure C.6)

A page with general statistics of the organization is included in the tool as well. This page shows general statistics such as total distance traveled, but also more advanced stats such as the average emissions per TEU km as a basic measure of sustainability performance. These statistics can be seen as transport sustainability KPIs.

LCA model documentation (Figure C.7)

For each of the necessary steps from the LCA method a page is included in the tool containing the important information and documentation for this step. Similar pages exist for the other three steps.

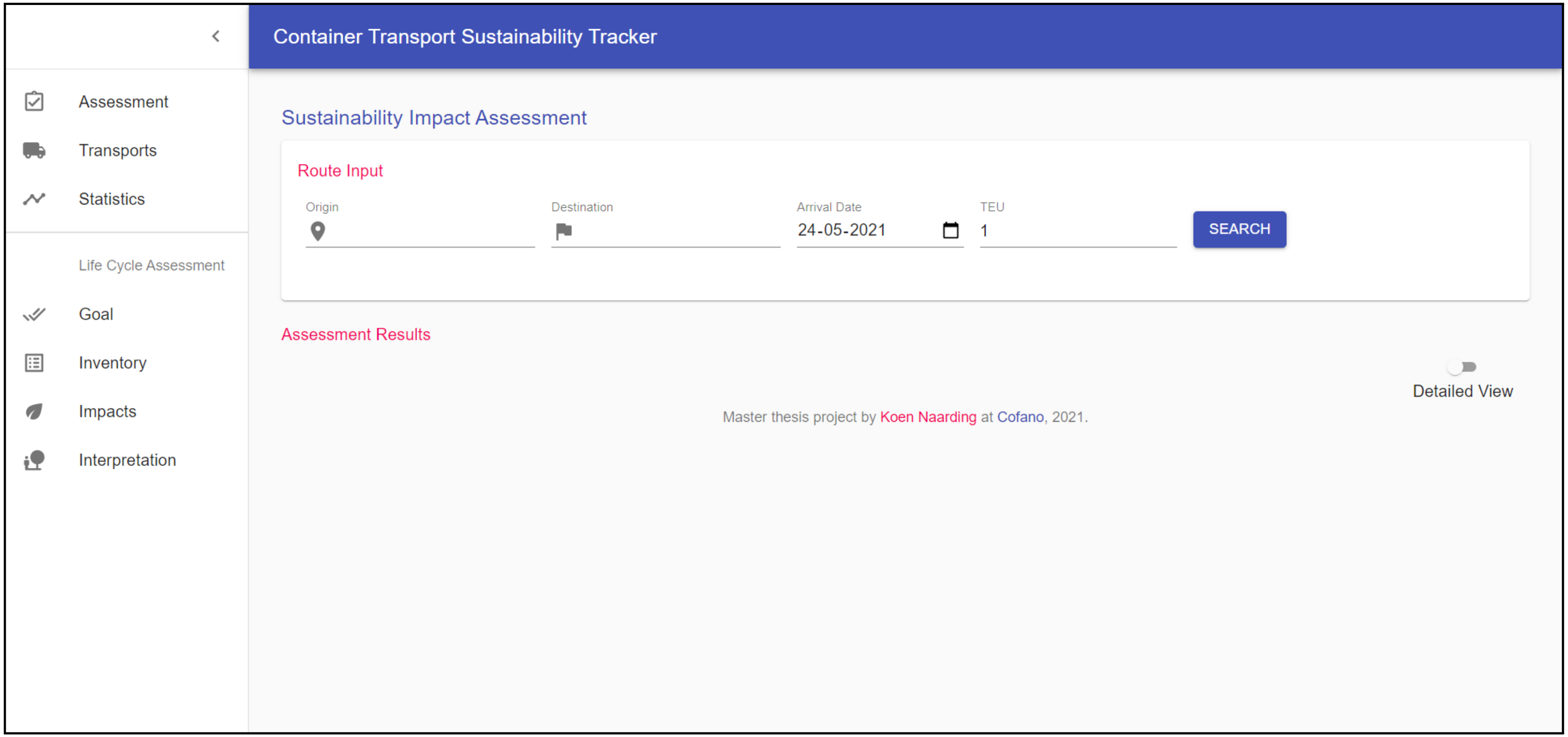

Figure C.1: The home screen of the sustainability assessment tool

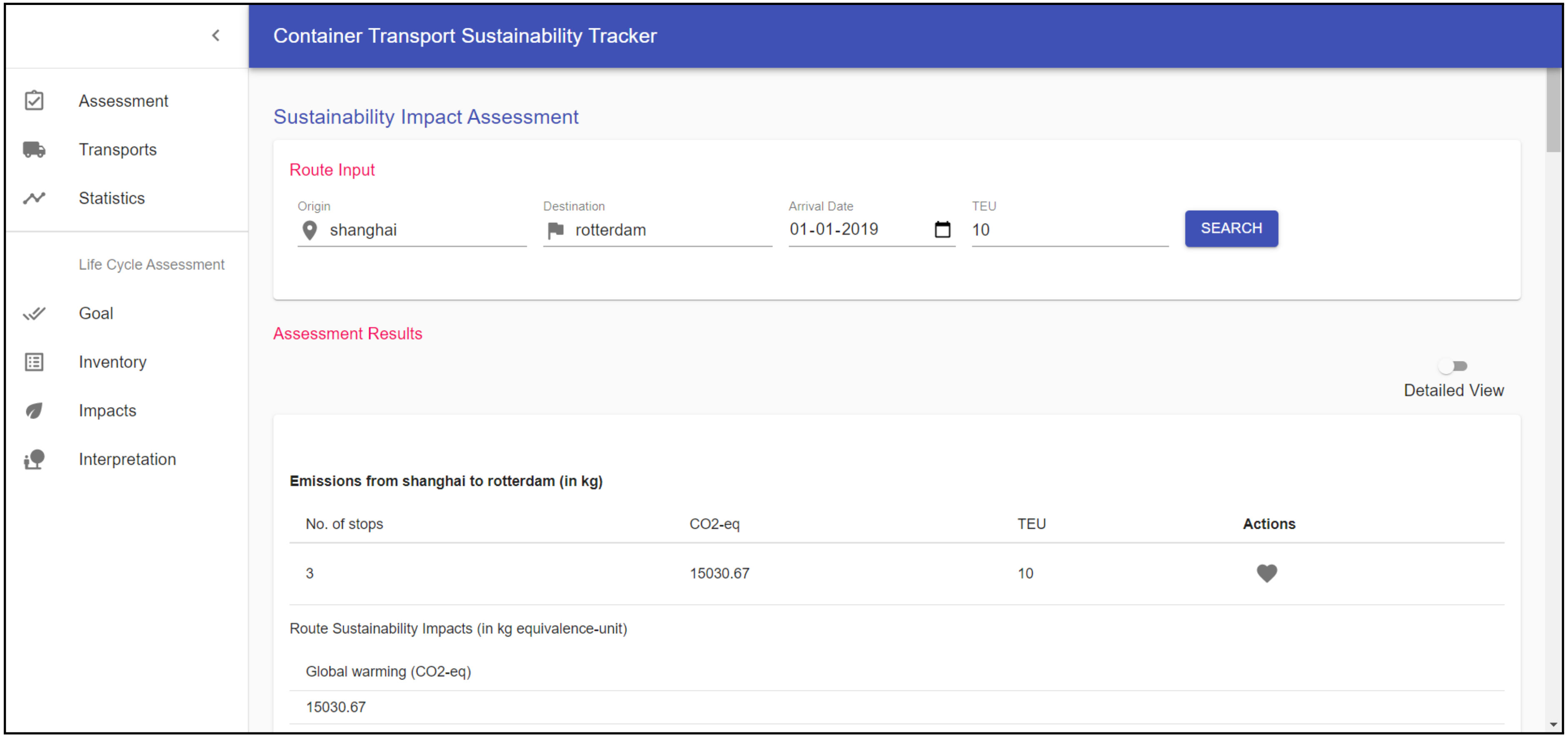

Figure C.2: Submitting a request

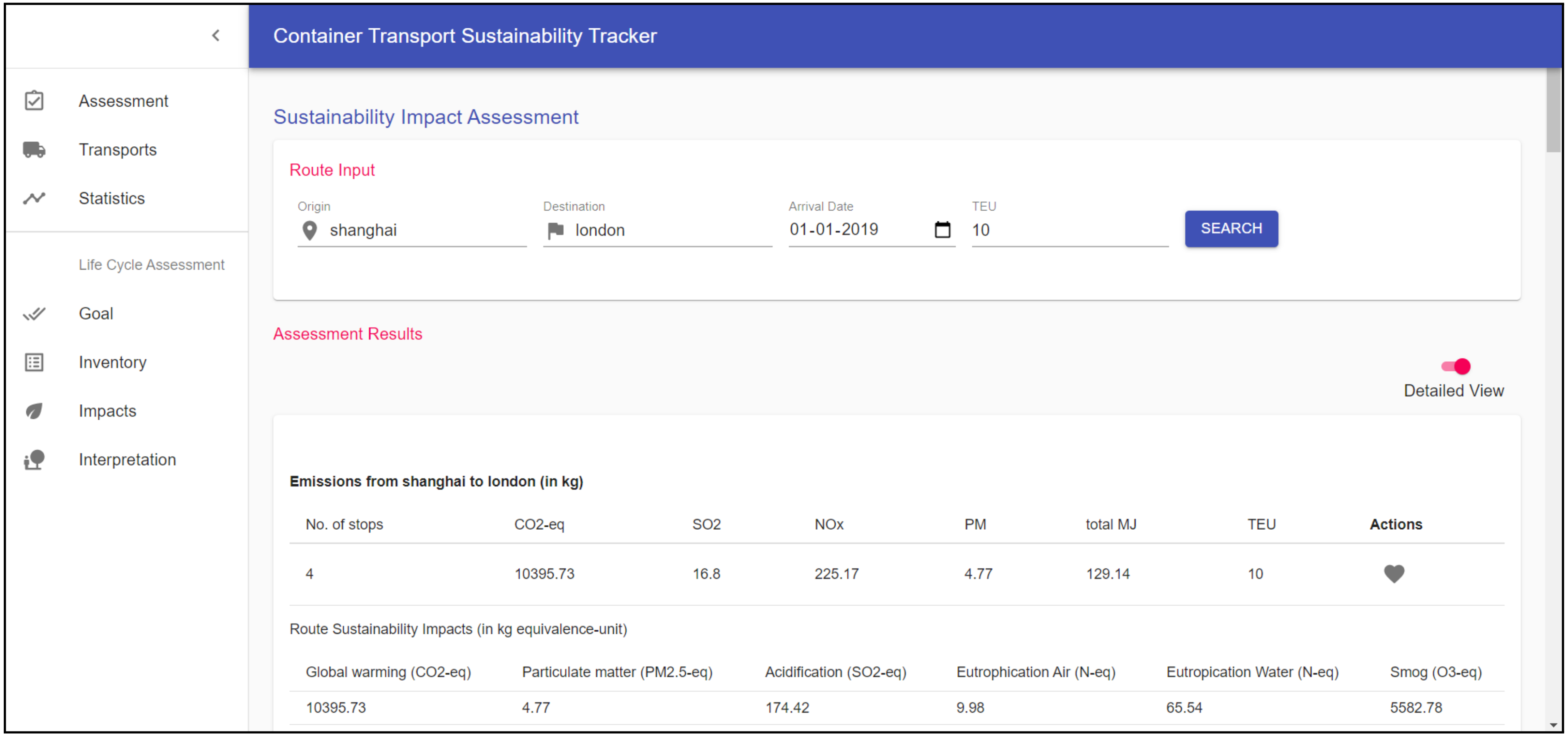

Figure C.3: More details in the advanced view

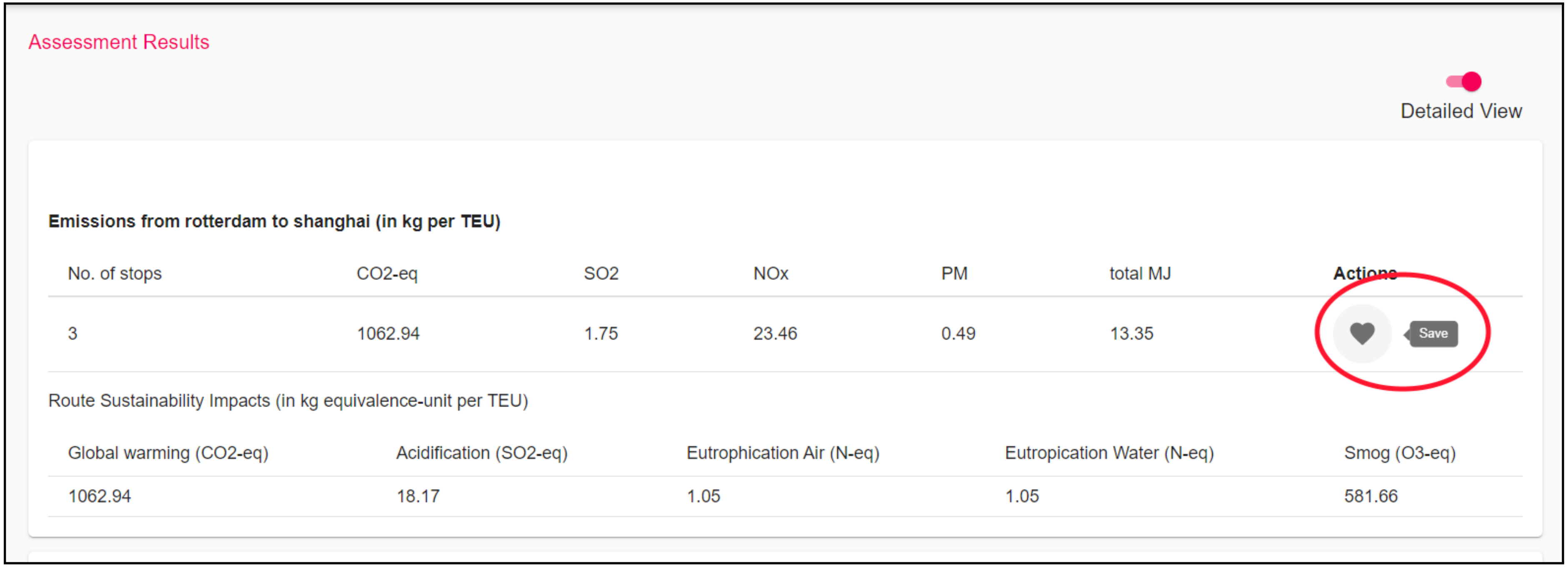

Figure C.4: Saving transports

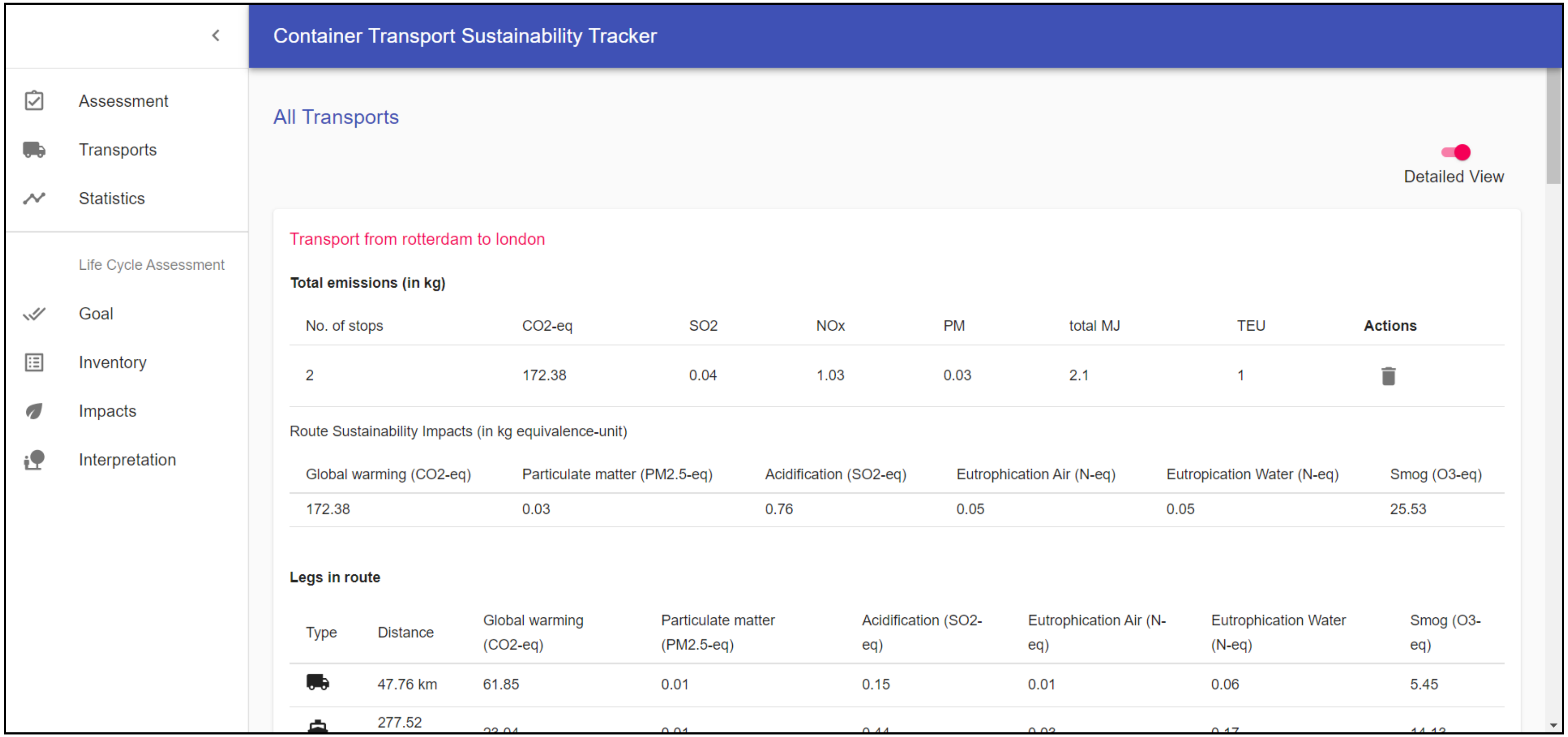

Figure C.5: Overview of saved transports

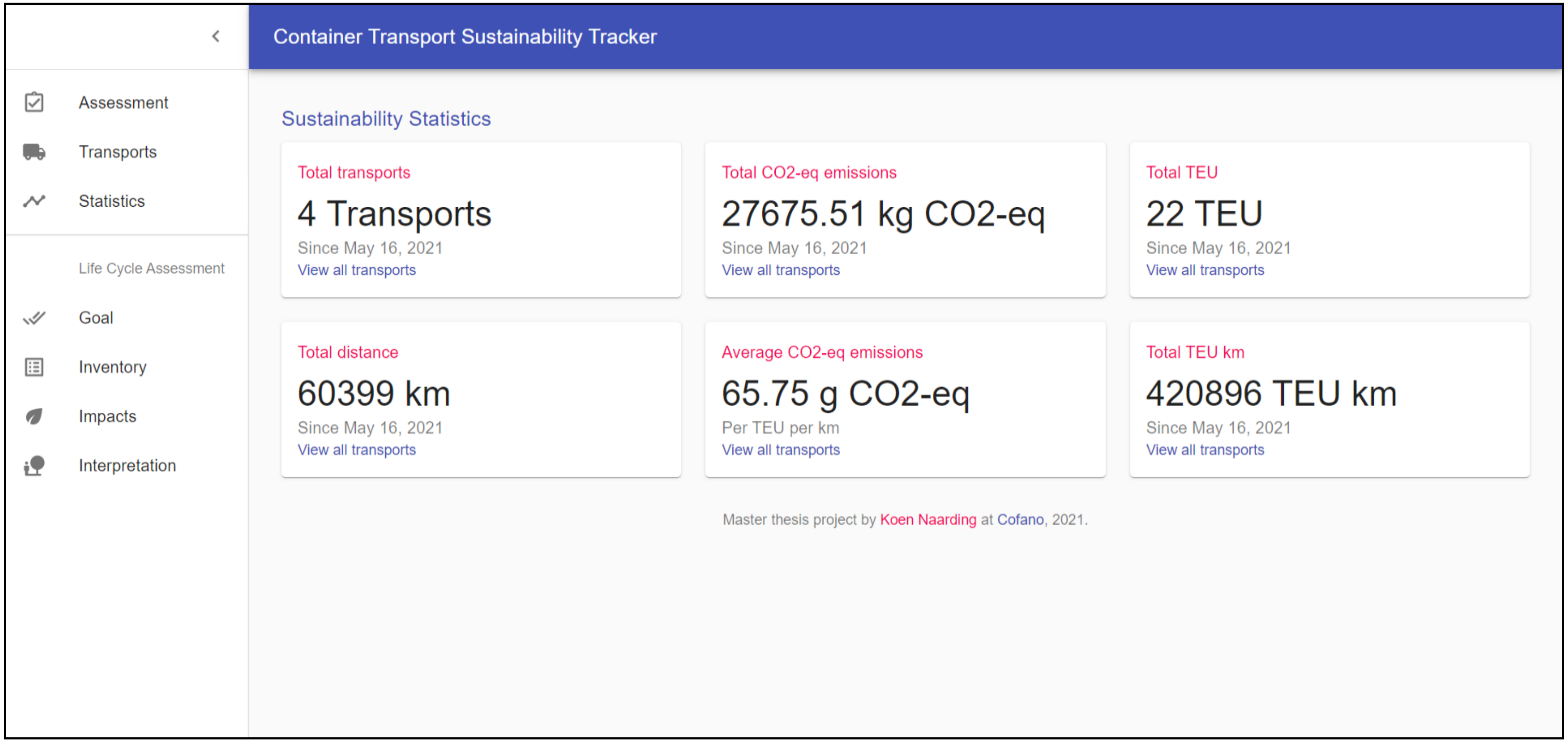

Figure C.6: Portfolio statistics

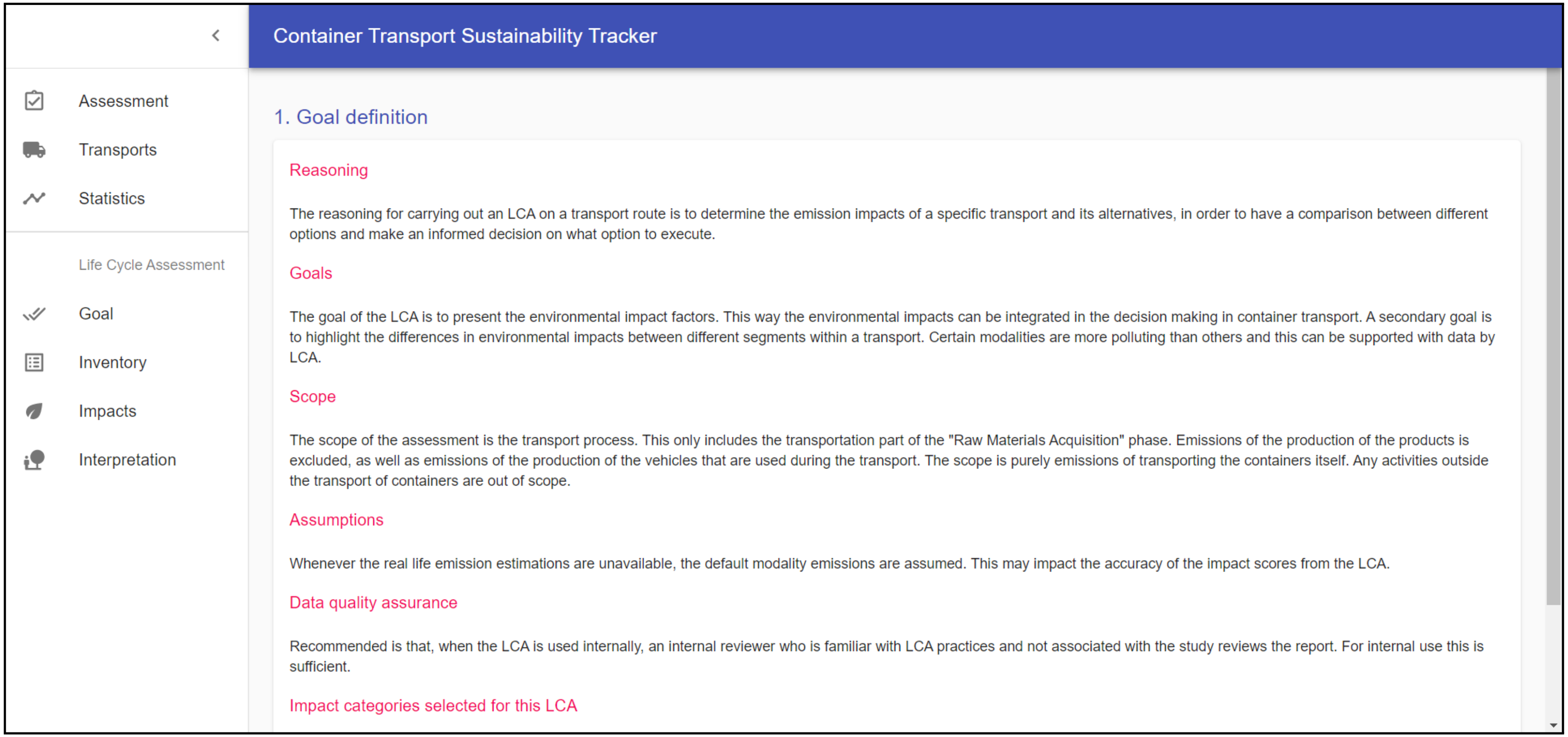

Figure C.7: LCA model documentation