

An information tool on the cost effectiveness of emission reduction measures in road freight transport

Msc Transport, Infrastructure and Logistics
Hannah de Regt

Delft University of Technology

DELFT UNIVERSITY OF TECHNOLOGY

MSC THESIS TRANSPORT, INFRASTRUCTURE AND LOGISTICS
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An information tool for shippers concerning the cost effectiveness of emission reduction measures in road freight transport

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Author:

Hannah de Regt (4386760)

Graduation Committee:

Prof. dr. ir. L.A. Tavasszy, Committee chair

Dr. ir. A. van Binsbergen, Committee member

Dr. J.A. Annema, Committee member

J. Sumner, Smart Freight Centre



Abstract

This report explains the design of an information tool, created to help shippers inform themselves on the emission reducing actions available to reduce road freight transport emissions. Different emission reducing actions for road freight transport are researched and compared based on emission reducing potential and cost. These different solutions, together with a calculation method to determine emissions per trip form the basis for an informational tool for shippers. As shippers buy road freight transport from logistic service providers, third-party logistics or directly from the carrier, they do not have a direct influence on the amount of emissions emitted during transport. However, by making use of collaboration, shippers can influence emission reduction by working together on implementing emission reducing solutions and influencing the corresponding decrease or increase in the price of transport.

Keywords

Road transport emission reduction, road freight transport emission calculation, road freight transport, CO_2e mitigating actions information tool, Cost and emission reduction potential of actions in road freight transport

Preface

My master thesis was written as the last course in fulfilling the requirement of my master program, Transport, Infrastructure and Logistics. With this report, I finalize my student days at the University of Technology in Delft, that started with a Bachelors degree in Mechanical Engineering and ends with a Masters degree. As the biggest part of my Master program took place during COVID-19, it was not easy to stay focused at all times. However, this experience made me grow not only academically but also personally.

During my Masters I realized that sustainability in logistics had piqued my interest. As it was not possible for me to follow the courses developed on sustainability in logistics, I decided that my thesis would be the time to learn more about the possibilities in this area. Smart Freight Centre turned out to be the perfect company to learn more about this topic and simultaneously write my thesis. Seeing first hand how easy some solutions are to decarbonizing logistics was sometimes frustrating but also helped me and my surroundings to realize what we can do ourselves to reduce emissions. It has therefore not only impacted my academic knowledge but also increase my awareness of real life situations making this research also a fun experience.

I want to thank the people who made this thesis possible. First James Sumner of Smart Freight Centre, who created this opportunity and supported me during this project, even after the agreed duration of my thesis. Also the whole Smart Freight Centre team, for making me feel so welcome during my time there. Second Arjan van Binsbergen and Jan Anne Annema, together they provided me with very welcome feedback and helped me at times when I just could not see it anymore. Also Lori Tavasszy, for chairing this committee, his feedback and being so enthusiastic about the topic. Lastly, I want to thank my family and Loek for all their support, ability to listen and cheer me on during this process.

Enjoy reading!

Hannah de Regt

It always seems impossible until it's done
- Nelson Mandela

Executive Summary

Introduction

To limit the effect of climate change, emission reduction is needed. Transport is responsible for over 25% of all emissions of which road transport accounts for 72% (European Environment Agency, 2021). Emission reduction in road transport is therefore inevitable and road freight transport plays an important role. The goal of this research is to help shippers gain insights in the emission reducing possibilities of road freight transport. With this knowledge, shippers can start a conversation with their road freight transport providers, carriers or Logistic Service Providers, on how to reduce these emissions.

In literature, little could be found on the comparison of emission reducing action regarding emission reduction potential and cost. Different studies have been done focusing on one solution or comparing different vehicle types but an overview of different solutions was not found. As tools are often found in grey literature, a study has been done on available tools for road freight decarbonization. Many initiatives are available but most focus on methods to calculate and report emissions instead of providing information on how to reduce emissions. Tools that do offer information on emission reduction actions mostly focus on one solution or on actions that can be implemented in other parts of the supply chain, without need for collaboration. This research is conducted to close the research gap in literature as well as to provide a practical tool which gives an overview of the potential of different actions.

The main research question of this study followed from the research gap and is answered through the sub-questions. The questions are answered using literature studies, interviews with experts and shippers and with a sensitivity analysis of the tool.

How can emission reduction possibilities be meaningfully presented to shippers?

1. Which aspects are of importance for companies when deciding on the ultimate choice for projects that reduce emissions?
2. Which information must the tool provide in order to inform the shipper?
3. What data do companies need to enter in the tool?
4. How can the effective emission reduction be determined?
5. What costs and negative effects are involved in the implementation of emission-reducing actions?
6. What are the different uncertainties in the tool and how can this be included in the calculation?

Methodology

As this is a design study, the methodology used in this research was based on a design method, the V-model. This model exist out of five phases from requirement analysis to final design. Some validation and verification steps were added to ensure error were spotted quickly. In the concept phase, the goal of the tool was determined through interviews and literature research and the requirements were drawn up. In the preliminary design phase a conceptual model was constructed and the architecture of the tool was determined. Literature was used to find the data and the calculation methods needed in the tool. The next phase was the critical design phase where the tool was actually built in Excel after which it was tested in the integration and test phase. Then a sensitivity analysis was conducted to examine the effect of the uncertainties of the different parameters used. After verifying and validating the tool, the last phase was entered, the release phase.

Design

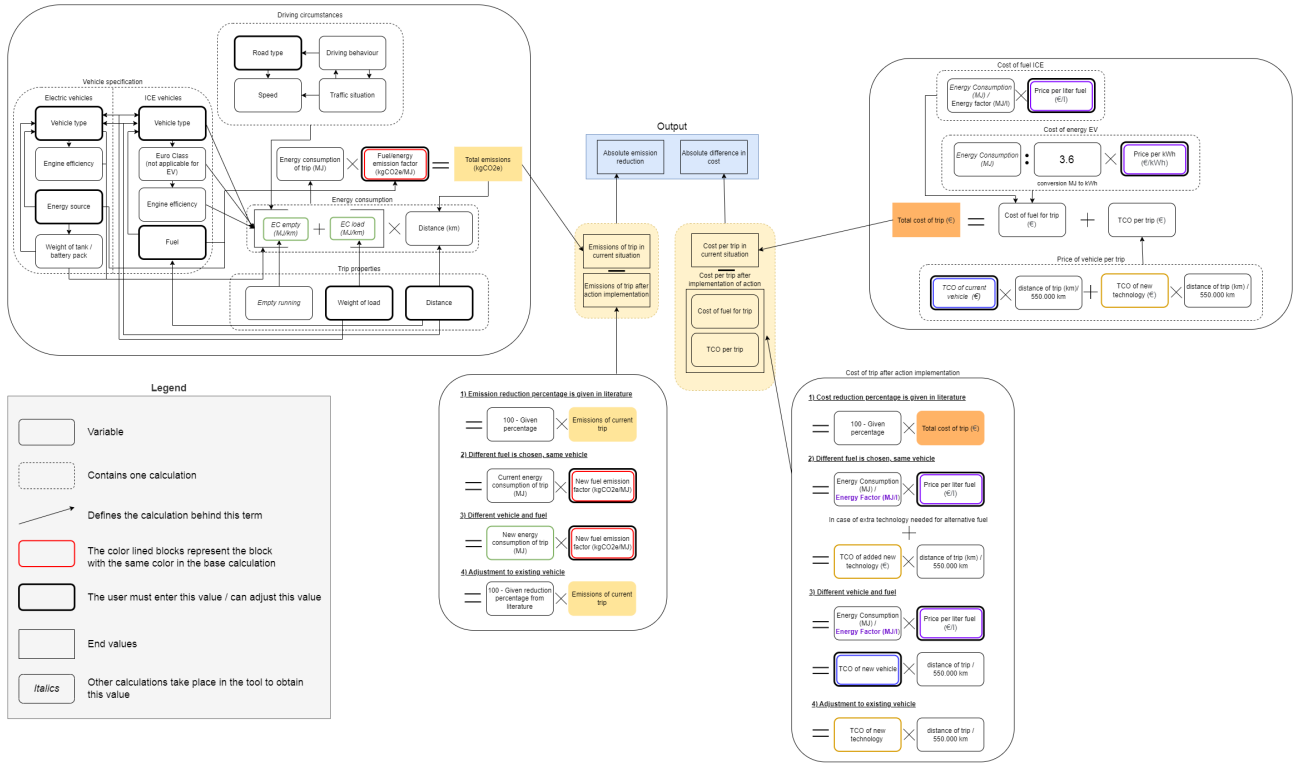


Figure 2: Conceptual model

The design of the tool follows from the conceptual model, Figure 2. The conceptual model was developed from the list of requirements from interviews with the potential users and literature research into existing tools for decarbonizing road freight. The working principle of the tool is to provide the user with insights into the emission reduction possibilities with very little effort of the user. The insights provided by the tool are related to the emission reduction potential and the costs of the action. The calculations done to determine the emissions of the trip are based on the energy consumption and the emission factor of the fuel or energy source chosen. The costs of the trip exist out of two parts, the Total Cost of Ownership of the vehicle, converted into the cost per trip, and the fuel cost. To determine the emission reduction of an action and the corresponding cost, alterations to the existing calculations must be done to determine the new values related to the action, see Figure 2.

The emission calculation methods used, are found in literature and the emission factors are from the ISO14083. The energy consumption factors used in the emission calculation are based on the factors found in HBEFA. The energy consumption factors are related to a specific road type and average traffic situations for that road type have been used. The road type distribution used as default in the tool is based on research done by TNO but this distribution can be altered by the user if the origin and destination of the shipment is known, creating a more accurate estimation of energy consumption for that specific trip.

The data regarding the cost of the different actions was found in literature. The increase or decrease of cost relies on the difference in total cost of ownership and fuel cost. The calculations in the tool are calculated per trip and are based on the first-owner principle. The first-owner principle assumes a certain amount of kilometres driven in the first five years of ownership. The cost associated with the specific action can therefore be scaled using the distance of the trip and the average amount of kilometers traveled in the first five years.

The input from the user, shown in Figure 3, exists out of information on the current transport and location. The user can then choose from different actions that can reduce emissions, these actions are divided into four categories, reduce freight transport demand, increase asset utilization, improve fleet energy efficiency and reduce carbon content of energy. A maximum of six actions can be selected, the actions are then sorted by lowest cost per tCO₂e and shown in the abatement curve. The cost per tCO₂e reduction are placed on the y-axis and the reduction potential in kgCO₂e are placed on the x-axis. If the user has more information about the shipment, extra details can be entered in the parameters tab, replacing the default values in the tools.

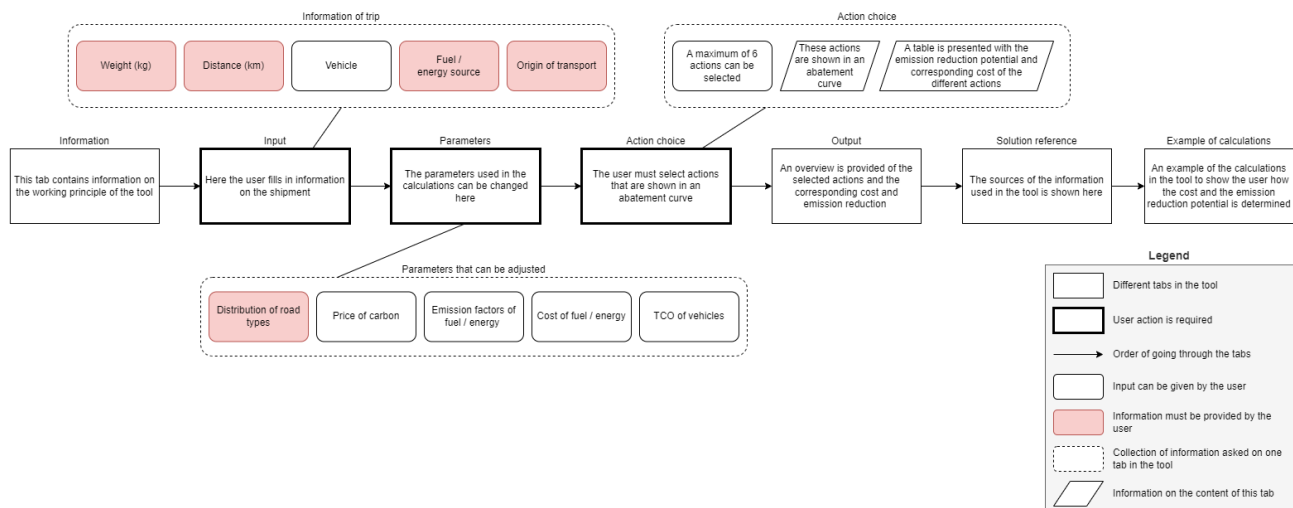


Figure 3: Overview of the different tabs in the tool

Analysis

The tool was used to perform a sensitivity analysis to determine which parameters have the greatest influence on the outcome of the tool. By varying the different input parameters and evaluating the difference in outcome of the tool, the effect of the parameters was determined. From this analysis, it was found that the road type distribution and the vehicle choice have a large impact on the outcome. It was seen that changing the vehicle from the smallest vehicle possible to a commonly used truck, rigid truck 20-26 tonne, resulted in twice the amount of emissions as for the small truck. The road type distribution was also found to be very sensitive to the different shares of road type, where the distance and weight of the shipment did not have a large effect.

Discussion

Since the tool depends on different variables, the uncertainty of these variables determine the reliability of the tool. The two most important uncertainties are the input uncertainty and the cost uncertainty. The input uncertainty, mentioned above, is related to the vehicle choice and the road type distribution. As the vehicle determines the energy consumption of the trip, the emissions can be calculated incorrectly if the wrong size is chosen. It is therefore advised that the user chooses the vehicle size. Next to the vehicle chosen, the trip distribution also affects the amount of emissions. If a higher percentage of motorway is selected than present in the trip, the emissions will be underestimated and vice versa. These two parameters have the biggest influence on the emission calculations and are therefore advised to fill in with care.

Another variable that has a large effect on the information presented by the tool, is the price of fuel. As the tool takes into account the difference in fuel cost, this can determine the feasibility of an action. As the price of fuel can vary strongly as a reaction to external factors and because companies often have predefined the price of fuel in their contracts with carriers, being able to change the price can improve accuracy and decrease uncertainty. Therefore the tool provides the opportunity to enter alternative values for these cost, so the user can influence the uncertainty.

Next to this it is important to mention that the tool calculates a snapshot and that the outcome must be handled with care. The uncertainty of these variables, as they can differ strongly, must be known by the user.

Conclusion

The answer to the research question is to develop an information tool that provides the user with an overview of the reduction potential and corresponding cost of action with little effort. By providing the tool with formulas found in literature and data that is used in the industry, the tool can determine estimations of the current emissions of users and the reduction potential of the chosen actions. The uncertainty present in the tool can be limited by making the user aware of the different uncertainties present and providing the opportunity to the user to decrease the uncertainty if data specific to the trip is used in the calculations. To ensure that the tool contains the most recent data, a maintenance plan was developed that provides the commissioner with a manual to keep the tool up to date.

It must be noted that due to scope limitations of this research, other modes of transport have not been taken into account. Including these in the tool will provide the user with more options to reduce emissions including the option of mode switch,

which can have an impact on the actions for road freight. Different emission reducing actions that can be implemented by shippers or carriers alone are also not taken into account. These actions can help reduce emissions in other parts of the supply chain, which can effect the emissions of transport. Additionally, the calculations done in the tool are simplified deliberately, by performing more detailed emission calculations, the tool can also be used to determine current emissions that can be used in reporting.

List of Figures

2	Conceptual model	4
3	Overview of the different tabs in the tool	5
4	Five pillars of transport emission reduction (Lewis & Greene, 2019)	15
5	V-model (Fowler, 2014)	17
6	Different steps per phase	18
7	IDEF-0 overview	20
8	Different scopes of emissions (Lewis & Greene, 2019)	26
9	Well-To-Wheel analysis (Kleebinder, 2019)	27
10	Comparison between three different technologies for HDV's (Cunanan et al., 2021)	36
11	Comparison between FCEV, BEV and ICEV components (Guandalini & Campanari, 2018)	36
12	Efficiency of EV components (Albatayneh et al., 2020)	37
13	Working principle of regenerative braking (Balali & Stegen, 2021)	37
14	Factors with influence on emission factors	40
15	Distribution of road types (Verbeek et al., 2018)	41
16	Power Interest grid (Guðlaugsson et al., 2020)	44
17	Power versus interest grid (Eden & Ackermann, 1998)	45
18	Interview part 1	46
19	Interview part 2	47
20	Overview calculations in the tool - left side	51
21	Overview calculations in the tool - right side	52
22	Overview of the different tabs in the tool	62
23	Information tab	63
24	Input tab	64
25	Parameters tab	64
26	Action tab	65
27	Output tab	66
28	Base case example	68
29	Abatement curve after changing parameters	69
30	Overview of the output of the base case	69
31	Overview of the output of the altered base case	70
32	Overview of existing tools and initiatives	77
33	Choices HBEFA tool	99

List of Tables

1	Existing tools	25
2	Actions included in information tool	29
3	Cleaner and efficient technologies	31
4	Efficient vehicle solutions	32
5	Increase load factor	53
6	Decrease fuel use	53
7	Cleaner and lower carbon fuels	54
8	Total Cost of Ownership of vehicles	54
9	WTW emission factors (ISO 14083 FDIS version)	56
10	WTW emission factors of grid electricity per country in Europe (Carbon Footprint, 2022)	57
11	Renewable electricity sources (CO2emissiefactoren, n.d.)	57
12	Different vehicle categories from HBEFA and capacities	58
13	Road type distributions	59
14	Carbon tax in Europe (Bray, 2022)	59
15	Sensitivity analysis of the user input	71
16	Sensitivity effect on actions	72
17	Total emission reduction after the implementation of the three actions	72
18	Chosen traffic situations in HBEFA	101
19	Overview of recommended updates	105

Glossary

- **Action:** A measure that reduces transport emissions and can be implemented in a company (such as change of fuel)
- **BEV:** Battery powered Electric Vehicle
- **Carrier:** An entity that operates a vehicle or vehicles with the purpose of transporting goods. Vehicle could refer to any form of transport, e.g. truck, train, aircraft, waterborne vessel
- **CSS:** Carbon Capture and Storage
- **Collaboration project/pitch:** An idea of one or multiple companies, can be shippers, carriers or LSP, to reduce transport emissions together. The idea is then put on the collaboration catalyzer to find more participants for this project
- **CO₂e:** *CO₂equivalent*, emissions of other GHG expressed in the polluting strength of CO₂
- **EF:** Emission Factor
- **Emission class:** The emission class of a vehicle, also called EURO-class, is based on the production year of a vehicle and provides information on the TTW emissions of a vehicle
- **EREV:** Extended Range Electric Vehicle
- **ETS:** Emission trading system
- **EV:** Electric Vehicle
- **FCEV:** Fuel Cell Electric Vehicle
- **FF:** Freight Forwarders, a company that receives and ships goods on behalf of other companies
- **GHG:** Green-House Gasses
- **GLEC:** Global Logistics Emissions Council, a framework created by SFC for Logistics Emissions Accounting and Reporting
- **HBEFA:** The Handbook Emission Factors for Road Transport
- **HEV:** Hybrid Electric Vehicle
- **HGV:** Heavy Goods Vehicle, used in this study with the same meaning as HDV (Heavy Duty Vehicle)
- **ICE:** Internal Combustion Engine
- **Initiative:** Gathering of companies that commit to a certain goal. Does not reduce any emissions on its own. Because of this initiative an action will need to take place to reduce the emissions (examples of initiatives include GLEC / coZEV / EV100+)
- **LCV:** Light Commercial Vehicle
- **LSP's:** Logistic Service Providers, they are outsourcing entities shippers leverage to manage a company's warehousing, distribution and transportation of freight
- **MHEV:** Mild Hybrid Electric Vehicle
- **PHEV:** Plug-in Hybride Electric Vehicle
- **Scope 3 emissions:** These are supply chain emissions, emitted during transport that is outsourced. This includes incoming transport and outgoing transport but also waste disposal for example

- **SFBA:** Sustainable Freight Buyers Alliance. Program uniting corporate freight buyers and freight decarbonization initiatives to shift to net-zero freight across all modes of transport
- **SFC:** Smart Freight Centre
- **Shipper:** Individual or entity that sends goods for transport
- **Solution Providers:** Company that offers a solution that reduces transport emissions, other companies can join in carrying out the solution
- **TCO:** Total Cost of Ownership
- **TTW:** Tank-to-Wheel, this includes only the emissions that occur when fuel is burned by a vehicle
- **WTT:** Well-to-Tank, this includes only the emissions from extraction till refuelling at a gas station
- **WTW:** Well-to-Wheel, this is the complete emission chain, from extraction to emission from a vehicle

Contents

Preface	2
Executive Summary	3
List of Figures	7
List of Tables	8
Glossary	9
1 Introduction	13
1.1 Research problem	13
1.2 Context analysis	14
1.3 Research Question	15
2 Methodology	17
2.1 Concept phase	17
2.2 Preliminary Design Phase	19
2.3 Critical Design Phase	21
2.4 Integration and Test Phase	22
2.5 Release / Production Phase	22
3 Literature Research	23
3.1 State of the Art	23
3.2 Freight emissions	26
3.3 Actions	27
3.4 Calculating reduction potential of Actions	38
3.5 Costs	41
4 Requirement Analysis	43
4.1 Literature	43
4.2 Requirement trawling	43
4.3 Requirements	44
5 Model Components	50
5.1 Conceptual model	50
5.2 Data in tool	53
5.3 Description of Information Tool	62
6 Substantive Analysis of the Tool	68
6.1 Examples of use	68
6.2 Effect of uncertainties	70
7 Verification & Validation	73
7.1 Verification	73
7.2 Validation	74

7.3 Process environment	76
8 Conclusion & Recommendations	77
8.1 Conclusion	77
8.2 Discussion	78
8.3 Recommendations	78
References	81
Appendix	86
A Scientific Paper	87
B HBEFA values	99
B.1 Guide to determine emission factors using HBEFA	99
B.2 Overview of Energy Consumption factors from HBEFA - CONFIDENTIAL	102
C Maintenance document thesis tool	103
D Usability for SFBA	106
E Tool Guide	107

1 Introduction

Emission reduction and climate change are two frequently heard words in the past years and even more often in 2022. Due to the increasing knowledge about climate change and the effects of emissions on nature and the livability of our planet, the voice that change is needed became louder and stronger. Different governments, UN climate conferences and experts came to the same conclusion, that emission reduction is needed in all different aspects of society. To limit the effects of climate change, the Paris agreement was adopted in 2015. This climate accord has the goal to limit global warming with a maximal increase of 2 degrees Celsius (European Commission, n.d.-c), and even trying to limit it to 1.5 degrees Celsius, resulting in many plans and treaties with targets to reduce emissions. One main polluter is transport, people as well as freight. With transport being responsible for over 25% of emissions in Europe and road transport being responsible for 72% of that in 2019 (European Environment Agency, 2021), road freight transport became one of the major sectors for change (DE Statis, n.d.). It resulted in a strategy in Europe, the European Green Deal (*The European Green Deal*, 2019), that greenhouse gas (GHG) emissions must be reduced by at least 60% in 2050 compared to 1990 (European Commission, n.d.-f).

1.1 Research problem

As part of the European Green Deal, the European Commission has decided that from 2026 the transport sector will also participate in the Emissions Trading System (ETS) (European Commission, n.d.-a). This measure puts a price on transport emissions making traditional (fossil fuelled) transport more expensive, which is expected to stimulate the use of cleaner fuels and increase investments in cleaner technologies. As a result, carriers as well as shippers need to decide on their transport strategy. As road freight transport is often purchased by shippers either directly from the carrier or through a logistic service provider (LSP) or third-party logistics (3PL), collaboration is needed in order to create change in the road freight sector. As carriers are responsible for their operational fleet, the change to vehicles and fuels used needs to take place here. However a change of mindset is also necessary for shippers as they purchase the freight transport and currently base their decision purely on cost and reliability. To implement emission reducing solutions, collaboration between shippers and carriers is needed.

Different institutions and companies already noticed the demand for collaboration and started setting up platforms to help get collaboration projects started between carriers, LSP and shippers, for example the Sustainable Freight Buyers Alliance (SFBA) (Smart Freight Centre, n.d.-b) but also ENTRANCE (Entrance, n.d.). It can be seen that these alliances are needed to help implement solutions and guide discussions such as monetary impacts for all parties involved. As these alliances are now based on existing ideas of carriers or shippers, the question arose as to how these came about. Only big companies, with enough money to research emission reducing solutions, now decided on collaboration projects and are starting to implement them. In order to increase the amount of companies interested and willing to collaborate, more information on different projects and solutions is needed. When shippers are aware of the available solutions and their emission reduction potential and corresponding cost, they can start looking into the possibilities of joining an alliance or start looking for collaboration partners themselves.

Many companies and institutions offer information on emission reducing actions as well as literature existing on this topic. Research has mostly been done on finding a solution for a specific situation, such as city logistics, long haul or multi-modal logistics. A. C. McKinnon & Piecyk (2009) researched the measurements of CO_2 emissions in the UK for road freight transport, Achour et al. (2011) looked into city emissions in Dublin and J. Klein (2019) developed a calculation method to determine emissions of transport in the Netherlands. The first step is understanding where the majority of the emissions originate so an approach can be drawn up. With these studies, many scientists also looked into the possibility of reducing emissions. This is often done for passenger transport and inner city logistics because of the direct impact on the health of people living in the city. Mavrin et al. (2020) researched the environmental impact of traffic management, improving traffic flow, in medium sized cities where Liimatainen et al. (2014) developed six scenarios for decarbonizing road freight in Finland.

A large group of companies and initiatives reacted to the obligation to calculate and report emissions and created methods and tools to help companies with the calculation and reporting of their emissions. Logistics Emissions Accounting & Reduction Network (n.d.), BigMile (n.d.) and Via Green Institute (n.d.) are all initiatives that mention to help companies reduce emissions, but are actually offering a method to calculate and report emissions in logistic chains so companies can see where emissions take place and mitigate these emissions themselves. Little work has been put into creating an overview of the different solutions available, which would allow companies to see which options fit their supply chain best. The Global Logistics Emissions Council Framework (GLEC), created by Smart Freight Centre (SFC), tried to capture all different categories of solutions into one table based on the book of A. McKinnon (2018) next to offering companies a method for emission calculation and reporting. By creating these kind of overviews, companies, shippers as well as LSP, can see what their options are with regard to implementing emission reduction solutions. However, only an overview of the options does not provide information on the emission reduction potential of these solutions or other factors that are

related to implementing a solution such as costs.

To fill in this gap, some organizations created tools which do compare options or solutions such as EcoTransIT (EcoTransIT, n.d.), which compares different modes for the same origin-destination pair. The International Transport Forum (n.d.), an overview of mitigation measures for passenger as well as freight transport, it includes emission reduction potential and cost information but lacks in number of solutions that are in need of collaboration. Vecto, a tool created by the European Commission to help calculate emissions of heavy-duty vehicles (HDV) above 3,5 t, but does not contain information on mitigation measures (European Commission, n.d.-g). And initiatives such as Science Based Targets (n.d.), that help their clients to set targets for emission reduction but do not provide information on how the emission reduction can be achieved. Looking into literature it seems as if little research has been done on comparing the different possible solutions and their impact on emission reduction and costs. Reviews of literature that unite information on the different possible solutions and their corresponding emission reduction potential and the cost impact on shipper companies were also not found. In grey literature no tool was located that combined information on cost and emission reduction of actions to reduce emission in road freight transport into one tool. With this study, the gap between companies and information that can be found in literature on different solutions for reducing emission in road freight transportation is closed by creating an information tool that takes into account not only emission reduction but also costs.

1.2 Context analysis

This thesis is being carried out at Smart Freight Centre (SFC). SFC is an international non-profit organization that works with companies on reducing freight transport emissions. One of their initiatives is the Sustainable Freight Buyers Alliance, which creates collaboration opportunities for shippers by providing them with information on solutions and offers a platform to reach other companies, shippers as well as logistic service providers and carriers. This thesis was written as part of SFBA.

1.2.1 Company analysis

Smart Freight Centre was founded in 2013 and has the goal to help eliminate transport emissions. They support companies with the calculation and reporting of their emissions and offer other services to help reduce transport emissions, such as e-learning courses on sustainable logistics. With their goal they want to limit global warming to 1.5 degrees Celsius and accelerate the transition to net-zero freight emissions.

In November 2021, SFC launched a new initiative called the Sustainable Freight Buyers Alliance (SFBA). With this initiative they want to bring different parties (shippers, carriers, freight forwarder and logistic service providers) closer together and provide them with information on how to reduce their transport emissions and together realise specific opportunities to accelerate the transition to net-zero freight emissions.

The service that is being created by SFBA consists out of multiple parts. Before a company joins SFBA, it is expected that they are reporting their transport emissions and must have clearly stated that they want to reduce their transport emissions. An information tool, which takes into account company data such as geographical location and uses that to compare the different available actions, would be very useful to SFBA. The emission reduction of the actions are calculated and presented with the corresponding costs of the action.

1.2.2 GLEC framework

Smart Freight Centre has previously developed the Global Logistics Emissions Council framework (GLEC) to help companies with calculating and reporting their logistic emissions. This framework consists mostly out of steps to calculate transport emissions for shippers, carriers and logistic service providers. It offers examples of these calculations and provides the different emission factors, in line with the EN16258 standard, needed to determine the GHG emissions. Many companies already use this method to calculate their emissions, in order to be in line with Smart Freight Centre and their method to calculate emissions, the tool created in this thesis is also in line with the GLEC method.

After calculating and reporting emissions, reducing emissions is the next step. Many options are available to reduce emissions and to help companies, an overview of different possibilities to reduce transport emissions is given based on the book of A. McKinnon (2018). These possibilities are split up into five fundamental principles, the pillars; Reduce freight transport demand, Optimize freight transport modes, Increase assets utilization, Improve fleet energy efficiency and Reduce carbon content of energy. The actions (see Glossary) related to these pillars are shown in Figure 4 and can be used as inspiration for companies to start reducing transport emissions. This list is not complete and other solutions can be thought of that can either be placed under a fundamental principle or as a subcategory of a solution, for example hydrogen can be placed in the fifth column, reduce carbon content of energy.

Long term solutions as well as short or medium term solutions can be used to reduce emissions. In this tool also solutions are included that can be used in the transition phase from conventional fossil fuelled vehicles to zero emission vehicles. Examples are CNG, LNG and bio-fuels and also the biological variants of CNG and LNG. Hydrogen can also be seen as a transition solution. As new ways of energy production also bring new challenges along, hydrogen can offer a solution. With the new energy generation processes, it is likely that energy storage is needed to capture the generated energy that cannot be used at that moment. As the production process of hydrogen is not energy efficient, creating hydrogen solely for the purpose of creating fuel is therefore not profitable but energy can be stored in hydrogen. This results in a different reason to create hydrogen, making it a useful solution to store the excess energy. The hydrogen can then be used to fuel specific vehicles or it can be transformed back into energy, which is also not an energy efficient process.

Reduce Freight Transport Demand	Optimize Freight Transport Modes	Increase Assets Utilization	Improve Fleet Energy Efficiency	Reduce Carbon Content of Energy
Supply chain restructuring	Modal shift	Load optimization	Cleaner and efficient technologies	Cleaner and lower carbon fuels
Standardized modules/boxes	Multi-modal optimization	Load consolidation	Efficient vehicles and vessels	Electrification
3D printing	Synchromodality	Logistics centers and warehouse management	Driving behavior	Fuel management
Dematerialization			Fleet operation	
Consumer behavior			Fleet maintenance	

Figure 4: Five pillars of transport emission reduction (Lewis & Greene, 2019)

1.3 Research Question

The goal of this information tool is to inform shippers about the reduction possibilities in road freight transport with the aim of starting a conversation between shippers and carriers to work together on reducing greenhouse gas emissions. By providing the shipper with information on the reduction potential and the corresponding costs of different emission reducing possibilities for their outsourced transport, responsible for scope 3 emissions, the shipper gets a clearer picture of where the solutions to reducing these emissions lie. With this in mind, this research focuses on the actions that need collaboration between shippers and carriers to make the change happen, actions that can be performed by only shippers are therefore not included. Also actions with regard to mode switch have not been taken into account, while this research solely focuses on road freight transportation.

As mentioned, this thesis is focused on road freight transport and scope 3 emissions for shippers, meaning the outsourced transport. Because the emissions (scope 1, scope 2 and scope 3) that need to be reported are calculated in CO_2e , in this thesis the same pollutants are taken into account. CO_2e includes, CO_2 , N_2O , CH_4 and fluorine-containing gases, these are converted into a CO_2 equivalent using the Global Warming Potential (GWP), that is the extent to which a gas contributes to the greenhouse effect.

With the foregoing limits of the research, the research question is as follows:

How can emission reduction possibilities be meaningfully presented to shippers?

Sub-questions to help answer the main research question are shown below. The answers help scope the research further and provide needed information to answer the main research question. The methods used to answer the main research question and sub-questions are elaborated on in Chapter 2.

1. Which aspects are of importance for companies when deciding on the ultimate choice for projects that reduce emissions?
2. Which information must the tool provide in order to inform the shipper?
3. What data do companies need to enter in the tool?
4. How can the effective emission reduction be determined?

5. What costs and negative effects are involved in the implementation of emission-reducing actions?

6. What are the different uncertainties in the tool and how can this be included in the calculation?

In this thesis a prototype will be created of an information tool that can help companies gain insight in which aspect of their supply chain the best emission reduction potential lies. When creating an information tool, it is necessary to understand why companies find it difficult to put potential projects into action and what is holding them back to start a conversation with a carrier. For this it is necessary to gain insight into the considerations that underlie the selection process of sustainable transport projects, sub-question 1. With this, sub-question 2 can be answered, which information is needed for shippers to actually start implementing an action or to start a conversation. What data of companies is necessary to provide this information will be answered in sub-question 3. The calculation methods used to determine emission of the current situation and the reduction of actions will be determined to answer sub-question 4. The costs of implementing these actions will follow from literature and research done by research institutes and provide an answer to sub-question 5. And the uncertainties of the data and the calculations of the tool and how to deal with these uncertainties in this study are answered for sub-question 6.

1.3.1 Report structure

The structure and outcome of this report serves as input for the design of the information tool. In Chapter 2 the methodology of this report is discussed and the different phases of the V-model are explained. As this report is written for a design thesis, the background information on the topic as well as the data for the tool can be found in Chapter 3, Literature research. In this chapter sub-question 4, 5 and 6 will be answered. The requirements for the tool and the techniques used to find them are described in Chapter 4, answering sub-question 1 and 2. The results of the literature research and the requirements are combined in Chapter 5 Model Components and answers sub-question 3. The design of the tool is then elaborated on in Chapter 6. Chapter 7 provides a validation and verification of the tool and Chapter 8 concludes with a conclusion of this study along with a discussion and recommendations for further research.

2 Methodology

The goal of this thesis is a working prototype for an information tool informing shippers on the emission reduction actions available. Therefore this is a design thesis for which a design methodology has been used.

Based on initial literature research, the V-model of Grady (1995), V stands for validations and verification, is chosen. It is the most appropriate method for this study due to the amount of feedback present during the design cycle. By connecting different phases to each other with a validation or verification step, the duration of the design process can be reduced. Defects are discovered early on and the direction of the design is monitored by making use of multiple verification moments where the requirements are checked. This creates the expected end result without discovering defects at the very end of the design process. The V-model is adjusted for this thesis, the feedback is made iterative by adding more validation moments where the design is checked against the requirements, this is done to reduce the chance of errors during the integration and acceptance tests.

The V-model

The model consist out of five phases. Each phase is consists out of 1 or 2 different activities. The activities in the first half are connected with the second half of the model by a control step. This iterative way of modelling ensures a shorter duration of the system design and a more accurate outcome. The different phases and activities are explained in more detail below including the methodology used for each activity.

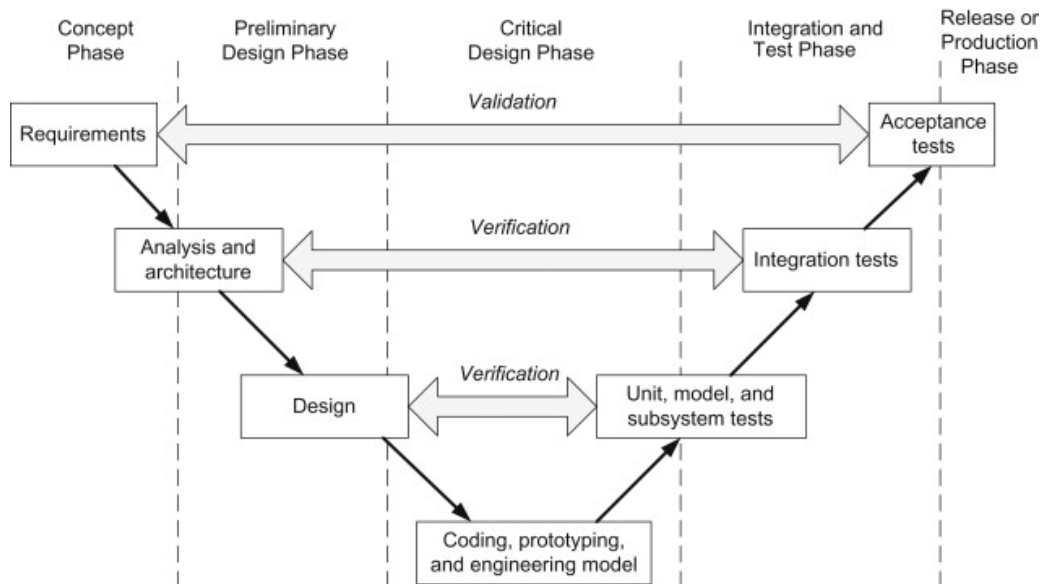


Figure 5: V-model (Fowler, 2014)

The different steps in the five different phases can be seen in Figure 6. The orange blocks are the results of the white blocks. It can be seen that only the first two phases have these orange blocks, these are the inputs for the following phases. After the critical design phase, the tool needs to be tested to validate and verify the working principle. After processing the feedback from the internal validation and verification, the tool is send to potential external users, the same companies as the interviews, to validate and verify. Again the feedback is processed and after this the tool will be released.

2.1 Concept phase

The concept phase started with determining what shippers need to start a conversation with carriers about decarbonizing road freight logistics, resulting in the goal of the tool. The next step is drawing up the different requirements for the tool from the goal and the main success scenario (see section 4.3.1). This was used to determine the wanted outcome of the tool. The requirements and the main success scenario were checked during interviews with potential users and extra requirements were found during these interviews. In the concept phase a literature study was done to get to know the state-of-the-art and determine the research gap. In the process of requirement trawling also sub-question 1 and 2 have been answered.

2.1.1 Requirement analysis

The first step of designing this tool, the requirement analysis, started with a literature search on different requirement trawling techniques. This resulted in attending meetings with companies involved in the SFBA initiative and talking with

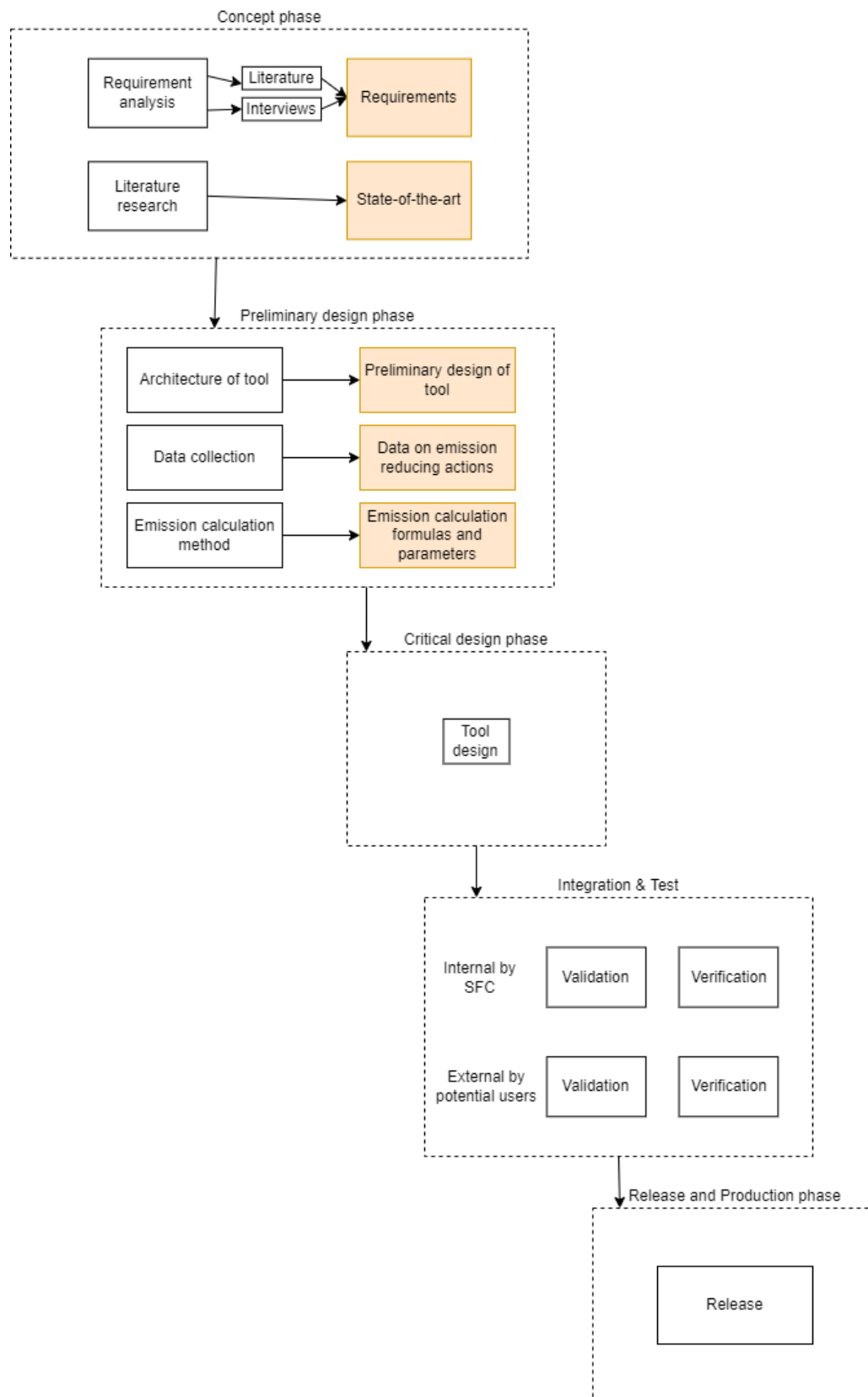


Figure 6: Different steps per phase

the people working on the SFBA initiative at Smart Freight Centre. The goal of the tool, the future use and the main success scenario was then drafted from the collected information from these meetings. This also led to a first draft of requirements using requirement trawling. In order to check the goal and the usefulness of the tool, requirement elicitation has been used. The method used for the requirement elicitation, checking and discovering requirements from users and stakeholders, was interviewing five different shippers (potential users). Preparations were made before conducting the

interviews online using MS Teams, this contained creating a list of questions based on methods from existing literature on requirement analysis used to guide the interviews with companies. The first draft of requirements have been formed in the way of Robertson (2001). Together with the requirement elicitation, also a stakeholder map was created to gain insight in the different stakeholders for this tool.

2.1.2 Interviews with users

Interviewing future users of the tool has been part of the requirement elicitation and was essential in understanding the needs of the decision support tool. Five shipper companies were interviewed, P&G, Dow, Unilever, Roche and Saint-Gobain. The interviews with these companies were done with employees in functions related to decarbonizing their companies logistics. The interviews were with the Global Transportation and Sustainability Director of P&G, the Global Procurement Sustainability and Advocacy leader of Dow, the Logistics support lead and product supply logistics & operations of Roche, the Transportation & Logistics manager at Saint-Gobain and the Global Sustainability Lead of Unilever. By making use of information gathered in previous meetings, the interview was scoped and the line of questions was set up. Making use of the success scenario of the tool, the potential future users could walk through the suggested working principles of the tool and provide feedback and thoughts on the working principle and provided outcome of the tool. During these interviews, information on decision making regarding decarbonizing logistics was also gathered. The companies were asked questions on the factors of importance when making transport decisions and the role of lower carbon solutions in their decision making. The outcome of the interviews was used in further determining the requirements and also to determine the outline of the working principle of the tool.

As an extra step in the requirement analysis, the goal of the tool and the success scenario were validated to ensure the right basis for the decision support tool. The second validation was based on the wanted end product, which was altered based on the interviews. As can be seen in Figure 5 the requirements were used to validate the purpose of the tool and the right outcomes of the tool based on the goal and the main success scenario.

2.1.3 Literature research

A literature study was performed to get to know the state-of-the-art of decarbonizing logistics tools for road freight transport. Using the search engines of Google Scholar and Scopus, many scientific papers were reviewed regarding existing tools for road freight transport, decarbonizing road freight logistics, methods to decarbonize road freight transport and comparing different ways to decarbonize heavy duty trucks in Europe. As existing tools on decarbonizing road freight transport are not present in scientific papers but are mostly placed on the internet, also a google search was done into the same subject. Key words used in this google search were "tools to reduce GHG emissions of road freight transport", "decarbonizing logistics of road freight transport", "solutions to reduce GHG emissions of heavy duty vehicles" and "Initiatives to reduce road freight transport emissions". Many combinations of these search words were also used to find the state-of-the-art in decarbonization tools that already exist.

In order to reduce the amount of papers found in existing literature on Google Scholar and Scopus and to only include useful papers for this research, a selection was made. This was done based first on the title, if it included "road freight decarbonization", "reducing emission in road freight", "solutions for reducing emission in road freight" or any combination of these words, the paper would be further evaluated. Second it was preferred that the paper was not older than 2018 except for when the title of the paper indicated a very useful topic combining the words "decarbonizing", "road freight" and 'Europe' or "solutions to reduce GHG emissions" and "road freight". The third evaluation was on the location of solutions and case studies, preferably in Europe. If the study was done in the US the paper was also selected, however if the study was done in Africa or Asia the paper was not taken into account. Lastly the abstract of the paper was read and it was decided if the paper was relevant to read. Next to a search in the two search engines, also sources mentioned in the selected papers were reviewed. If papers were found with promising titles, these were also reviewed following the same selection as the papers found using the search engines. The result of this literature study can be found in Chapter 3.

2.2 Preliminary Design Phase

During the preliminary design phase, a conceptual model was constructed. From this the architecture of the tool was determined based on the success scenario and the list of requirements created in the concept phase. The information from the literature study on the state-of-the-art of existing tools was used to determine the layout. Next the data needed for this tool was collected again using literature. The calculation methods and the parameters for these calculations were also determined using existing tools, expert opinions and again literature. All this information was then used to create the first draft of the information tool.

2.2.1 Analysis and Architecture

In this activity the architecture of the decision support tool was captured. First, from the requirements and the success scenario it was determined which elements were needed to obtain the emission calculation results expected to be the outcome of the tool (sub-question 2), see Figure 7. For example the emission reduction calculations (sub-question 4). This was completed using literature and expert interviews and making use of previous work at Smart Freight Centre.

The different functions of the tool, as presented in Figure 7, are the input of the company and the calculation method with the needed parameters. With the goal of the tool in mind, a program was chosen to build the tool, Excel. This program was chosen so that the tool could later be easily maintained by SFC. The architecture of the tool also included choosing a method to intuitively display the results of the comparison of emission reducing solutions. Based on existing programs that provide a visual overview of similar comparisons and after talking to experts, the abatement curve was chosen. In this phase also the construction of an abatement curve in Excel took place.

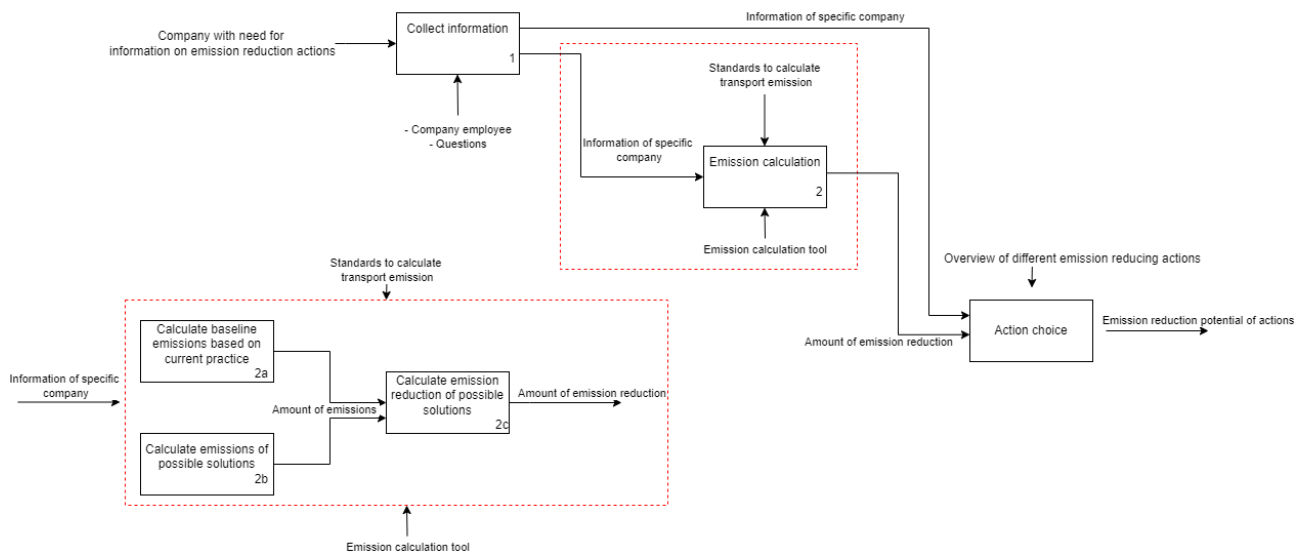


Figure 7: IDEF-0 overview

2.2.2 Data collection

Providing the tool with the needed information for the emission calculation was also part of the preliminary design phase. This existed out of two parts, first of all the information needed to determine the emissions associated with the current situation. Second the information needed to determine the emissions associated with emission reducing actions. In order to determine the emissions of the current situation the formulas from the emission calculation method needed to be filled in. The data needed for this is the answer to sub-question 3, the data that companies need to enter in the tool. The second set of data that was collected in this phase is related to the actions that reduce transport emissions. A literature study was conducted on the different available emission reducing actions for road freight transport. Search words were again used to determine the different available actions, "ways to reduce road freight emissions", "Reducing road freight transport emissions", "reducing GHG emissions of heavy duty trucks in Europe" and different combinations of these words. The same selection criteria of the concept phase were used to determine which articles were useful. After determining which emission reducing actions were available for road freight transport, a selection was made of actions that can be implemented by carriers in collaboration with shippers. This resulted in a list without actions that can only be implemented by shippers without carriers. These actions were then also researched in literature to determine their emission reduction potential and their corresponding costs. The actions that were studied in literature are:

- Standardized modules & boxes
- Load optimization
- Load consolidation
- Cleaner & efficient technologies
- Efficient vehicles
- Driving behaviour
- Fuel management
- Fleet operation
- Cleaner & lower carbon fuels

- Electrification
- Hydrogen

The names of the actions were combined with search words as "reduction potential", "costs", "heavy duty vehicles", "emission reduction" and "Implementing". From this literature study, actions that belonged to another action were also researched and included if they met the criteria for actions.

2.2.3 Emission Calculation

As part of the preliminary design phase, the method for emission calculation needed to be determined. Literature was used to find the emission calculation methods for road freight transport. A small literature study was done based on (a combination of) the search words "GHG emission calculation in road freight transport". From this different formula's were found which were based on different aspects of road freight transport such as amount of fuel used, amount of tonne-kilometre with specific vehicle or amount of energy consumption. Based on the method from the GLEC Framework and in accordance with the NEN16258 and the new ISO 14083, the emission calculation was based on the amount of energy consumption. For the emission calculation, energy consumption (EC) factors and emission factors (EF) were needed. The energy consumption factors were determined using the Handbook Emission Factors for Road Transport (HBEFA) tool, the emission factors used in these calculations were from the new ISO14083 Final Draft International Standard.

Emission factors

The information tool will be focused just on Europe, therefore only emission factors for Europe have been determined. For determining the emission factors, the HBEFA tool was used. The HBEFA tool, developed by many different transport institutes such as the Swiss Federal Laboratories for Materials Science and Technology, Institut für Energie- und Umweltforschung, the Joint Research Centre of the European Commission, TU Graz Austria, Statistics Norway, TNO NL and more, is created to combine traffic data and emission data in one tool and use the different techniques for the six countries. This tool can calculate the emission factors of many different pollutants and includes different vehicle categories including Light Commercial Vehicles (LCV's) such as delivery vans and Heavy Good Vehicles (HGV's). This tool offers the opportunity to create the emission factors for specific traffic situations including an average traffic situation in the selected country. The emission factors for this tool are created from the energy consumption (EC) factors calculated in the HBEFA tool using the average traffic situations. These factors display the energy (MJ) needed per vehicle type for the different road types (urban, rural and highway) for an average traffic situation, including average traffic, speed, stop and go and gradients for the six countries available in HBEFA. These energy consumption factors were then multiplied with the specific fuel emission factors (EF) from the new ISO 14083 standard on calculating emissions. This results in emission factors specific to the vehicle type, weight of shipment, road type and fuel used.

The accuracy of the EC from HBEFA depends on the data used by HBEFA and the inputs used. First of all the data in HBEFA is based on the specific vehicle types and the different EURO-classes making the data very accurate. Second, only the hot emission factors were used. Hot emission factors relate to the emissions of a vehicle once the engine is hot. When the engine is started is the engine is cold, excess emissions are released due to the cold temperature of the engine and starting the engine. These cold emissions are not taken into account as these depend on the trip length, the time of parking and surrounding temperature specific for each trip (Benedikt Notter, 2022). Third, the data of HBEFA is based on the data from the six countries, Austria, Germany, Norway, Sweden, Switzerland and France, this is not the same as the average of Europe. However no data could be found that is more accurate than the HBEFA values, this is therefore used as the average data for Europe.

A detailed description on how HBEFA is used to determine the energy consumption factors is added in Appendix B.

Verification

In order to verify the architecture of the decision support tool, the different elements of the tool have been walked through, the requirements have been used to see if all of them are featured in the preliminary design. The needed outcome of the tool was used to check if the elements produce the right output.

2.3 Critical Design Phase

The critical design phase existed out of the actual building of the tool and deciding on the layout. The building phase included deciding on the final list of questions asked as input of the tool, where the company need to fill in their transport data. Building the tool also meant to engineer and encode the emission calculation model, engineer the abatement curve and decide on the visual output of the results of the tool. During this phase, the tool in Excel was tested on a weekly basis to ensure that it met the requirements and that the calculations in the tool worked correctly.

The questions that were created as the input of the tool needed to meet the demands of the user and be useful in the emission calculation. The user interface of these questions has also been determined based on the interviews, being it a requirement of the system. Building the emission calculation of the current situations and the actions, a function of

the tool, included determining the emission reduction potential of the different actions. This was used as the outcome of the tool. Comparing these actions was done in the abatement curve, here the different elements of decision making of companies, reduction potential and costs, have been mapped against each other.

After completing the design and validating the emission calculation method, the tool was build. During this phase there was also contact with the platform provider of SFBA to eventually implement the tool on the platform of the SFBA initiative.

2.4 Integration and Test Phase

In this part the created tool was put to the test. First the different subsystems were checked, validating the different formulas used in the tool. By implementing company specific data into the different elements of the tool, the working of the tool was checked. The company specific data, entered as input to the tool, was changed multiple times to ensure the working principle of the tool. The different formulas in the tool were also walked through and the units were checked to see if the calculations were correct. After this first validation, the tool was verified using the requirements.

The second verification was done by three employees of Smart Freight Centre. Two of them work on the SFBA initiative and one was not involved with SFBA. This verification was done based on the success scenario and a small list of questions regarding the ease of using the tool and the clarity of the explanations and the different steps in the tool. The validation was based on the working principle of the tool, it was asked if the tool worked correctly and whether there were no errors during testing. The feedback from this verification round was then used to improve the tool. After the improvements the tool was again validated against the requirements.

A third set of validation and verification was done by two other employees of SFC and an associated consultant. This last validation also included verifying the needs and demands of the commissioner of the tool. The improvements that were found during this round of validation were taken into account for further research / improvements of the tool.

During this phase also a sensitivity analysis was performed to examine the effect of the uncertainties of the different parameters used. The different parameters in the tool were varied and the effect on the outcome was analyzed.

2.5 Release / Production Phase

As this thesis was focused on building a prototype of the information tool for shippers, the outcome of the Integration and Test phase was the prototype of this tool. After the implementation of the last feedback the complete tool was checked against the requirements and the file of the tool was cleaned and the file was eventually protected. During this phase an accompanying explanation document was created that explained the working principle of the tool, the origin of the data used in the tool and the uncertainties of the tool. Also a maintenance document was written to help the employees of SFC to maintain the tool. A short introduction of the information tool was created to explain the usefulness of the tool to the SFBA initiative. The information tool, the explanation document, the maintenance document and the addition to the SFBA initiative explanation were then released to SFC.

3 Literature Research

In this chapter the different literature studies performed in this research are shown. In the concept phase, a literature study took place on the state of the art of road freight emission reduction tools and initiatives, the results of this literature study can be found in Section 3.1. In this section also the current regulations regarding road freight emission have been researched. Related to the state of the art is the study on freight emissions, Section 3.2, explaining the different aspects regarding freight emission reporting and the difference between well-to-wheel emissions, tank-to-wheel and well-to-tank. In the preliminary design phase a literature study has been done on the different actions that can reduce emissions in road freight transport. This study was performed with the goal of deciding on the actions that will be available in the information tool and the data belonging to these actions being the reduction potential and the corresponding cost. With this also the cost structure of the current scenario was researched in this section, Section 3.3. Determining the emission calculation methods was also part of the preliminary design phase and a literature search was done to determine this methods, Section 3.4. Part of the emission calculation research was on the needed parameters for these formula's, energy consumption factors, emission factors and the effect of different aspects of a trip on emissions. A method to determine the increase of cost per trip from the total investment needed for an action is proposed in Section 3.5.

3.1 State of the Art

Looking into the state of the art of emission reduction in transport, a lot of literature and grey literature can be found. As road transport is one of the main polluters, different solutions for freight and passenger transport are available with the goal of keeping global warming below the 2 degrees Celsius of warming (United Nations Climate Change, n.d.-b). There are already rules and regulations for the reduction of GHG emissions, these and the possible future regulations are discussed below.

3.1.1 Rules and regulation

At this point in time only the Kyoto protocol and the Paris agreement are worldwide agreements that are related to reducing GHG emissions. The Kyoto protocol means that industrialized countries commit to reducing emissions, in a later commitment period a certain amount of reduction per country was recorded and extra means to meet the targets were laid down (United Nations Climate Change, n.d.-c). At the Conference Of the Parties (COP), the countries participating gather, they review and discuss the progress of the implementations made by the parties of the convention (United Nations Climate Change, n.d.-a). The parties to the Kyoto protocol, the Paris agreement and the COP are required to calculate and report emissions of countries and companies in order to be able to track emissions. The European standard EN16258 was designed with the purpose of guiding countries and companies in the calculation and reporting process. This standard turned out not to be clear enough to make sure calculating and reporting was done in the same way and more guidance was needed. In the mean time, other institutions provided more detailed methods for calculating and reporting, one of these being the GLEC Framework, design by SFC. In 2019 the project for a new ISO standard for calculating and reporting emissions was introduced, this standard is more complete and provides the guidance needed for countries and companies to calculate and report emission in a unified way. The ISO standard is based on the existing GLEC framework and is called ISO 14083 "Quantification and reporting of greenhouse gas emissions of transport operations". It will replace the European standard EN16258 and will be presented at the end of 2022 (Smart Freight Centre, n.d.-a).

Carbon cost

In order to make users pay for the damage to the climate caused by GHG emissions that are released in transport, a carbon tax or emission trading system can be used. This cost of carbon will automatically have an effect on the amount of carbon-based fuels used because of the principle of price elasticity. Therefore these methods can be used to reduce emissions (European Commission, n.d.-b).

An Emission Trading System (ETS) works with permits to emit a fixed amount of carbon. The permits can be bought or received by the companies that are submitted to the ETS, if a company needs more permits it can buy permits from other companies that do not use their full received or bought amount of carbon emissions (European Commission, n.d.-b). Currently there are multiple ETS active in different parts of the world; the EU, Canada, China, Japan, New Zealand, South Korea, Switzerland and the United States (The World Bank, 2022). At this moment, the European ETS and a carbon tax are both implemented in the EU. The EU ETS is implemented in all EU countries and Iceland, Liechtenstein and Norway (European Commission, n.d.-b), however this does not include transport emissions yet. From 2026 road freight transport emissions will be included in the current ETS or a separate ETS will be created. The price of carbon taxes and ETS is being tracked in the Carbon Pricing Dashboard developed by the World Bank (The World Bank, 2022). A big difference between a carbon tax and carbon pricing is that a carbon tax is a fixed amount that can be adjusted only once or a couple of times a year, ETS on the other hand is dynamically priced. This means that the price differs at the demand of the product. For the EU ETS, without transport, the price was almost €100 per tonne at the highest in August 2022 and is

now back to around €80 per tonne (Trading Economics, n.d.). Germany, that already implemented an ETS for transport emissions, started with €25 per tonne (Basma et al., 2021) but the price is expected to increase in the coming years. Trading Economics (n.d.) also collects data on the cost of a carbon permit and displays the cost of a permit per day on its website.

A carbon tax is a price per metric tonne CO_2e emitted. The carbon tax has only been implemented by some countries and only for specific gasses (Bray, 2022). Bray (2022) created a map of Europe including the cost of the carbon tax per country, the data comes from The World Bank (2022). Countries or regions can decide for which sectors this tax will be implemented and to which exhaust gases this applies. Countries can therefore also use a carbon tax to only put a price on different types of GHG emissions (Bray, 2022), for example only on fluorinated gasses or methane.

When the price of the carbon tax and / or the price of the permits in the ETS system is high, it becomes profitable for companies to switch to lower or non-carbon fuels and more efficient vehicles. The carbon tax and carbon pricing can therefore play a big part in the drive for companies to invest in more sustainable forms of road transportation. However, carbon cost also have a societal aspect. The price of carbon influences the cost of many products that are used daily by all layers of society. Because the carbon tax in the country of origin and the price per permit make up the total cost of carbon, this price can be used in the calculations to determine the cost or benefit of an emission reducing alternative or adjustment. This explains why some companies use a carbon tax internally to create business cases for sustainability investments, using the carbon cost as a monetary incentive (A. McKinnon, 2018). It is expected that the price of the permits in the EU ETS, when transport is added from 2026, and the country specific carbon tax will go up in the coming years.

3.1.2 Existing tools

As mentioned in Section 1.1, there are already different tools available regarding decarbonizing road freight logistics. Most of these tools focus on helping companies with their emission calculation and reporting. With this first step, insight is created in the amount of emissions that are produced with the business of companies. It also creates an overview of the areas that emit the most. These tools are based on the scope 1, scope 2 and scope 3 emissions that occur different sections of a company, see Section 3.2. Other existing tools that look into reducing road freight emissions mostly focus on only one action, for example modal switch. They are created to show the user what a switch of mode will do with the emissions associated with that route. An overview of the existing tools and models will be given below, in Table 1.

The transport climate action directory of the International Transport Forum (ITF) provides the user with an overview of mitigation measures for passenger as well as freight transport and also includes all modes. The information for these measures exist out of CO_2 impact, costs and other benefits and considerations. This tool lacks measurements for road freight transport that need collaboration, only one of such an action is present in this directory (International Transport Forum, n.d.). The toolkit from the Global Fuel Economy Initiative exists out of information on policies, different vehicle types and includes resources such as baseline calculations and links to other tools. This toolkit gathered different tools and created an overview, impacts from policies can be estimated by making use of the Fuel Economy Policies Impact Tool, VECTO is linked to simulate CO_2 emissions for HDV and the ITF directory is also linked to this toolkit. This toolkit lacks (links to) information on different emission reducing actions, the different tools can be used to find some information but no tool offers an overview of different actions (Global Fuel Economy Initiative, n.d.). The VECTO tool of the European Commission can be used for determining CO_2 emissions and fuel consumption from HDV's over 3500kg. As this is a simulation tool of emissions, this tool can be used to see the impact of actions, these actions are not implemented so the impact must be simulated manually (European Commission, n.d.-g). It lacks practical comparisons between different actions. The GLEC Framework guides companies through emission calculation and reporting, as mentioned it also includes a chapter on emission reduction possibilities, however this lacks information on costs and reduction potential of these possibilities (Lewis & Greene, 2019). The emission calculator of EcoTransIT shows companies different mode options for their transport routes with information on corresponding emissions (EcoTransIT, n.d.). This tool is focused on mode switch and does not include information on other emission reducing actions, lacking overview of different actions and their potential. Greenrouter also offers a tool that calculated emission reduction of actions, however this tool lacks information on the cost associated with these actions (Greenrouter, n.d.). Pledge, Tracks, Smartway, BigMile, ECOEMISSION, the Logistics Emissions Calculator and LEARN all offer methods to calculate or measure and report emission of transport, the Ref Assessment Tool offers a method for measuring and reporting emissions of logistics sites. All these tools lack information on emission reducing actions. The calculator tool from the Department of Energy & Climate Change in the UK shows the energy pathway for the UK. It is possible to adjust the model in 42 sectors and see the impact on emissions, this is done on a country level and cannot be used to determine emissions and the impact on emission of companies and lacks this feature (Department of Energy & Climate Change, n.d.). The SRF optimizer of The Centre for Sustainable Road Freight is a tool that calculates emissions and energy consumption of road freight. This tool also takes into account the cost of transport and the effect of carbon reducing solutions of transport (The Centre for Sustainable Road Freight, n.d.). This tool lacks in simplicity by asking very detailed information from user.

Table 1: Existing tools

Name	Lacks	T O O L	I N F O	C A L C U L A T E	R E P O R T	T A R G E T S	O T H E R
Transport climate action directory (International Transport Forum, n.d.)	Has very few mitigation measures for road freight transport, only 1 solution that needs collaboration		X				
Truck Ecodriving Toolkit (Jattin & Sehleier, 2020)	More mitigation measures		X				
The Global Fuel Economy Initiative toolkit (Global Fuel Economy Initiative, n.d.)	Information on reduction possibilities	X	X				
Vecto (European Commission, n.d.-g)	Practical comparisons between actions	X					
GLEC (Lewis & Greene, 2019)	Information about reduction possibilities, other than an overview of the possibilities			X			
Emission calculator (EcoTransIT, n.d.)	Only offers mode switch solutions, no other road specific options	X		X			
AMBITIOUS CORPORATE CLIMATE ACTION (Science Based Targets, n.d.) (Science Based Targets)	No specific solution information					X	
LEARN (Logistics Emissions Accounting & Reduction Network, n.d.)	Information about reduction possibilities				X		
European Matchmaking Platform (Entrance, n.d.)	No information on solutions, only offers platform to collaborate						X
The logistics Emissions Calculator (BearingPoint, n.d.)	Information about reduction possibilities			X	X		
Reff Assessment Tool (Fraunhofer, n.d.)	Focussed on logistics site, no information on emission reducing solutions				X		
TK Blue (TKBlue, n.d.)	Compares existing carriers, does not provide information on emission reducing solutions				X		
Bigmile (BigMile, n.d.)	No specific solution information			X			
ECOEMISSION (Via Green Institute, n.d.)	No specific solution information			X			
Greenrouter (Greenrouter, n.d.)	Includes a few solutions and their emission reduction potential, no cost analysis	X					
Pledge (Pledge, n.d.)	No specific solution information				X		
Tracks (Tracks, n.d.)	No specific solution information				X		
Smartway (EPA, n.d.)	No specific solution information				X		
Calculator Tool (Department of Energy & Climate Change, n.d.)	Information on all sectors in the UK, not only road and no specific solutions	X	X				
SRF optimizer (The Centre for Sustainable Road Freight, n.d.)	Needs very detailed information from user, emission calculations are based on DEFRA carbon emission factors 2015	X					

3.2 Freight emissions

Reporting emissions and understanding where they come from is the first step in reducing them. By reporting emissions a company gains insights in their emissions and the different parts of the company where they are generated (The Carbon Trust, 2020). In the Greenhouse Gas Protocol three different scopes are determined, called scope 1, scope 2 and scope 3. The GLEC framework, which helps companies report their emissions in a standardized way, contains Figure 8 to explain the different scopes of emissions to users of the framework.

Scopes of Logistics Emissions Accounting

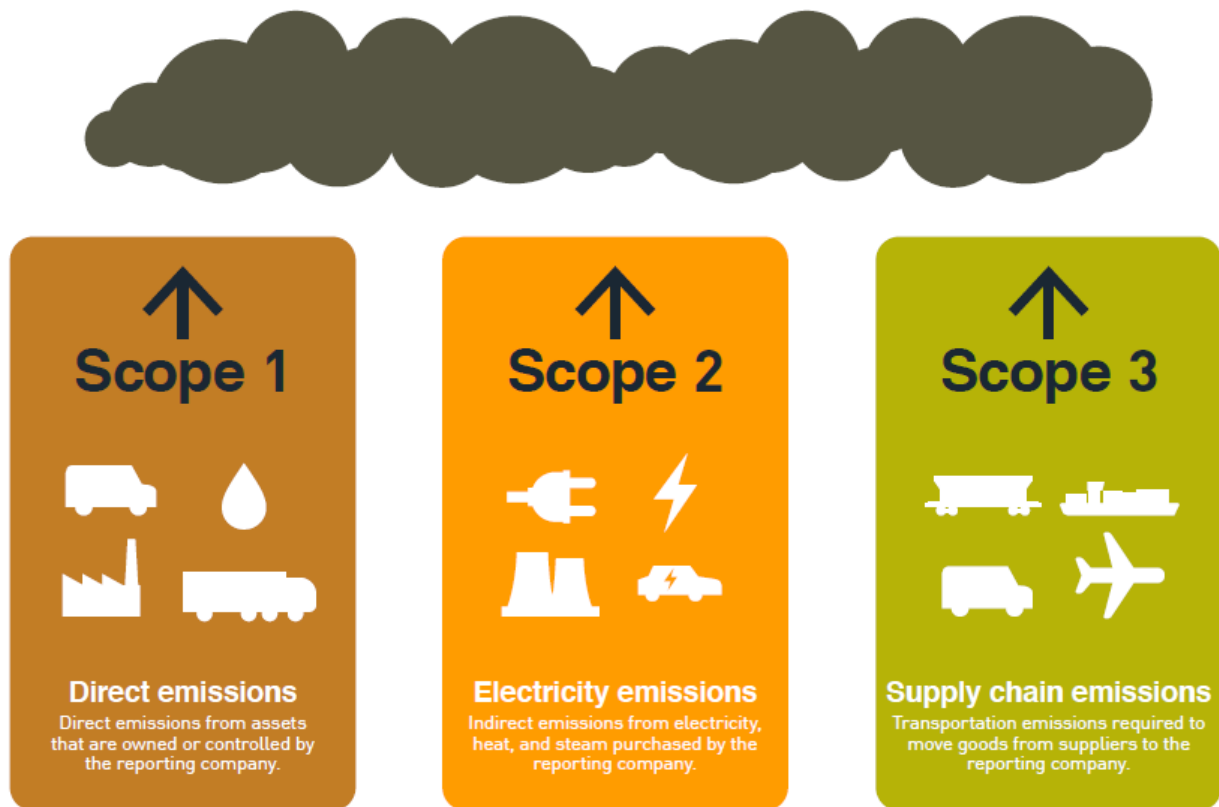


Figure 8: Different scopes of emissions (Lewis & Greene, 2019)

Scope 1: Direct emissions includes all the emissions that are related to the core business of the company. Emissions from the factories and the trucks and vans that are owned by the company but also the emissions from the boiler that heats the water etcetera.

Scope 2: Electricity emissions exists out of all the emissions that are generated for the needed electricity and gas needed for the company, this includes the energy need for offices.

Scope 3: Supply chain emissions which consist out of the emissions related to all the transport that is outsourced to other companies. This covers incoming goods, such as raw materials, as well as outgoing products. It also refers to travels from employees, trips and commuting to and from work. Waste disposal is another example of scope 3 emissions.

When the emissions are reported, all three scopes need to be calculated. Important to note is that scope 3 emissions are scope 1 emissions of another company.

Reducing emissions

For reducing emissions the options differ per scope. To reduce scope 1 emissions, less energy should be consumed. Another option is to replace products with new ones that are more energy efficient, for example other light bulbs. Scope 2 emissions can also be reduced when a more sustainable kind of energy is purchased. Companies can also consider to generate energy themselves by for example installing solar panels. Scope 3 reduction need to take place at a third party organization outside of own operations, engaging these suppliers to reduce their emissions can be a way to bring scope 3 emissions down. With scope 3 mostly relating to transport needed in a supply chain, an overview of solutions to reduce

emissions has been provided in the GLEC Framework, Figure 4. This can of course also be used to reduce emissions when a company has an own fleet and does not outsource transport.

CO_2 equivalent

With greenhouse gas existing out of different gasses that have an impact on global warming and climate change, a simplification has been created to make it easier to compare the emissions of different solutions or companies. Because GHG emissions for logistics consist mostly out of CO_2 this simplification is called the CO_2 equivalent, usually shown as CO_{2eq} or CO_{2e} . The CO_2 equivalent takes into account the effects of the different gasses that differ in environmental impact and duration of time in atmosphere (MyClimate, n.d.), their global-warming potential. This is converted in the equivalent amount of carbon dioxide with the same effect to the environment (Eurostat, n.d.-a). The different gasses that are part of the CO_{2eq} and contribute to global warming according to the Kyoto Protocol are CO_2 , N_2O , CH_4 and the gasses that contain fluorine (CBS, n.d.) ($HFCs$, $PFCs$, SF_6 and NF_3 (Eurostat, n.d.-b)).

Emission analysis

Emissions can be described in three different ways quantifying the impact of burning fuel. The three different types are Well-To-Wheel (WTW), Well-To-Tank (WTT) and Tank-To-Wheel (TTW), where $WTW = WTT + TTW$. The well-to-wheel factors include all the emissions in the complete cycle of fuels, from mining the raw materials to burning the fuel in vehicles. The three analysis methods are useful in different situations and can be used to evaluate the process of fuel production and distribution or the energy efficiency of vehicles. Together it includes all losses among the fuel life cycle, providing insights in the complete efficiency of different fuels, making is easier to compare. The WTT emission factors of the different fuels depend not only on the carbon content of the fuel but also on the mining process and the production process. Next to fuel specific effects, the distribution of fuel to gas stations including possible losses while fuelling the pump or the vehicle are also included in the WTT numbers. The TTW emission factors take into account the basic engine efficiency that differs per fuel and the emissions of fuel consumption for driving as well as other appliances such as air-conditioning. In Figure 9 the complete WTW cycle is shown, also divided into WTT and TTW. Next to the WTT and TTW wheel division it is indicated where in the process CO_2 is emitted. The energy efficiency and thus the effect on the WTW numbers depend on the fuel and engine. In Section 3.3.4, it can be seen that although electric vehicles and hydrogen vehicles both make use of electricity, the WTW factors are different. This is dependent on the energy efficiency of the hydrogen production and the energy efficiency of the conversion of hydrogen in the engine.

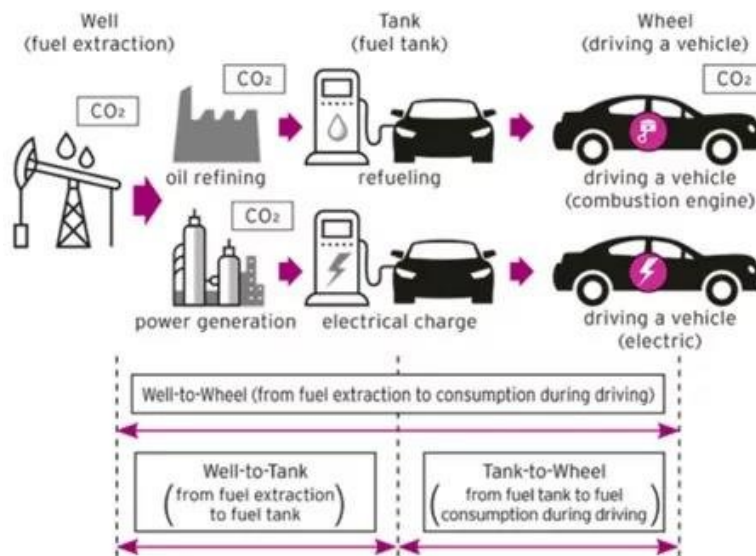


Figure 9: Well-To-Wheel analysis (Kleebinder, 2019)

3.3 Actions

This research focuses on road freight transport in Europe and on the collaboration between shippers and carriers. This is central in SFBA and thus actions must be based on cooperation. In the first part of this section, every pillar of the overview from A. McKinnon (2018), Figure 4, will be elaborated on and the different actions will be explained. It will also be explained which actions are and which are not included in the tool. In the second part, the chosen actions will be further discussed and their emission reduction potential as well as their corresponding cost will be studied. The chosen actions are divided into three categories, increasing the load of trips, decreasing the fuel use of trips and changing the energy source used for a trip. The sections on emission reduction potential and costs are arranged in these three

categories.

3.3.1 Action overview

The 5 pillars from A. McKinnon (2018) all contain several actions that can reduce freight transport emissions. In this paragraph the effects of these actions and possibility to include the actions in the tool are studied.

Reducing freight demand can be done in different ways, first the amount of trips can be decreased. This can be done either by decreasing the amount of goods that need to be transported, by decreasing the metric volume of the goods that need to be transported, by increasing the truck size or by changing the supply chain. By restructuring a supply chain, the distances between locations can be made shorter, reducing the amount of kilometres needed to transport the goods. It can also entail changing the modality of the transport, impacting the emissions of the transport. Another possibility is changing the shipping module size or box size. This would make the trucks, containers or ships easier to fill and also give back lost space when packaging is better sized related to the product. By 3D printing products or parts, the supply chain is partially shortened and located closer to the final destination, reducing weight shipped, kilometers as well as volume. This creates the opportunity to only ship the material needed for the printers, making the volume easier to handle. In the book of Alan McKinnon, *Decarbonizing Logistics*, different dematerializing processes are described: waste minimization, recycling, digitization, miniaturization, Material substitution, additive manufacturing (3D printing) and postponement (A. McKinnon, 2018). These processes are focused on using less materials, this will not only reduce pollution caused by these materials but have an effect on the complete production. The superfluous material does not have to be produced thus resulting in less emissions and pollution, the material does not have to be shipped to the company previously using the material and to the customer, reducing volume and weight twice. As it also does not have to be disposed of, it makes dematerialization one of the most effective methods to reduce emissions. Consumer behaviour relates to this, it can also have an effect on the amount of product used, the wishes of customers related to shipping and packaging methods and the need to purchase. If products are made to last longer or if consumers spend longer with products, the amount of product needed will also decrease.

Reducing freight demand is related to different aspects of transport. First there is the amount of goods that need transportation that can be influenced. The goods are packaged and the size of the boxes, and more specifically the empty volume in the box, impacts the total metric volume that need to be transported. With standardized modules and boxes the amount of empty volume in the transported boxes can be reduced or increased, depending on the different sizes available. The more different sizes for the standardized boxes, the more difficult it is to deliver the shipment in well fitted manner without useless air in between. The next aspect of transport is the weight of the shipments, vehicles have a weight restriction which can result in a heavy truck that is half empty. To reduce the weight of shipments, dematerialization and 3D printing can be applied.

Optimizing freight transport modes relates to the actual shipping of products. With modal shift being one of the most well-known possibilities to bring emissions down. By changing the modality to a less polluting one, emissions could decrease. This can have an effect on the different properties of delivery such as lead time or delivery time thus making trade-offs necessary but can also have an effect on the cost. Multi-modal optimization is related to modal shift but taking into account longer routes that require multiple modes and also switching modes somewhere in the route. Synchromodality is multi-modal optimization in its flexible form. By booking a route mode-free the logistic service provider or freight forwarder can choose the modality or multi-modality to provide the best option for that specific shipment (Pfoser et al., 2016). This can result in a longer distance that is travelled by the shipment, sometimes also resulting in a longer delivery time, while emissions go down. Synchromodality is often used in combination with load consolidation.

Increasing asset utilization is maybe the easiest and least intrusive form of emissions reduction. By optimizing the load, fuller trucks or with the help of standardized modules, the amount of trips can be reduced. With load consolidation different shipments, possibly from different shippers, are combined by the consolidator into one shipment, making more efficient use of a container, truck or trip. Logistics centers and warehouse management can be related to supply chain restructuring if the centers or warehouses change locations but can also contain more efficient logistics inside those locations. Reducing emissions is not only restricted to transport but also contains all energy used on site and for logistics on location such as a warehouse.

By **improving the energy efficiency** of the fleet, the same distance can be covered with less fuel. With the help of cleaner and efficient technologies, existing vehicles can be adjusted and made more energy efficient reducing the amount of fuel needed. Efficient vehicles and vessels also make use of new technologies but these are implemented in newly produces vehicles. These contain an improvement with regard to conventional vehicles, such as rear view camera's instead of mirrors. These adjustments can reduce the amount of fuel needed for trip but do have extra costs compared to conventional vehicles. Driving behaviour can also impact the energy efficiency: if drivers have more knowledge about sustainable and efficient driving, the amount of fuel needed can again be reduced.

Fleet operation can help reduce emissions if it is done in the right way. By managing the assets in a way that the cleanest and most efficient vehicles are used the most, a small change can already be made. Also other aspects such as driving

monitoring and licensing compliance are part of fleet operations. Fleet maintenance is one of the most important aspects of fleet operation. Due to good and in time maintenance, especially on the engines, a fleet can be more efficient as well as cleaner.

Reducing carbon content of energy has to do with the fuel that is being used. By switching to cleaner and lower carbon fuels, the amount of emissions can go down. Examples are bio-diesel and bio-ethanol from various feed stocks. In order to use these fuels, an adjustment to the existing engines must be done in order for engines to work correctly. Depending on the kind of fuel used this adjustment can be expensive or low cost. Electrification is another possibility for alternative fuels. This does require new vehicles and other charging infrastructure and is therefore quite expensive. The amount of emission reduction for this option relies mostly on the energy source chosen to charge the vehicles. Lastly fuel management can also help bring emissions from fuel use down. By mixing the right fuels together, for example fossil diesel and bio-diesel, a cleaner and efficient fuel can be produced. In addition, often no to very little changes need to be made to the vehicles.

As the emission reducing solutions must need collaboration between shipper and carrier to make progress. The solutions that were not taken into account are:

Supply chain restructuring, this must be decided only by the shipper. Also this solution can have an impact on the mode of transport, where this study only focuses on road transport. 3D printing and consumer behaviour, the impact of these solutions differ a lot between sectors and are therefore hard to generalize in this tool. Also no collaboration is needed because this is only a shippers decision. Dematerializing is also not taken into account. Where some of the options can be implemented by every company, shipper or carrier, others are only applicable to particular sectors. All of these options have in common that no collaboration takes place in implementing these solutions, therefore this is not taken into account in this study. The complete Optimize Freight Transport Modes pillar is not taken into account because this implicates more modes than road, which is not the scope of this research. For the same reason the solution Logistics center & warehouse management is not taken into account, the location of warehouses and logistics sites is a shippers choice and it can effect the modes used to transport the goods. Fleet maintenance can have an impact on the amount of fuel needed for a trip. Because the maintenance of a fleet is up to the carrier and no collaboration is needed for better maintenance, this is not included in this study.

The actions that are taken into account are shown in Table 2.

Table 2: Actions included in information tool

Increase load	Decrease fuel use	Changing energy source
Load optimization	Cleaner & efficient technologies	Cleaner & lower carbon fuels
Load consolidation	Efficient vehicles	Electrification
Standardized modules & boxes	Driving behaviour	Hydrogen
	Fuel management	
	Fleet operation	

3.3.2 Increase load

The average filling rate of trucks in the EU depends on the size of the truck. Sacchi et al. (2021) uses the survey data of TRACCS and found that for LCV's the average European filling rate is around 60%, for heavier trucks this decreases to 41% and even 36% for the most heavy duty trucks, leaving room for improvement. The load factor does not only depend on the weight of the shipment but also on the volume, both are restricted by the properties of the vehicle. The characteristics of the goods have an effect on the conditions under which they are transported and can also limit the available space in the truck, for example the possibility to double stack for fragile goods or combining loads for refrigerated transport. With increasing the load factor, these different aspects must be taken into account. With this in mind, when trucks increase their load factor, the emissions and cost per unit per kilometer go down, resulting in a positive effect for reducing emissions as well as cost. Many different solutions are available that can increase the load or decrease the size of a shipment.

Load optimization

The average load of vehicles also differ per country and depends on the logistics method used by the company for inventory control. In the past years the load factor has gone up and empty running has gone down to around 30% (Logistics UK, 2022). This indicates that companies are already looking into this method of emission reduction. As load optimization is closely associated with lead time and amount of storage, this also impacts the purchase and delivery strategy of companies.

Methods to increase load optimization are next to changing shipping strategy also load consolidation and standardized boxes and modules. All three methods have in common that they increase the load factor. There are a lot of interventions in these categories that resemble and/or influence each other, because all actions are interlinked, determining which action

belongs to which method is very complex. All solutions increase the load factor of shipments and hereby decrease emissions and cost. Load consolidation, combined transport of multiple Less-than-Truckload (LTL) shipments, results in more kilometers driven per shipments but less distance travelled in total if all trips were handled separately. Standardized boxes and modules can help organize shipments better, leaving more room for extra parcels. However, introducing different and/of more box sizes will also cost money. It is only useful if there are actually more parcels shipped per shipment, increasing the load factor. Punte et al. (2019) indicates that load optimization can decrease emission between 10- 20%.

Load optimization is dependent on the logistic method for inventory control, if a company has chosen for Just-In-Time delivery, increasing the load will also change the method for inventory control as shipments are bigger. This results in extra costs later in the supply chain as more space in warehouses is needed to accommodate the larger shipments.

Load consolidation

Load consolidation, sharing transport for Less-Than-Truckloads (LTL), is an option to increase the load factor and decrease amount of trips as LTL shipments are first transported to a hub and from there transported together to their final, or intermediate, destination. American Council for an Energy-Efficient Economy (2021) wrote a tropic brief on maximizing truck loads and researched different solutions, one of them being load sharing. With a net reduction of miles up until 51% and a maximum cost reduction of 20%, this is a significant reduction of emissions as well as cost. Horizontal collaboration, a form of load consolidation, also reduces emissions as well as cost. In A. McKinnon (2021) it is mentioned that it can reduce cost with 7-9% while reducing CO_2 emissions with 5-10%. In Punte et al. (2019) many different options are mentioned to consolidate load and share assets, it is indicated that reduction can go up to 20% depending on the consolidation method chosen.

Standardized modules and boxes

By implementing standardized modules and boxes the utilization of vehicle efficiency is increased, resulting in a higher load in the truck (Ahmad et al., 2022). Standardized modules or units can also increase loading efficiency and hereby decreasing handling cost, creating opportunities for load consolidation. Kye et al. (2013) explains that Packaging Logistics (PL) exist out of four different factors, box modularity, palletization, returnable system and an information system. From these, the first and second, modularity and palletization can increase the load factor and are taken into account as part of standardized modules and boxes.

The cost reduction exist out of packaging cost reduction, material cost and material handling cost, and transportation cost reduction (Salenborg et al., 2020). Salenborg et al. (2020) also included the environmental impact in their research, this was based on the amount of vehicles required and the amount of tonne-km driven. Introducing a new packaging strategy also brings along cost, limiting the total cost reductions to 8%. The emission reduction potential is much higher up until 31%.

Ahmad et al. (2022) looked into the existing research available on standardized modules and boxes and the effect on emissions and cost. Many papers are reviewed in this research and all agree that emissions as well as cost go down with a higher fill rate and a higher load efficiency. However, no paper provides information on the actual reduction of standardized boxes. García-Arca et al. (2020) looked into the impact of palletization and also concludes that next to cardboard reduction, the volume reduction of packages was significant, up to 19%. The volume reduction of palletization is between 5-32% creating space for 6-62% more parcels depending on the box chosen. The overall logistics savings in this study was over €120.000 per year. Liljestrand (2016) evaluated the effect of different actions improving freight density. They found that the use of High-Capacity Vehicles (HCV) can decrease emissions with 7-15% (Leach et al., 2013) and Double stacking in vehicles can reduce emissions up to 23%. The cost of transport can respectively go down with 5-11% and 8-28%. Double stacking can be a useful solution if floor space in trucks is limiting the load factor. It relies on different ways of packaging, which provides protection against damage from stacking, therefore this action is included in this solution.

3.3.3 Decrease fuel use

When the energy efficiency (TTW) increases, the amount of fuel needed for a trip decreases. This reduces emissions and saves in fuel costs. Many different solutions can help increase the TTW energy efficiency. Cleaner and efficient technologies are solutions that can be implemented on existing vehicles, called retrofitting. Efficient vehicles are solutions that are included in newer vehicles and need to be installed when the vehicle is produced. The owner can often choose between different properties of the vehicle, these differences, their costs and reduction potential, are discussed within the Efficient Vehicles solution. Driving behaviour and eco-driving also impact the TTW energy efficiency as stop-and-go and accelerating are two moments when emissions increase. Fuel management and fleet operation are both solutions that are related to the trip and the vehicle choice, both can be deployed in ways that result in more sustainable transport.

Cleaner and efficient technologies

In the study from TNO in collaboration with TU Graz, CE Delft and the ICCT (European Commission and Directorate-General for Climate Action, 2018) different solutions have been discussed, some of these can be implemented on existing vehicles, retrofitting these vehicles. The main solutions from this study that fall under "Cleaner and Efficient Technologies" are tire pressure management and low resistance tires. In the TNO research, both tire pressure and low resistance tires have been researched, the following solutions have been determined:

Tires

- Low rolling resistance tires on truck/tractor
- Low rolling resistance tires on truck/tractor + trailer
- Tire pressure monitoring system (TPMS) on truck
- Tire pressure monitoring system (TPMS) on truck and trailer
- Automated tire inflation system (ATIS) on truck
- Automated tire inflation system (ATIS) on truck and trailer
- Wide base single tires

Both the emission reduction of the solutions as their associated cost are displayed in Table 3. The vehicle groups mentioned in this table differ in configuration. Vehicle group 4 is a rigid truck (RT) > 16 t, vehicle group 5 is a tractor trailer (TT) > 16t, vehicle group 9 is a rigid truck for heavier weight and vehicle group 10 is a tractor trailer for heavier weights. All vehicles are used for long haul delivery and regional delivery. The difference between a rigid truck and tractor trailer is the setup of the vehicle, a rigid truck is fixed to the container where as the tractor trailer tows the trailer behind the tractor.

Table 3: Cleaner and efficient technologies

CO₂ reducing technologies	TNO-2018-R10214	Vehicle group 4		Vehicle group 5		Vehicle group 9		Vehicle group 10	
<u>Tyres</u>	<u>TNO code</u>	%	€	%	€	%	€	%	€
Low rolling resistance tyres on truck/tractor	TYRES1	-6,10	140,00	-5,10	350,00	-6,40	210,00	-5,20	420,00
Low rolling resistance tyres on truck/tractor + trailer	TYRES2	-	-	-8,50	350,00	-	-	-8,50	420,00
Tyre pressure monitoring system (TPMS) on truck	TYRES3	-1,20	140,00	-1,90	350,00	-1,40	210,00	-2,00	420,00
Tyre pressure monitoring system (TPMS) on truck and trailer	TYRES4	-	-	-2,00	350,00	-	-	-2,10	420,00
Automated tyre inflation system (ATIS) on truck	TYRES5	-1,20	1.080,00	-1,90	1.080,00	-1,40	1.080,00	-2,00	1.080,00
Automated tyre inflation system (ATIS) on truck and trailer	TYRES6	-	-	-2,00	1.350,00	-	-	-2,10	1.350,00
Wide base single tyres	TYRES7	-1,20	-35,00	-1,9	-70,00	-1,40	-35,00	-2,00	-70,00

As tires can be replaced on existing vehicles, this solution belongs to cleaner and efficient technologies. The cost shown in the table are the total investment cost.

Efficient vehicles

The different actions that are related to efficient vehicles that are researched by TNO in combination with TU Graz, CE Delft and ICCT are (Verbeek et al., 2018):

Aerodynamics

- Roof spoiler plus side flaps
- Side and underbody panel at truck chassis
- Aerodynamic mud flaps
- Rear/side view cameras instead of mirrors
- Redesign, longer and rounded vehicle front
- Side and underbody panels at trailer chassis
- Boat tail short, additional Aerodynamics

Mass

- 5% Mass reduction (truck/tractor)
- 10% Mass reduction (truck/tractor)

Transmission

- Reduced losses (lubricants, design)
- Transition from manual to AMT

Engine

- Improved turbocharging and EGR
- Friction reduction + improved water and oil pumps
- Improved lubricants
- Waste heat recovery
- Downsizing (combined with DCT optimization)
- 10% Engine downsizing

Hybridisation

- 48V system with starter/generator
- Full electric hybrid

Table 4: Efficient vehicle solutions

CO2 reducing technologies	TNO-2018-R10214	Vehicle group 4		Vehicle group 5		Vehicle group 9		Vehicle group 10	
	TNO code	%	€	%	€	%	€	%	€
Aerodynamics									
Roof spoiler plus side flaps	AERO1	0,00	2.000,00	-2,20	2.000,00	0,00	2.000,00	-2,10	2.000,00
Side and underbody panel at truck chassis	AERO2	-1,40	750,00	-1,50	750,00	-1,10	750,00	-1,50	750,00
Aerodynamic mud flaps	AERO3	-3,00	1.000,00	-3,20	1.000,00	-2,40	1.000,00	-3,20	1.000,00
Rear/side view cameras instead of mirrors	AERO4	-0,80	3.078,00	-0,90	1.539,00	-0,70	3.078,00	-0,90	1.539,00
Redesign, longer and rounded vehicle front	AERO5	-0,80	40,00	-0,90	100,00	-0,70	60,00	-0,90	120,00
Side and underbody panels at trailer chassis	AERO6	-	-	-1,10	200,00	-	-	-1,10	200,00
Boat tail short, additional Aerodynamics	AERO7	-	-	-1,30	3.000,00	-	-	-1,30	3.000,00
Mass									
5% Mass reduction (truck/-tractor)	MASS1	-2,20	794,00	-3,20	1.416,00	-2,90	1.402,00	-3,30	1.416,00
10% Mass reduction (truck/-tractor)	MASS2	-3,30	1.588,00	-4,70	2.831,00	-4,50	2.805,00	-4,80	2.831,00
Transmission									
Reduced losses (lubricants, design)	TRANS1	-2,00	250,00	-2,60	250,00	-2,20	250,00	-2,80	250,00
Transition from manual to AMT	TRANS2	-2,90	2.661,00	-3,50	3.288,00	-3,10	2.661,00	-3,60	3.288,00
Engine									
Improved turbocharging and EGR	ENG1	-4,80	1.050,00	-4,80	1.050,00	-4,80	1.050,00	-4,80	1.050,00
Friction reduction + improved water and oil pumps	ENG2	-2,40	309,00	-2,40	309,00	-2,40	309,00	-2,40	309,00
Improved lubricants	ENG3	-1,20	23,00	-1,20	23,00	-1,20	23,00	-1,20	23,00
Waste heat recovery	ENG4	-2,40	5.000,00	-2,40	5.000,00	-2,40	5.000,00	-2,40	5.000,00
Downsizing (combined with DCT optimization)	ENG5	-0,20	1.250,00	-0,20	1.250,00	-0,20	1.250,00	-0,20	1.250,00
10% Engine downsizing	ENG6	-1,00	-400,00	-1,20	-640,00	-1,10	-560,00	-1,30	-700,00
Hybridisation									
48V system with starter/generator	HYBRID1	-1,70	4.184,00	-2,60	6.694,00	-2,00	5.857,00	-2,80	7.321,00
Full electric hybrid	HYBRID2	-2,50	8.367,00	-3,70	13.387,00	-3,00	11.714,00	-4,00	14.642,00

These solutions all need to be implemented when the vehicles are created as this is not possible in a later stadium. Increasing the aerodynamics from a vehicle will have an impact on the air resistance, lowering the energy consumption of a vehicle. As the air resistance relies heavily on the speed of a vehicle, this solution will have the most impact on longer distances with a higher share of motorway and thus higher speeds, it will not reduce a lot for regional delivery. Mass reduction of vehicles will also impact the energy consumption as this relies on the total weight of the vehicle. Reducing the weight will therefore decrease emissions for every trip, urban delivery, regional delivery and long haul. Losses in transmission can be reduced by lubricants in the transmission or by driving automatic instead of manually. These solutions will also reduce emissions regardless of the road type and driving conditions. The same applies to engine improvements as well as hybridisation. The emission reduction potential and associated cost are shown in Table 4, again the cost shown in the table are total investment costs for these actions.

Driving behaviour

Changing Transport created a toolbox for truck ecodriving which is focused on driving behaviour of all drivers on the road. The toolbox contains a lot of information one of which is a briefing paper called "The cost and financing options of ecodriving training programs for truck drivers" (Jattin & Sehlleier, 2020). Ecodriving, another way of driving a truck and thus changing driving behaviour, is a cost-effective solution for reducing emissions. The change in driving style results in less fuel needed to cover the same distance and thus less GHG emissions. The cost of a training in ecodriving vary based on different factors that are different per country. Also the amount of drivers taking part in a training and the duration of the training have an influence on the cost. Repeating the training can refresh the knowledge of drivers and may reduce emission even more but will also cost more than an one-time training. The training itself can be given in different formats, also influencing the price. It can be a practical training including driving or a classroom lecture, an online learning program of a simulator or a combination. The cost of a training can therefore vary between €100 and €300 per driver (Jattin & Sehlleier, 2020). The reduction that can be obtained by drivers on a trip can go up to 9.4% for heavy-duty vehicles, this ensures a payback time of less than 6 months, which can go up to 4 years for light duty vehicles because of the lower reduction potential and shorter mileage of trips (Jattin & Sehlleier, 2020). Greening et al. (2015) mentions the same cost and reduction potential for ecodriving. The reduction potential was split up according to type of delivery. For long haul delivery the reduction potential is up to 9%, urban delivery 5% while regional delivery emission reductions can be up to 7%.

Fleet operation

A fleet operator manages vehicles that are located on one site and are operated as a unit. Actions that are related to fleet operation are fuel efficiency, ecodriving, lightweight equipment (trailers), planning of vehicles and routing. As fuel efficiency from a fleet operation standpoint, fuel management and ecodriving are very intertwined, the reduction potential of these three is combined into one factor for fleet management together with routing and maintenance. Lightweight equipment, as discussed in efficient vehicles, can reduce emission for every delivery type. Reducing weight can also increase capacity of the vehicles. The planning of vehicles and renewal of the fleet is considered as fleet operation. Making the planning for a fleet relies on the capacity of the vehicles and the weight and metric volume of a shipment. This method can also be used to make the most efficient planning of vehicles with regard to emissions. Li et al. (2018) mentions the usefulness of vehicle routing to reduce emissions and also minimize cost. Kazanç et al. (2021) calculated the effect of modelling a heterogeneous fleet based on lowest emissions instead of maximized profits and found that emissions can be reduced with almost 90%, profits are also reduced with 89%. In Punte et al. (2019), fleet operation is mentioned to include routing, re-timing, de-speeding, planning of use and maintenance. All of these separate actions are expected to reduce up to 10% of emissions. Light weighting and fuel management are mentioned in this roadmap as part of cleaner and efficient technologies and also reduce up to 10%. Fleet renewal can even reduce emissions up to 20% (International Energy Agency, n.d.). The indications from Punte et al. (2019) are taken into account for the two separate actions fleet operation and fleet management based on the distribution of the different options among the two main actions.

3.3.4 Changing energy source

Changing the energy source of transport can bring GHG emissions from transport operations down to even zero depending on the fuel and production process of the fuel or electricity. However it can also require major changes to the vehicle fleet, from adjustments to the existing engine to total replacement, depending on the fuel and drive chosen. Next to the fuel used in the vehicle, there is also a more fundamental difference between fossil fuel vehicles and electric vehicles: the engine. A fossil fuelled vehicle makes use of an internal combustion engine (ICE) where fuel is burned to generate energy, an electric vehicle makes use of an electric motor where electricity is converted into energy. Because the energy efficiency of the fuel generating process, the distribution of the fuel and the energy efficiency of the engine and components (such as batteries) together creates the overall energy efficiency of a vehicle, these component must be studied separately to create an overview of the total energy efficiency of different fuelled vehicle types. The energy content of fuel also determines the amount of fuel needed to achieve the same travelled distance under the same circumstances. This determines together with the carbon content of the different fuels what the total GHG emissions are of different fuelled vehicles. Changing

the energy source exist out of three possible solutions: 1) Cleaner and lower carbon fuels, 2) Battery electric vehicles, 3) Hydrogen vehicles. This sections is therefore divided into these three solutions and is concluded with an elaboration on the difference in energy efficiency between the different powertrains and the different fuels or energy sources.

Cleaner and lower carbon fuels

Switching to cleaner and lower carbon fuels can reduce emissions without major changes to the used vehicle fleet. Depending on the fuel chosen little or no changes are needed to the existing vehicles. This solution cannot bring emissions down to zero and is therefore often thought of as a transition solution to help bring emissions down in the short term before moving to zero emission vehicles in the longer term.

The carbon content of the different fuels can be compared to determine the possible emission reduction of changing fuel. However the energy content of the different fuels also plays a role, as this determines the distance that can be travelled on 1 l or kg of fuel from which the needed amount of fuel for a trip can be determined and thus the emissions of a trip.

Carbon & energy content of fuels

There is a large difference in carbon content of the different fuels available; diesel, bio-diesel, gasoline, bio-ethanol, LNG, CNG and HVO. The carbon content depends on the feedstock used and the ratio between fossil fuel and the bio equivalent when used in a blend. The energy density of these fuels is also different, impacting the distance that can be travelled on a full tank. The energy density of ethanol is 36% lower than the energy density of gasoline and the energy density of bio-diesel is 14% lower than the energy density of diesel (Smart Freight Centre, n.d.-a). With these lower energy densities, the range of vehicles using these fuels are also shortened with the same factor.

As can be seen in Table 9, the emission factors of diesel and bio-diesel differ but the WTW emissions do not go down to zero. Depending on the kind of lower carbon fuel chosen and the ratio of bio-fuel, the existing engine needs alterations. For bio-diesel or bio-ethanol the effect of the fuel on the engine depends on the percentage of bio-fuel present in the used fuel (Alternative Fuels Data Center, n.d.-a). For more than 20% of bio-fuel the vehicles needs different tubes that are resistant to the corrosive effect of bio-diesel (Alternative Fuels Data Center, n.d.-b). When the level of bio-fuel exceeds the 50% more alterations are necessary such as an addition or warmer to keep the fuel from freezing at a higher temperature than normal diesel (Parker, n.d.). Because B100 can clean the engine, old residue can come loose and clog the filters, extra maintenance is therefore necessary in the beginning to change the filters when B100 is used after B5. The cost of these changes are low, however the increase in fuel price does have an effect on the price of transport. The emission reduction potential of bio-diesel(blends) compared to B5 diesel goes up to 55%, where the emission reduction potential of ethanol can go up 44%.

Another lower carbon fuel is HVO, it is a chemical version of diesel and is created out of different feedstocks. As no alterations to ICE are needed to make use of HVO, investments in technologies are not needed, making HVO a good replacement of diesel (Neste, n.d.). The emission reduction potential of HVO is over 65% depending on the feedstock used to create the HVO. The cost of changing to HVO depend on the difference in fuel cost as the energy content stays the same. The increase in fuel price for HVO is around 20%.

Although liquid natural gas (LNG) and compressed natural gas (CNG) have been around for a while. The advantage is that both fuels burn cleaner than diesel (UN Climate Technology Centre & Network, n.d.). However, natural gas is also a fossil fuel and will eventually run out. CNG and LNG are therefore no long term solutions but it can be a useful short term solution, bio methane however can be a long term solution for gas fuelled cars. The energy content of bio-CNG and bio-LNG is also the same as for the fossil variant. The emission reduction potential of these fuels start from 4% and go up to 67% for the bio variants. Diesel cannot be replaced by gaseous fuels, new vehicles are therefore needed that can run on these fuels. The difference in investment cost can go up to 12% (Moultak et al., 2017) while the fuel price is lower.

With the reduction of CO_2e emissions, other air pollutants are also effected such as PM_{10} , NO_x and SO_2 . In A. Klein et al. (2021) an overview is given of these air pollutants and how they change if other fuels are used. Especially in urban areas, the effect of these air pollutants is of importance, as it can have an effect on human health. Hydrogen and HVO emit a higher amount of PM_{10} and NO_x , while CNG and electric vehicles emit a much lower amount. The amount of SO_2 is reduced for all alternative fuels.

The price of fossil fuels is very dynamic and based on the price of oil. With the war in Ukraine in 2022, the price of fossil fuels rose to unprecedented heights. With this the demand for alternative fuels went up, increasing these prices as well. This shows how dynamic the price of fuel is and the risk associated with fuel prices. Next to this the price also differs per country because of taxes and distribution cost. From the past, an estimate can be made of the price of different fuels, however this cannot be used as an indication of future prices because of the dynamic aspect of these prices, it can only be used as a possible price of fuels based on past prices.

Battery electric vehicles

Electric vehicles are dependent on electricity and the emission factor of electricity depends highly on the way the energy is generated and the grid mix differs per country. Green energy such as solar power, wind energy, hydro power and tidal energy are all generated without fossil fuels, and no CO_2e is emitted in the complete WTW cycle. Emissions for electricity generated with nuclear power are also very low. The emission factor for green electricity is therefore much

lower, or even zero, than the emission factors for grey electricity, created from coal, oil and gas. Because not every country has the same accessibility to the different sources of energy, the availability differs per country, impacting the emission factor of electricity. Carbon Footprint (2022) created an overview, Table 10, of the different electricity emission factors of many different countries to help their clients to track their carbon emission. The difference between the average grid electricity factor from the ISO14083 and the overview of Carbon Footprint (2022) can be explained by the large difference between the countries. The emission reduction potential of BEV's can go up to 100% depending on the source of energy.

Cost increase

Electric vehicles are more expensive than internal combustion engine vehicles at this point in time. However, Basma et al. (2021) researched the possibility of closing the gap of Total Cost of Ownership (TCO) between BEV and ICEV in seven European countries, together responsible for more than 75% of truck sales in Europe. The study looked into the difference in TCO in 2020 and 2030 and concluded that with regulation the TCO can be the same for BEV and ICEV as soon as 2023. As the analysis is based on the first-user perspective, the first 5 years, the use of the vehicle in that time is taken into account in all calculations regarding cost per trip. Basma et al. (2021) also mention that maintenance cost are 30% lower than for ICEV's as no battery change is needed in the first 5 years of ownership. It is expected that there is no difference in TCO of BEV's and ICEV's in 2030 and in some countries ICEV's will be more expensive by then. The price of electricity and diesel also plays a large role in the costs difference between them, if the diesel price increases, what can be seen from March 2022, the TCO gap is closed much earlier if the electricity prices stay the same. This is mainly because the energy consumption of ICEV's is much higher and is therefore more reliant on the price of diesel. Based on the fuel cost analysis performed in the research of Basma et al. (2021) it is expected that with this increase in price the gap between the TCO of BEV's and ICEV's is closed before 2025 in most rich European countries. The TCO of an ICEV in the first 5 years in 2022 differs per country and the financial incentives and is between 400.000€ and 570.000€ and in 2030 between 380.000€ and 550.000€. Whereas the TCO of BEV's in the first 5 years in 2022 are between 500.000€ and 630.000€ and in 2030 between 350.000€ and 480.000€. It can be seen that the TCO of BEVs is almost 13% lower in 2030 than the TCO of ICEVs.

Hydrogen

The emission factor of electricity not only effects BEV but also hydrogen vehicles. Hydrogen is created using electricity, depending on the electricity source it can result in green hydrogen, produced with renewable energy, blue hydrogen, created with grey energy but makes use of carbon capture and storage (CCS) and grey hydrogen, created with grey energy without CCS. Carbon capture and storage is the process of capturing carbon when electricity is created and storing this carbon instead of releasing it into the air. If CCS is used when electricity is created from natural gas, the efficiency decreases with 5% - 10% (Haugen et al., 2021). Around 90% of the CO_2 produced in the production process of hydrogen can actually be captured and stored, still emitting some of the CO_2 that is released during the production of blue hydrogen.

Hydrogen vehicles, indicated with the name fuel-cell electric vehicle (FCEV), use hydrogen as the source of energy which requires a fuel-cell to convert the energy from hydrogen into water and electric energy. Hydrogen cars and freight vehicles dependent on the process of electrolysis for which energy is needed. The emissions of hydrogen vehicles is therefore highly dependent on the emission factor of the electricity used to produce the hydrogen. In Kolbe (2019) it is discovered that hydrogen vehicles driving on hydrogen created with electricity from the average grid mix leads to a higher amount of CO_2 than fossil fuelled cars. This is however dependent on the grid mix available which differs per country. Hydrogen can also be seen as an energy carrier, which is very useful when energy needs to be stored. If hydrogen is created at moment when there is an excess of green or grey electricity, it saves the energy that would otherwise be wasted. This should be taken into account when the emission factor is determined, due to time limitations this is recommended for further research.

In 2021 the price of blue hydrogen was 55% to 65% lower than the price for green hydrogen. Lau et al. (2021) mentions the price at the time was around \$3–\$7/kg compared to \$1.4–\$2.4/kg.

The cost of a fuel cell vehicle is estimated by Sharpe & Basma (2022). In this meta study the price of zero-emission trucks are discussed and the price of fuel cell vehicles are estimated around the same prices as BEVs. It also shows that prices will go down to less than 50% of the cost in 2020. In 2020 the price of a FCEV is around 2-3.5 times as expensive as a conventional diesel truck.

The energy efficiency of engines

The energy efficiency of the engines used, partly determine the emissions of a trip. Different WTT and TTW efficiencies can be distinguished for different fuels and engines. In Cunanan et al. (2021) a table is created which compares the characteristics of the three main powertrains, a hydrogen heavy-duty vehicle, battery electric vehicle and a diesel HDV. In Figure 10 not only the different efficiencies but also the costs are compared.

It can be seen that ICEs have the lowest TTW efficiency but do have a high WTT efficiency. This indicated that the main energy losses occur in the engine. Next to this it can also be seen that ICEVs have the largest range and the fastest refuelling time. Albatayneh et al. (2020) found that the TTW efficiency of the ICEVs are in a range of 14–33 % for gasoline ICEVs, 28–42 % for diesel ICEVs and 14 % to 26 % for NGCV (Natural Gas Combustion Vehicles). This is a higher efficiency than Cunanan et al. (2021).

Table 1. Comparison between three discussed heavy-duty vehicle powertrains.

Criteria	Diesel	Battery	Hydrogen Fuel Cell
Tailpipe emissions	Yes	No	No
Total vehicle cost ¹	119,000–134,000 USD	164,641–585,000 USD	135,503–249,900 USD
Well-to-tank efficiency ²	~86% [91]	~55.3% [91]	~76% [91]
Tank-to-wheel efficiency	~23% [32]	~68% [32]	~45% [32]
Fuel consumption	6.5 miles/gallon [24]	0.5 miles/kWh [50]	5.5–9.2 miles/kg H ₂ [73]
Range	975–1950 miles	62–500 miles	660–1104 miles
Refueling time	6–12 min	2.85–20 h	16.67 min
Specific Energy	42.9 MJ/kg [33]	0.432–0.792 MJ/kg [56]	118 MJ/kg [14]

¹ The total vehicle costs were taken from a specific case study conducted for California. Reproduced from [92], UC Davis: National Center for Sustainable Transportation: 2020. ² The well-to-tank efficiencies of the fuels were of the same pathway (natural gas as the source) for comparative purposes.

Figure 10: Comparison between three different technologies for HDV's (Cunanan et al., 2021)

In Figure 11, Guandalini & Campanari (2018) compared the different components of fuel-cell, battery electric and internal combustion engines. Guandalini & Campanari (2018) sets the energy efficiency of ICEs at 39% which corresponds with the findings of Albatayneh et al. (2020).

Table 1 – Selected efficiencies of drivetrains components.

Component	Efficiency (%)	
Internal combustion engine	39.0	
Gearbox and transmission	98.0	
Electric motor/generator	92.0	89.3
Inverter DC/AC	97.0	
Battery (charge/discharge)	96.0	
Fuel Cell	55.0	

Figure 11: Comparison between FCEV, BEV and ICEV components (Guandalini & Campanari, 2018)

Electric vehicles make use of an electric motor instead of a combustion engine. The different types of electric vehicles, Battery Electric Vehicle (BEV), Hybrid Electric Vehicle (HEV), Fuel Cell Electric Vehicle (FCEV), Plug-in Hybrid Electric Vehicle (PHEV) all make use of an electric motor. Where BEV, HEV and PHEV use a battery and thus electricity as the energy source, fuel cell electric vehicle use hydrogen as their energy source and thus need extra equipment to transform the hydrogen to useful energy. Therefore the energy efficiency of FCEVs will be discussed separately from the battery electric vehicles in the next section.

Albatayneh et al. (2020) did a deeper study into the efficiency of electric engines and its components and created the following overview, Figure 12, of the different components of a battery electric vehicle that have an effect on the efficiency. It can be seen that the biggest losses occur in the electric motor and the electric generator, however the TTW efficiency of BEV is much larger than that of ICEV as can be seen in Figure 10.

The higher TTW efficiency of electric vehicles can partly be explained by the fact that electric vehicles can make use of regenerative braking. Due to this recovered energy, the range of electric vehicles can be extended and the energy use per km of electric vehicles can be reduced (Balali & Stegen, 2021). Balali & Stegen (2021) use Figure 13 to explain the working principle of regenerative braking. When the vehicle slows down, the kinetic energy that is released converts into electricity which is stored in the vehicle's battery, charging the battery and extending the distance that can be covered. This technique is mostly relevant in urban areas where a lot of stop and go takes place, increasing the amount of energy that can be regenerated.

An hybrid electric vehicle makes use of both an electric motor and an internal combustion engine. The electric motor is mostly used for stop and go and for slow speeds, the internal combustion engine is used for constant speeds or high acceleration and therefore a smaller ICE is needed. The combination of electric motor and ICE provide the vehicle with a greater driving range, lower fuel consumption and emissions in comparison to fossil fuelled vehicles.

In Haugen et al. (2021), it is mentioned that the energy efficiency WTW of BEVs is more than 2.8 times greater than the energy efficiency of FCEV when normal grid electricity is used. This shows that the process of creating hydrogen is very inefficient. The two aspects that contribute the most to the energy inefficiency are the process of electrolysis and the fuel cell in the vehicle (Haugen et al., 2021). Although the theoretical efficiency of electrolysis is 95%, in reality the efficiency

EV components	Efficiency	Efficiency range
AC/DC converter	96 % [32] 90 % [33]	90–96 %
Battery input	96 % [32], [34] 95 % [35] 99 % [35] 90 % [9]	90–99 %
Battery output	95 % [32] 96 % [34] 93 % [35] 98 % [35]	93–98 %
DC/AC converter	96 % [32] 97 % [34] 98 % [33]	96–98 %
Electric motor	90 % [32] 92 % [34] 95 % [33] 81 % [35] 89 % [35]	81–95 %
Electric generator	85 % [32] 92 % [34] 95 % [33] 82 % [35] 88 % [35]	82–95 %
Mechanical transmission	98 % [32] 98 % [34] 97 % [33] 89 % [35]	89–98 %

Figure 12: Efficiency of EV components (Albatayneh et al., 2020)

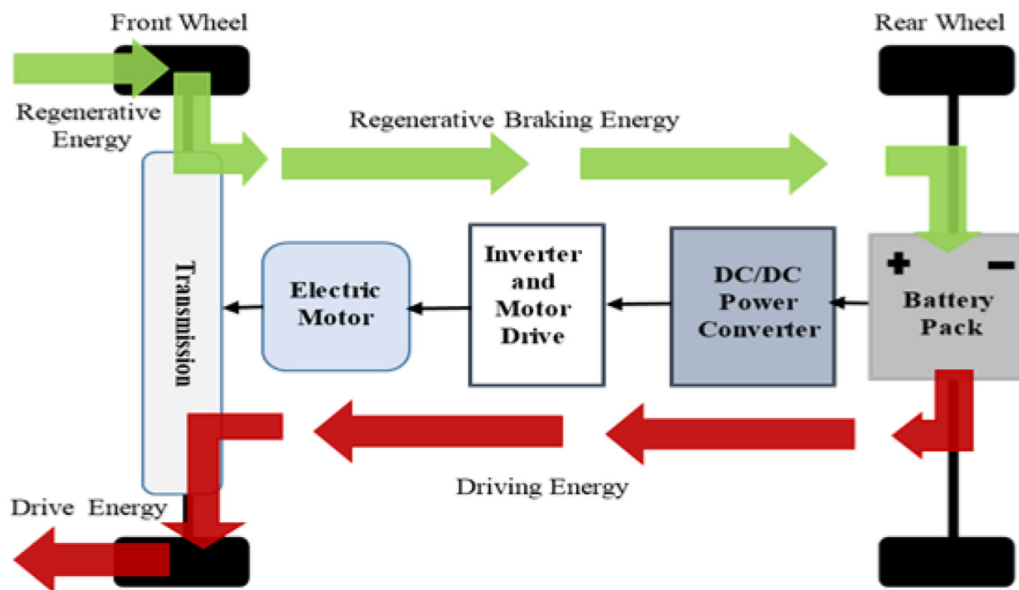


Figure 13: Working principle of regenerative braking (Balali & Stegen, 2021)

is lower, the same is true for the efficiency of the fuel cell, 83%. In Figure 11 it can be seen that the efficiency of a fuel cell is estimated at 55% (Guandalini & Campanari, 2018) which is even lower than the expectations of Haugen et al. (2021).

If electricity from fossil fuels is used in the production of hydrogen, the emission factor is around 17% higher than BEVs that use the same electricity. This is because of the energy efficiency of converting energy into hydrogen discussed above. A way to reduce carbon intensity of grey hydrogen is by carbon capture and storage (CCS).

The energy efficiency of fuel

As mentioned, the energy efficiency differs per fuel or energy source as the production process of fuel differs, the efficiency of these processes are captured in the WTT emission factors. These efficiencies are also shown in Figure 10 for the three most common drive trains. In Figure 9, the different production processes can be seen for fossil fuels and electricity. Creating diesel, bio-diesel, LNG, CNG and petrol all includes the extraction (or collection in case of bio fuels) of raw materials that is later converted into fuel. The energy that is needed to extract (or collect) the materials differs per fuel

and is taken into account in the WTT values. The energy efficiency of the conversion process from raw material to fuel is also part of the WTT values as well as the distribution of the fuel to the gas stations and the refuelling of the tanks from the gas station and eventually the vehicles.

For electric vehicles the WTT energy efficiency contains different elements. The energy generated can either be produced from fossil sources such as oil, gas and nuclear energy or from renewable sources such as windmills, solar panels, tidal energy or biomass. The power generation process that converts the fossil material into energy contains energy losses which are taken into account in the WTT values for electricity. For the renewable energy sources, very low or no emissions are generated in the power generation step. The generated power then enters the grid and is distributed to the customer. No vehicles are needed to distribute the energy but losses do occur in the grid. This is also taken into account in the WTT values for both grey electricity (from fossil sources) and green electricity (from renewable sources). The losses that occur during charging are again taken into account in the WTT factors, the same as for refuelling the fossil fuelled vehicles. In figure 10, it can be seen that the WTT efficiency of electricity is very low in comparison to the WTT efficiency of diesel. In the figure it is mentioned that for comparison purposes the WTT efficiency is based on natural gas, the difference can be explained both by the low energy efficiency of the conversion from natural gas to electricity and with the losses that occur in the electricity grid.

The process of distributing the different fuels to the refuelling stations is also part of the WTT production cycle and the energy efficiency of this process differs per fuel. However the energy efficiency of fuel distribution is not elaborated on in this study due to lack of time and looking into this is advised for further research.

3.4 Calculating reduction potential of Actions

Research has also been done on emission calculation as it being one of the main parts of the decision support tool. Emissions of road transport can be calculated in different ways, based on amount of liters fuel used, kilometers driven or with amount of energy needed for a specific vehicle with a specific load over a specific distance. The main relation between emissions and transport is the amount of energy needed for transport which results in a very general formula (Zadek & Schulz, 2010):

$$CO_2eq\ emissions = energy\ consumption_{specific} \cdot emission\ factor \quad (1)$$

In reality, many different things affect the total emissions of a trip. In this sections these are explained and used in the formulas. By using more specific formulas, a more accurate estimate can be made of the emissions released during a specific trip.

3.4.1 Formula's used in calculations

For the different starting points, associated formulas can be found in literature, to show the fundamental difference between them, they are discussed below.

Liters

Using the amount of liters used in a trip, combined with the specific conditions such as the surrounding temperature and the age and maintenance level of the engine, provides the user with a very reliable estimate of TTW GHG emissions produced in a trip. However the specific vehicle information is not shared knowledge and can therefore not be known by freight buyers. When simplified the formula from Zadek & Schulz (2010) can then be rewritten into:

$$CO_2eq\ emissions(kgCO_2e) = liters\ of\ specific\ fuel(l) \cdot specific\ emission\ factor(kgCO_2e/l) \quad (2)$$

The specific emission factor takes into account the specific conditions. This indicated the level of complete combustion and the amount of other non GHG emissions that are released. The specific conditions of a trip as well as the precise amount of fuel used is information that is hard to get. Carriers want to keep this confidential as it can release details of their method of transportation.

Kilometers

Using the amount of kilometers driven is a second method to determine the emissions released in a trip. Because the amount of kilometres is not directly convertible into amount of fuel used, a conversion factor is needed. This factor is based on the vehicle choice, fuel choice, driving speed, weight and load characteristics of the shipment. In the GLEC framework factors are given to convert the amount of kilometres into the amount of fuel needed based on the mentioned criteria, called road emissions intensity factors. In this conversion factor also empty rides are taken into account that are needed to get the truck on the right location without a shipment. By multiplying this factor with the amount of tonne

kilometres, the amount of fuel can be determined. Again multiplying the amount of fuel with its emission factor gives the amount of CO_2 produced, see formula 2.

$$weight \text{ (in tonnes)} \cdot kilometres \text{ (km)} \cdot specificroadintensity \text{ factor (l/t-km)} = amount \text{ of liters fuel (l)} \quad (3)$$

Amount of energy needed

Zadek & Schulz (2010) also determined a formula that is much harder to fill in as a company, based on the amount of energy needed for a shipment, called the energy consumption (EC). However, by making use of amount of the energy needed per shipment, it is easier to compare different fuels or compare it to battery electric vehicles. It is therefore a main method to use in emission reduction potential calculation when looking into the different fuels.

$$EC \text{ net load} = EC \text{ empty} + (EC \text{ empty} - EC \text{ full}) \cdot (weight \text{ load} / load \text{ capacity}) \quad (4)$$

As mentioned above, the amount of kilometres and weight shipped can be used to determine the amount of fuel needed. It is possible to use formula 4 to determine the amount of energy needed for a specific shipment. In order to be more precise, other factors are also of importance when calculating how much energy is needed to transport a certain shipment being:

- Speed
- Road type (urban, rural, highway)
- Vehicle (van, light duty, heavy duty)
- Fuel (diesel, ethanol, different blends etc)
- Distance (short, medium, long)
- Driving behaviour
- Surrounding temperature
- Combustion temperature
- Vehicle age
- Cold or hot start

Together this is part of the efficiency-factor of a specific vehicle depending on a specific region. To determine the exact impact of these factors a lot of information is needed.

A simplified overview can be given of the formula, using the weight of the load and the distance travelled. This formula was created by combining the energy formula of Zadek & Schulz (2010) together with the kilometer formula:

$$EC(MJ) = (EC \text{ empty} + EC \text{ load})(MJ/t - km) \cdot weight \text{ load(tonne)} \cdot distance(km) \quad (5)$$

3.4.2 Emission factors

Fuel emission factors (EF) are part of emission calculations and form the basis for comparing fuels. Different institutions derived emission factors expressed in CO_2eq . RED 2 (European Commission, n.d.-d) (European Commission, n.d.-e), UK BEIS (GOV.UK, n.d.), JECv5 (PRUSSI et al., 2020), and STREAM are some examples of institutions that gathered emission factors (A. Klein et al. (2021)). The old standard, EN16025 also contains emission factors for all types of fuels. These factors are considered the default values for the transport sector. The new ISO standard, ISO 14083, will replace these values after its release in 2022.

STREAM is a report written about transport in the Netherlands and therefore only includes transport that takes place within the Netherlands. As explained by A. Klein et al. (2021) in the STREAM report, there are two types of emissions, GHG emissions and air polluting emissions. GHG emissions are expressed as CO_2eq and this is used to compare the emissions of different options. Air polluting emissions, SO_2 , PM_{10} and NO_x , are not included in GHG emissions and thus not used in the GLEC framework when calculating emissions. These values are therefore not in this study used when different options are compared.

Energy consumption

The energy consumption of a vehicle for a certain trip depends on many factors, see Figure 14. These different factors can be taken into account in the emission calculation in various ways. STREAM distinguished different logistic properties such as types of transport, bulk goods and containers, and weight of transport, light, medium and heavy weight. These properties are used to divide the different vehicle types and types of transport into categories and determine specific energy consumption factors and load factors for these categories. This same method is used in J. Klein (2019) and Geilenkirchen et al. (2022). However a different method is used in "The handbook of emission factors for Road Transport (HBEFA)". This handbook does not use the difference in goods transported but uses the different vehicles available, their EURO class

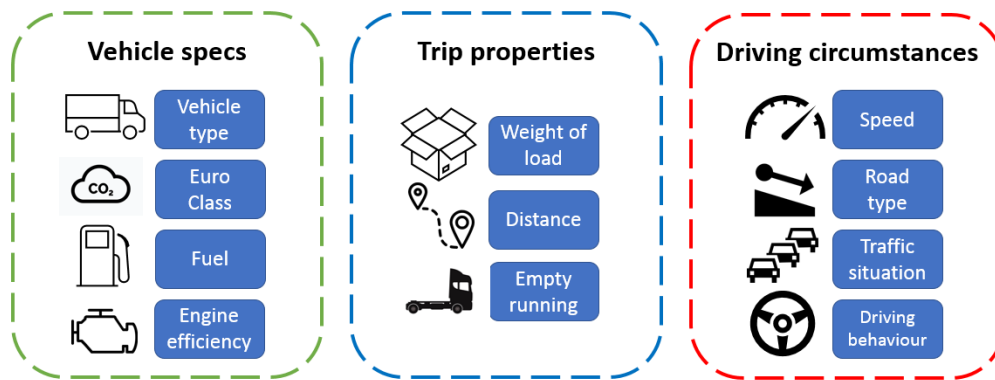


Figure 14: Factors with influence on emission factors

and their maximum load as basis for their energy consumption factors (Benedikt Notter, 2022). Together with the distance of the trip and emission factors, total emissions can be determined. A remark has been made by A. Klein et al. (2021) that emission calculation based on tonne kilometers is not as accurate as calculations based on fuel used of kilometers driven.

HBEFA, first created for the environmental agencies of Germany, Switzerland and Austria, has become a reliable source for energy consumption (EC) factors for all current vehicle types. Today many different research institutes and universities are part of the research into EC and emission factors including the JRC (European Research Center of the European Commission), also more countries are now involved, being France, Sweden and Norway. The handbook is made into a tool which can be downloaded from their website when a membership is bought. This tool offers the opportunity to calculate different types of factors depending on the vehicle type, traffic situation, type of emission, pollutants, year, fuel and emission class. As explained in Section 2.2.3, the tool provides the option to download very specific energy consumption factors per country, per vehicle type and euro class and per traffic situations. Offering the user a detailed EC for a specific vehicle (Benedikt Notter, 2022). When base emissions and possible emission reduction of action need to be calculated, two different factors are of importance. First of all the EC related to the vehicle and second the fuel emission factor related to the fuel used. Both factors are included in HBEFA and can be used either at the same time or separately by using the emission factors after the EC for vehicles have been determined. The most accurate option is to use HBEFA to determine the energy needed per trip per vehicle type and use separate emission factors.

Next to different vehicle types, emission classes and fuels also the traffic situation has an effect on the EC. As the exact traffic situation of a trip is often not known, an average is needed. HBEFA can take an average traffic situation and slope into account to include the possibility of a traffic jam and the influence of stop-and-go and heavy traffic scenarios on the EC. This handbook is therefore able to take into account all the different factors from Figure 14 and provide very detailed energy consumption values.

3.4.3 Specific trip properties

As mentioned in Section 3.4.2, many aspects of a trip have an influence on the total emissions of a trip. In Figure 20 the influence of trip properties are related to emission calculation. It can be seen that most properties can be used in calculating the energy consumption in HBEFA, however more trip specific properties cannot be implemented in these calculations. Origin and destination together with trip length also has an impact, this relates to the distribution of road types in a trip: motorway, rural and urban road. The different road types differ in maximum speed, gradients, amount of stop and go moments, heavy traffic and constant driving conditions. The HBEFA tool therefore offers the possibility to calculate different emission factors for the different road types but does not include an overview of distribution of the different road types per vehicle segment and trip distance.

It is acknowledged that the distribution of road types depends heavily on the country of origin, the kind of transport and the chosen route, however averages must be used for emission calculations that include the division of road types per trip length and vehicle segment. In a study performed by TNO, a distribution between the different road types for Dutch traffic situations has been found. The study shows a difference in distribution between regional delivery and long haul transport (Verbeek et al., 2018), see 15. The velocity profiles only provide a possible example of the different speeds and stop and go moments of vehicles on the different road types and do not show averages for velocity profiles on these road types. No logistics operations are included in these velocity profiles, moments of unloading, possible idling and loading at distribution centres are not included. The distributions shown are averages for road freight transport in the Netherlands and can be used as an indication for a road type distribution in trips. By making use of routing programs and the shown velocity profiles, a more fitting distribution of road types can be determined for specific trips.

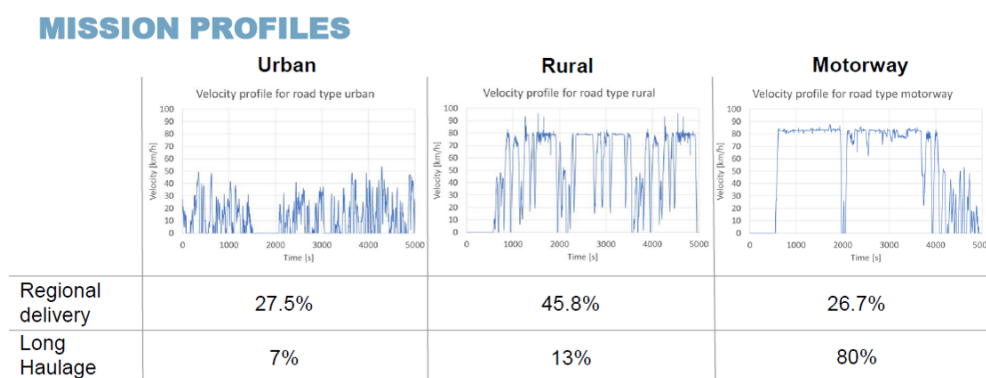


Figure 15: Distribution of road types (Verbeek et al., 2018)

3.5 Costs

The cost of trucking exist out of seven different aspect; fuel, the purchase of truck and trailer, salary of the driver, repairs and maintenance, insurance, tires and permits, licenses and tolls (Truckers Report, n.d.). When emission reducing solutions are applied, these aspects of costs will change.

Fuel cost is currently the largest cost item, with new technology the fuel can change, changing the price of fuel and with changing energy contents of fuel the amount of fuel needed can also change. The costs can therefore go down if less fuel will be consumed after implementing actions that for example increase the aerodynamic of the vehicle. It is also possible that other kinds of fuel need to be purchased, resulting in higher or lower fuel cost depending on the fuel chosen. *Purchase costs of truck and trailer* will likely be higher for new technology trucks than standard diesel trucks, however with financial help from governments and tax reductions on these vehicles, the gap can be made smaller and even be closed (Basma et al., 2021). The costs will also go down when these vehicles are being sold more frequently and it is therefore expected that the purchase costs will decrease in the future. The *salary of drivers* will stay the same if the required skill-set of the driver stays the same. If more knowledge or skills are required, the price of this aspect will go up. *Repairs and maintenance* depend on the change to the vehicle or the different vehicle chosen. However, as mentioned in Section 3.3.4 the cost of maintenance relies on the technology chosen, for electric vehicles the costs are expected to go down. The *tires* on existing vehicles will be the same as on newer technology vehicles. However also the tire choice can have an impact on emissions, if a solution is chosen which includes different tires, the price can go up. *Insurance* is related to the solution choice. If only small adjustments are done to existing vehicles, the cost will most likely stay the same. For newer technology the cost of insuring vehicles will probably be higher due to being a more valuable asset. With a higher share of new technologies, also the price of insurance will reach a price more alike of traditional vehicles. *Permits, licences and tolls* will go down for zero emission vehicles. No extra costs are expected in these categories, only advantages. Many cities in Europe already have an emission zone installed that bans older vehicles and trucks from the cities and city centres. By improving existing vehicles with small adjustments that can change the Euro-class or by buying newer technology vehicles, these cities are accessible again. Also permits and tolls are cheaper for zero emission vehicles (Basma et al., 2021).

The investments done by carriers in less polluting solutions and technology will have an impact on the transport cost for the buyer of transport (shipper). The investments needed for the different solutions, as can be seen in Section 3.3, vary from rather small to large investments. The impact on the transport cost plays an important role for the shipper in selecting more sustainable road transport. It can be expected that from the seven different aspects mentioned above, the purchase of truck and trailer together with the fuel costs have the largest influence.

Experts have been asked how cost of these investments will be passed on to the customer. It is expected that the investments will be passed on in the same way the current pricing is created. The cost of the purchase or adjustment will be proportionally added to the bought transport. As carriers keep the exact way of determining their prices a secret as part of their trading secret, information comes from literature. As Dan Meszler & Muncrief (2018) describe in the white paper of the ICCT on European Heavy-Duty Vehicles, practice differs per truck owner but usually trucks are kept less than 10 years. As practices differ per truck purpose and truck owner, an average of 5 years is used in the study when looked at the cost in the lifetime of new technology. In this time the first-owner of the vehicle benefits most of the new technology or adjustment where new technologies and adjustments are around after 5 years making the old solution less valuable. These cost can then be passed on to the buyer (shipper) of transport, charging the cost per kilometre. By making use of the average amount of kilometers driven in a new vehicle in 5 years (European Commission and Directorate-General for Climate Action, 2018), around 550.000 km, and using the trip distance, a share of cost can be determined by calculating the share of the trip in relation to the average distance in 5 years. With this information, the cost of every solution can be determined per kilometer, which makes it possible to determine the cost increase or decrease associated with implementing a

particular solution using formula 6.

$$\text{Cost of vehicle per trip (€)} = \text{Total cost of purchase (€)} \cdot \frac{\text{distance of trip (km)}}{\text{average distance in first 5 years(km)}} \quad (6)$$

$$\text{Cost of trip (€)} = \text{Cost of vehicle per trip (€)} + \text{Cost of fuel per trip (€)} \quad (7)$$

4 Requirement Analysis

The design of this thesis follows from requirements. These requirements define the working principle of the tool. Next to the working principle also the expectations of the users of the tool will be covered in the requirements. The list of requirements will act as the list of properties that the tool must meet. This can be used in the different design phases to check if the tool is still in line with the expectations and demands, hereby validating the tool.

4.1 Literature

Requirements exist out of two types: constraints and objectives (must haves and nice to haves (Robertson, 2001)). First of all the requirements will include information on the functionality of the tool, these are mostly called constraints. For example, what do companies want as the outcome of the tool, what does it need to take into account to help decision making and what is the working principle. To create a decision support tool that provides the outcome wanted by companies, data is needed. In the requirements a description of the needed data must be present, describing them as constraints. Because companies will use the tool themselves, aspects regarding ease of use are also part of the requirements as well as costs and programming information such as speed and program used, these will be objectives too.

Next to objectives and constraints, requirements can be described as functional requirements, things a system has to do, and non-functional requirements, such as qualities, performance and usability. The non-functional requirements can also be project goals, or a reason for the project, which are high level requirements and constraints, such as time, money and technology.

To find the requirements, there are many different techniques (Robertson, 2001), however not all different techniques can be used in this situation. The most common technique is *interviewing* the stakeholders (Robertson, 2001). The different stakeholders explain their needs and wants and from this requirements can be created. However there are always unconscious requirements that are often forgotten when asking stakeholders about their requirements. These unconscious requirements can be very general and common requirements that are forgotten because of the assumption that they will already be satisfied because of the necessity. Therefore it is good to make use of more methods, increasing the chances of finding all the requirements, including the unconscious requirements. Different methods that can be used for finding requirements for a design are:

- Abstraction
- Apprenticing
- Business events
- Brainstorming
- Family therapy
- Interviewing
- Mind mapping
- Simulation models (scenarios, prototypes)
- Systems archaeology
- Use case workshops
- Viewpoints

4.2 Requirement trawling

Apprenticing is a method that can easily be used in the beginning of a project. By listening to meetings or by following along for a short period, a lot of information can be gathered about the scope of the project. During the meetings between SFC and the shippers a lot of information about the requirements of the tool was available. By sitting in on these meetings, a lot of knowledge has already been gained. By combining the apprenticeship with *Business events* and thus splitting the tool up into different activities, it was easier to think of requirements that are solely of importance for one activity. This was then used as the intake phase of the *Family Therapy* method. Listening to the different needs and deciding on what is most important for the shippers, significance phase, resulted in a well thought response, the last phase of family therapy. Already framing the requirements from previous sessions by making use of the family therapy method we can provide feedback to the stakeholders and in the mean time check if the requirements are correctly formulated, avoiding misinterpretations and at the same time validating them. These three different requirement methods are all used to support *interviews*. As explained by Robertson, it is important to enter the meeting with a clear purpose and boundary. To avoid very detailed explanations a time limit was used.

The first round of requirements of the tool can be drawn up from the research gap and the success scenario. The research gap can be drafted after using the apprenticeship method, by using the information from the meetings between SFBA and the shipper companies. During these discussions it was obvious that companies need a certain baseline of knowledge

before making changes to their supply chain. The knowledge gap for companies was followed by a success scenario to eliminate this gap. The first round of requirements was then created. The best method to determine the requirements from the user, after collecting the requirements from the research gap and success scenario, is by interviewing the stakeholders.

As Bahill & Dean explain in the book of Sage & Rouse (2014): "Each requirement must be verifiable by test, demonstration, inspection, logical argument, analysis, modeling, or simulation." This means that as part of the validation of the concept phase, the requirements need to be verified. If the requirements are constructed according to Robertson (2001) this should be easy to do using mainly the logical argument verification.

Types of stakeholders

Stakeholders are of importance to any project. Where stakeholders can vary from very influential to only interested in the project, the involvement of stakeholders in a project can help the project to become more successful and easier to implement (Voinov & Bousquet, 2010).

According to Eden & Ackermann (1998) stakeholders can be mapped in a "power versus interest grid". This grid provides a visual overview of the points of view of the stakeholders, the y-axis shows the level of interest of the stakeholder where the x-axis shows the power of the stakeholder. This created four different points of view, (1) high power, low interest, keep these stakeholders satisfied, (2) Low power and low interest, minimal effort (can be ignored), (3) low power and high level of interest, keep informed, (4) high power and high interest, focus on these. Guðlaugsson et al. (2020) used the grid of Eden & Ackermann (1998) with the same axis and named the four quadrants after the role the stakeholders play in a project, see Figure 16.

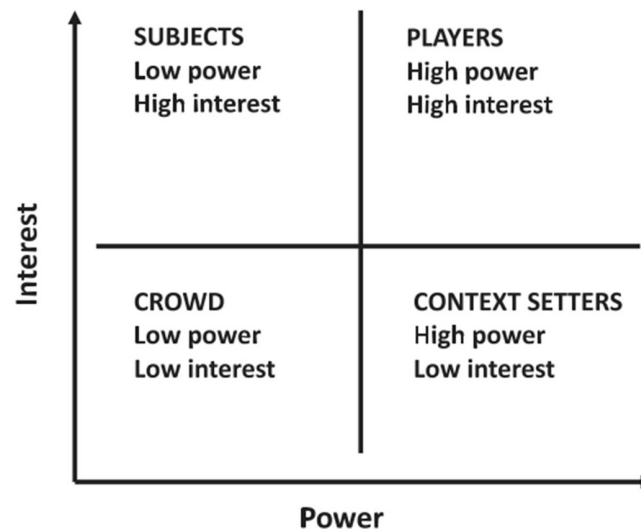


Figure 16: Power Interest grid (Guðlaugsson et al., 2020)

The main stakeholders for this design thesis are Smart Freight Centre, the client of this tool, and the shippers, the users of this tool. Other parties of interest are the solution providers, carriers but also car manufacturers, fuel providers, tire manufacturers and electricity providers.

4.3 Requirements

4.3.1 Main Success Scenario

As mentioned in Section 2.1.1, drafting requirements can be done by first deciding on the success scenario. From this success scenario the basic requirements, mostly functional requirements, of the tool can be determined. To check if the tool also fits the needs and wishes of the user the success scenario was validated during interviews.

The success scenario:

1. Company fills in questions with company transport data
2. Company chooses actions that are of interest
3. Tool calculates the base line of the current transport emissions
4. Tool calculates the emissions of different actions and determines the emission reduction potential
5. Tool takes into account costs of actions and possibly CO_2 tax and pricing

6. Tool displays the different actions with emission reduction potential and cost overview
7. Company can choose to go back and enter other data / preferences
8. In the tool the user is provided the opportunity to change parameters used in the calculation if own parameters are available

4.3.2 Stakeholders

As explained in Section 4.2 different stakeholder have different goals and needs. For this tool two groups are the main stakeholders, SFC and the users (shippers). SFC being the owner of the tool and shippers as the users of the tool. When these stakeholders are placed in a "power-vs-interest" grid, it can be seen that the users, shippers, are the most important stakeholders of this tool, see Figure 17. The users of the tool can either be subjects or players according to Guðlaugsson et al. (2020). As this tool is developed in the service of SFC, they are the context setters. The users will be players, as the tool will be developed for them and otherwise would not exist, it is therefore of importance that the tool meets their needs. In the crowd, low power and low interest, the other parties of interest are located, the so called solution providers: carriers but also car manufacturers, fuel providers, tire manufacturers and electricity providers.

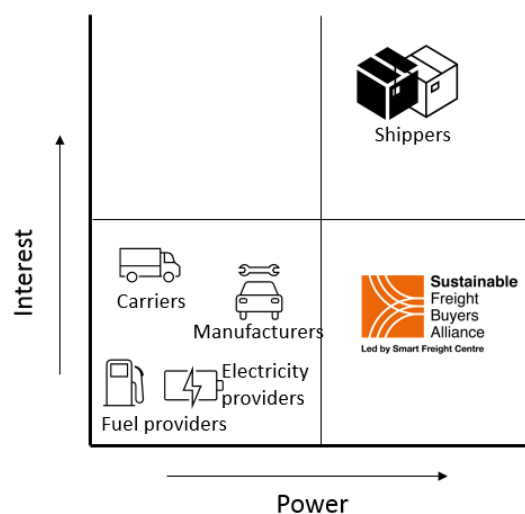


Figure 17: Power versus interest grid (Eden & Ackermann, 1998)

SFBA wants to create a tool that meets the expectations of the companies part of SFBA. It is therefore important for them that the tool they are providing for SFBA members works correctly and is as detailed as possible while keeping the development costs low. They also want to keep the program as simple as possible due to two reasons. The first one being that the use of the program must be easy to keep the users happy. The second one is keeping the amount of maintenance of the platform and the amount of support needed for the companies low.

4.3.3 Outcome of Interviews

The results from the interviews with shipper companies have been worked out into Figure 18 and Figure 19. These results have been used to find requirements from the future user and to validate the requirements that were drawn up with the apprenticing method.

The companies that have been interviewed are: Proctor & Gamble, Dow, Roche, Saint-Gobain and Unilever. Next to these companies, also James from Smart Freight Centre was interviewed with the same questions to see if the client (SFC) had the same interests as the users (shipper companies).

4.3.4 Part 1: Decision making within companies

The results of the five interviews with shipper companies and with James from Smart Freight Centre can be seen in Figure 18. The decision making within companies is elaborated on and a conclusion has been drawn.

Conclusion

During the interviews it became clear that cost is always an important factor for transport decisions. However, companies

	Global Transportation and Sustainability Director P&G	Global Procurement Sustainability and Advocacy Leader Dow Europe GmbH	Logistics Support Lead Product Supply Logistics & Operations PTSL / MMSL F. Hoffmann-La Roche Ltd	Transportation & Logistics Manager Saint-Gobain Performance Plastics	Global Sustainability Lead Unilever	Technical manager SFBA Smart Freight Centre
Specific information on the company and their supply chain that is of interest for the decision making	-	The process of supplier selection exists out of 2 to 3 parts. a) Request for proposals (RFI) Questionnaire has sustainability questions (Climate goals, use of greener fuels etc) b) Tender, more on sustainability	Currently a project with mode switch from air to sea. 95% of shipping is airfreight at this moment. Reason for air2sea not only sustainability but mostly for resilience (diversify modes) Increase lead time = increase stock = expensive	SG has a climate goal for 2050 to be neutral, wants to change that to 2040 They are looking into BEV because of commitment, market advantage, market position Indirect stock prices Carbon offset is being taken into account	For greener alternatives we ask proposals and want to know the CO2/cost ratio	
Which factors are of importance?	1. Cost 2. Lead time (service) 3. Reliability, on time delivery Emission reduction Resilience (weather) Triangle with Service, Cost and Cash, first service and cost are being looked at, then cash Sustainability will be there from 2030, will be a factor within cost	For the tender there are two factors most important: 1. Cost 2. Safety then 3. Reliability There is no standard yet for evaluating tenders. Use of existing questionnaires from CDP or ecovadis to maintain standard	Procurement looks at: 1. Costs 2. Availability (use of 3PLs / 4PLs) Information needed on fleet, costs and tariffs. Sustainability is not yet in there. Roche does pressure them to innovate	1) Capacity 2) Service (Also at 1) OTIF, on time in full 3) Safety 4) Costs 5) Sustainability Looking at maximum load potential	We use a decision matrix for this 1) Cost 2) Service 3) Security / safety 4) Quality Delivery quality and DITIF Experience with suppliers Future elements: social standards (LSP mandatory) and sustainability (5)	1. Safety - Driving behaviour - Technology 2. Cost 3. Availability 4. Reliability Cost and availability are a trade-off
How are the different factors taken into account?	Financial business case	No weights or ranking. Each tender has their own process and their own evaluation We want to go to a minimal threshold for the company but not there yet	For sustainable projects: amount of CO2 reduction and costs. Partly also timeline and size of the project Future: implementation ratio Roche uses an internal carbon tax to compare the initiatives	Capacity is most important Willing to pay more for the right solution and to change providers. Will not pay for additional infrastructure	Service, security and quality are mandatory and costs is just the lower the better, same with sustainability Future improvements planned, the have a preference Track record of the last years is important	Use of threshold for all factors, if more options pass the threshold, the choice is based on cost
Are there go / no go factors		No go: Human rights Safety Also other social factors such as bribery	No go: Stock outs	Safety Insurance Acceptance of the freight terms of SG Future: sustainability program / initiative	Security Service	No go: Safety Strict threshold for reliability
Which position has cost in the decision making?	Most important	Requirements differ per tender	-	Not important when related to capacity and service, willing to pay extra for more sustainable options	Ranked behind service and quality	If more options are ranked the same, this will be the dealbreaker
Is there a difference in decision making with regard to your own fleet?	90% outsourced carriers North America, 10% own fleet No impact on decision making	No own fleet, all outsourced	Everything is outsourced	Some fleet in Europe US all is outsourced through contracts No information on the fleets in Europe	99% outsourced	Difference in decision making because of own fleet being scope 1 and outsourced being scope 3.

Figure 18: Interview part 1

are willing to pay more for more sustainable solutions. This is partly for the image and partly because it is becoming increasingly important within the corporate culture to make conscious choices, the cost / impact ratio plays a significant role. Although companies do not have a threshold value for this ratio, this ratio is being used to make decisions and compare alternatives. Next to cost also availability is mentioned in every interview, companies do want to change and buy greener transport but are dependent on the availability of greener alternatives at their locations and the location of their carriers. This can also be seen in reliability, companies need the assurance that the more sustainable transport is as reliable or more reliable than the current transport method. If fuel is not available or not widely available, it is not an option. Lead time and on time delivery are also part of reliability as well as safety. The new transport method should be safe and secure, the overall quality of the shipments should stay the same.

Per region and per tender the criteria differ and the choice is mostly based on the cost and quality differences between carriers. While assessing these offers, companies are looking closely at safety and human rights as well as previous experiences with a carrier company.

Important to note is that companies do not have different requirements for their own fleet. This has mostly to do with the fact that emissions of their own fleet are within scope 1 emissions and are thus have a bigger cost impact on companies

at this moment than scope 3 emissions. Another reason is because the companies interviewed had no or very few own vehicles.

4.3.5 Part 2: Tool

Part 2 of the interviews was about the tool itself, the working principle and the layout. The answers from the different companies can be seen in Figure 19. Again a short conclusion has been written.

	Global Transportation, Sustainability Director - P&G	Global Procurement Sustainability and Advocacy Leader Dow Europe GmbH	Logistics Support Lead Product Supply Logistics & Operations PTSL / MMSL F. Hoffmann-La Roche Ltd	Transportation & Logistics Manager Saint-Gobain Performance Plastics	Global Sustainability Lead Unilever	Technical manager SFBA Smart Freight Centre
Success scenario - Feedback		We have our own transport carbon tracker tool, mostly used for modal switch, this would not be useful for us but we see very much the value for other (smaller) companies that do not have the insights yet	Provide visibility with a CO2/cost ratio Road: affiliate site	Useful tool for central level employees to gain insights in different carriers, use for comparing different carriers	Be very clear about the assumptions for fuels, what is assumed and where is the data coming from	Provide information to fill in the input questions, in line with GLEC (how to calculate ton km) Useful for beginning shippers without own tool, or companies that haven't started yet
Input	We don't know the amount of litres used, do know kilometres	Use trade lanes instead of region and country Add the amount of kg's shipped (weight)	Extra: necessities of each companies, for example cold shipments, does it have an influence on the supply chain (longer lead time)	Miles per gallon (maybe known, should be asked for at carrier) Use of LTL Use of miles instead of km Have no point to point delivery		Hard to use countries, try to avoid trade lanes. Only ask where the transport started. How to implement shared shipments. Carriers don't share km info, guess
Who is going to use it	We work with a matrix, people in transport and people from the business unit, regional and vertical	Sourcing managers that put out the RFI and tenders Supply chain managers (day to day operations)	Procurement department Sustainability council Supply chain & logistics	Central level to monitor carriers and sites. To determine which carriers are the best for their network. Change carriers even if for certain sites that means increase in emissions is overall is lower Transport manager	Logistics team Carbon champion per region Works with the operational team (procurement team)	Logistics department If there is a sustainability department, then also these people Sustainability manager Central use in company
Output: • Uncertainty • Output results		Uncertainty, qualify in low, medium, high instead of explaining and giving numbers	Add influence on lead time change and route Clarity in uncertainty	Story to tell is important, not the actual uncertainty or confidence.	Provide the information in a way to compare to the information	Show current fuel in overview
• in between answers		Box & whisker plot with threshold Be as transparent as possible with calculations and uncertainty and confidence interval (See Science based targets) Make it visible	Uncertainty will evolve in time, results will become more robust Only in between answers that are straightforward Simple user interface, just input output, do have the possibility to access the calculations if needed	In between answers very useful to create insights and also to compare to other methods	provided by carriers In between answers should be presented Uncertainty is not really interesting, carriers also not show their uncertainty	Important to see the uncertainty for the credibility of the tool (how is hard, maybe range of confidence) Display clearly the sources Provide the opportunity to see all the calculations Also to download to compare different scenario's
Other feedback		Currently it is not that easy to switch fuels, there is not much on the market yet	Other modes would be useful for us (air), very useful for scenario planning	Carrier selection is not yet centrally fixed, sites can have influence and also central managers can choose their own carriers through brokers Broker of carriers for sites	This kind of tool would be helpful to compare to the data of suppliers	Fuel management: mixture of fuels, maybe just provide the opportunity to select fuels For ships: dual fuel, provides flexibility, not possible for road

Figure 19: Interview part 2

Conclusion

The first important result of the second part of the interviews relate to the information that shippers have on their shipments. Carriers do not provide a lot of information to their customers because that also provides insights in their efficiency and other competitor sensitive information, this makes it difficult for shippers to know their emissions exactly. Shippers do know the weight of their shipments and the distance that it travels before reaching destination. However, this is not related to the distance actual travelled, but based on the origin and destination. Because shippers often send LTL (less than truck loads), it happens that carriers combine shipments of different companies and destinations and the actual amount of

kilometers is much higher. Another aspect of the region where the transport takes place is the associated emission factor of the fuel. Asking companies for a region where the transport takes place also gives problems, easier is to only ask for the region where the transport originates, this is information that the companies do have and are most important with relation to the emission factors.

A different factor mentioned by the shippers that were interviewed is that different companies have different necessities, for example cold shipments or time sensitive shipments. This is noted for further research due to time limitation of this research.

Looking into who is going to use this information, is it clear that there are two departments within companies that find such a tool useful. First of all the sustainability council of a company and second of all the logistics department together with the procurement team. The sustainability council, often working together with other departments within a company, can use this tool to find the right solution and assess if there are carriers that already offer this solution. The logistics department together with the procurement team can use this tool to look at more sustainable transport and decide if the cost / impact ratio is acceptable.

The last question of the interview was based on the uncertainty of the calculations. Most companies would like to know the sources of the emission factors and other parameters used to check if the same values are used for internal calculations and are thus accepting the same level of uncertainty. Only one company would like to see the range of values that are within the uncertainty. This could then be used as a more realistic estimate when presenting emission values within the company. All companies indicated that they liked being able to download the results, calculations and uncertainty ranges.

Sub-question 1: Which aspects are of importance for companies when deciding on the ultimate choice for projects that reduce emissions?

From the interviews it can be concluded that **cost** is the most important factor for shipper companies when carriers are chosen for road freight transportation. Other factors that are also of importance are:

- Availability of technology
- Reliability
- Availability of infrastructure and fuel
- Lead time and on time delivery
- Safety

4.3.6 List of requirements

The requirements can be divided into two categories as explained in Section 3, functional requirements and non-functional requirements. The requirements that are imposed by SFC are marked with (C) for commissioner.

Functional requirements

1. The tool shall only take actions into account for road transport
2. The tool shall provide a location where the user can enter their transport data
3. The tool shall calculate the emissions of the current situation by using the data provided by the user
4. The tool shall use calculation methods found in literature to determine the emissions
5. The tool shall take into account the weight of the shipment in either kg, lb or tonne
6. The tool shall take into account the distance of the shipment in either km or miles
7. The tool shall take into account the origin of the shipment for determining the emission factor
8. The tool shall provide the user with opportunity to choose from the list of actions which are of interest and which are not
9. The tool shall determine the emission reduction potential of the different actions that are chosen by the user
10. The tool shall determine the cost of emission reduction actions per trip
11. The tool shall show the different actions in an abatement curve
12. The tool shall adjust the abatement curve within 10 seconds after changing the input
13. The tool shall provide an overview of the outcome separately from the abatement curve
14. The tool shall provide information on the uncertainty of the calculations in the tool
15. The emission calculation in the tool shall be in line with the GLEC Framework (C)
16. The emission factors used in the tool shall be in line with the GLEC Framework (C)
17. The energy consumption calculations shall be based on the HBEFA tool (C)

Non-Functional Requirements

1. The tool should be easy to use
2. The tool should include information on the working principle of the tool
3. The tool should be understandable for users with a road freight logistics background

4. The tool should present the emission reduction possibilities in a meaningful way to shippers
5. The tool should display the outcome in a clear way
6. The tool should be possible to download
7. The tool should be accessible on the SFBA platform
8. The tool should be available as a MS Excel download file
9. The tool should have a size that is downloadable
10. The tool should work with all versions of MS Excel
11. The tool should be easy to maintain (C)

5 Model Components

In this chapter the conceptual model will be discussed that is created as part of the preliminary design phase. This model shows the analysis and architecture of the tool as well as the relation between the different trip properties. From the conceptual model, the design was created. The data needed in the sub-models of the design will be discussed in the second section, showing the different emission reduction percentages and costs for the actions included in the tool. It will also elaborate on the emission calculations, the different values used in these calculations and the uncertainty. In the third part of this chapter the tool itself will be shown and it will be explained how the user should use the tool, this is the result of the critical design phase from the V-model.

5.1 Conceptual model

The conceptual model consists out of two parts, the emission reduction and the associated costs. Both contain a set of calculations that form the basis of determining the emissions and costs of the current situation. Alterations are then made to these calculations to determine the emissions after implementing the action and ultimately to determine the reduction potential and the increase or decrease in cost of the trip with regard to the current situation. The different alterations for the emission reduction calculation can be based on:

1. A reduction percentage of the action is provided in literature and this is applied directly to the total emissions of the current situation
2. A different fuel is chosen with a different emission factor, the new emission factor is used in the calculations
3. A different vehicle is chosen with a different energy source, the new emission factor of the energy source is used in the calculations
4. An adjustment is done to the existing vehicle, a reduction percentage is provided in the study or by the manufacturer and this is applied directly to the total emissions of the current situation

The increase or decrease of the costs of the trip after an action is implemented is also determined by adjusting the set of calculations used to determine the costs of the current situation. The different alterations for the cost increase or decrease are:

1. A cost reduction percentage of the action is provided in literature and this is applied directly to the total costs of the current situation
2. A different fuel is chosen, the new price per liter or kg is used in the costs calculations. The amount of fuel needed is also recalculated based on the energy content of the new fuel, possibly also changing the amount of energy needed and influencing the total cost of fuel per trip. In case new technology is needed for the use of the chosen fuel, the extra costs for this technology are also calculated for this trip and added to the total costs of the trip
3. A different vehicle is chosen including a new energy source, the TCO of the new vehicle is then used in the calculations that determine the cost of equipment per trip. The costs of the different energy source are determined by making use of the energy content of the energy source and by multiplying the needed amount of energy by the cost of the fuel
4. An adjustment is done to the vehicle, the cost of this adjustment is then used to determine the increase of the trip cost by making use of the first owner principle

This model provides an overview of the calculations in the tool as well as an overview of the data needed to perform the calculations in the tool. The different trip properties have an impact on the total emissions of a trip, the relation between these properties can be seen in the overview of the emission calculations in Figure 20.

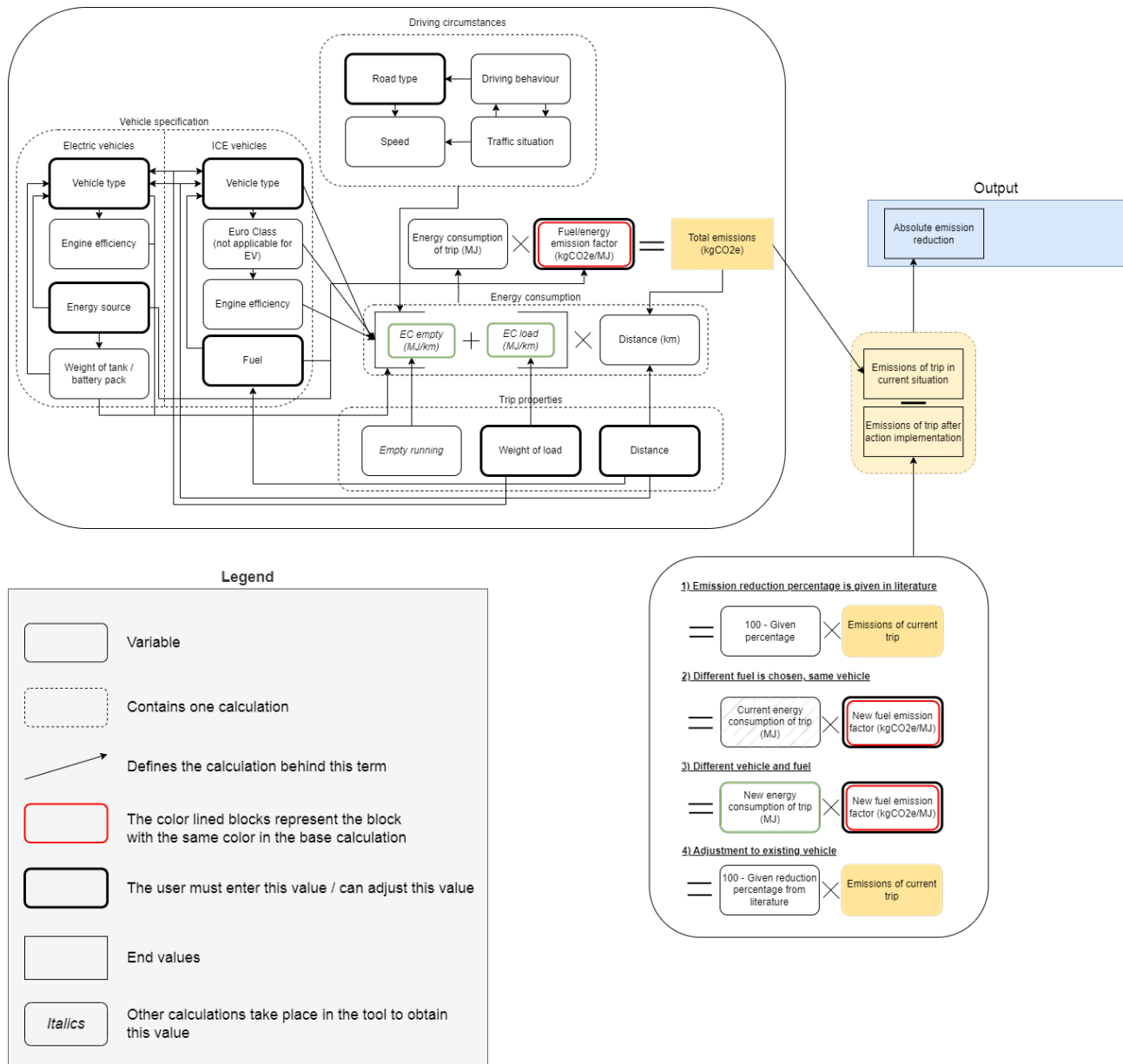


Figure 20: Overview calculations in the tool - left side

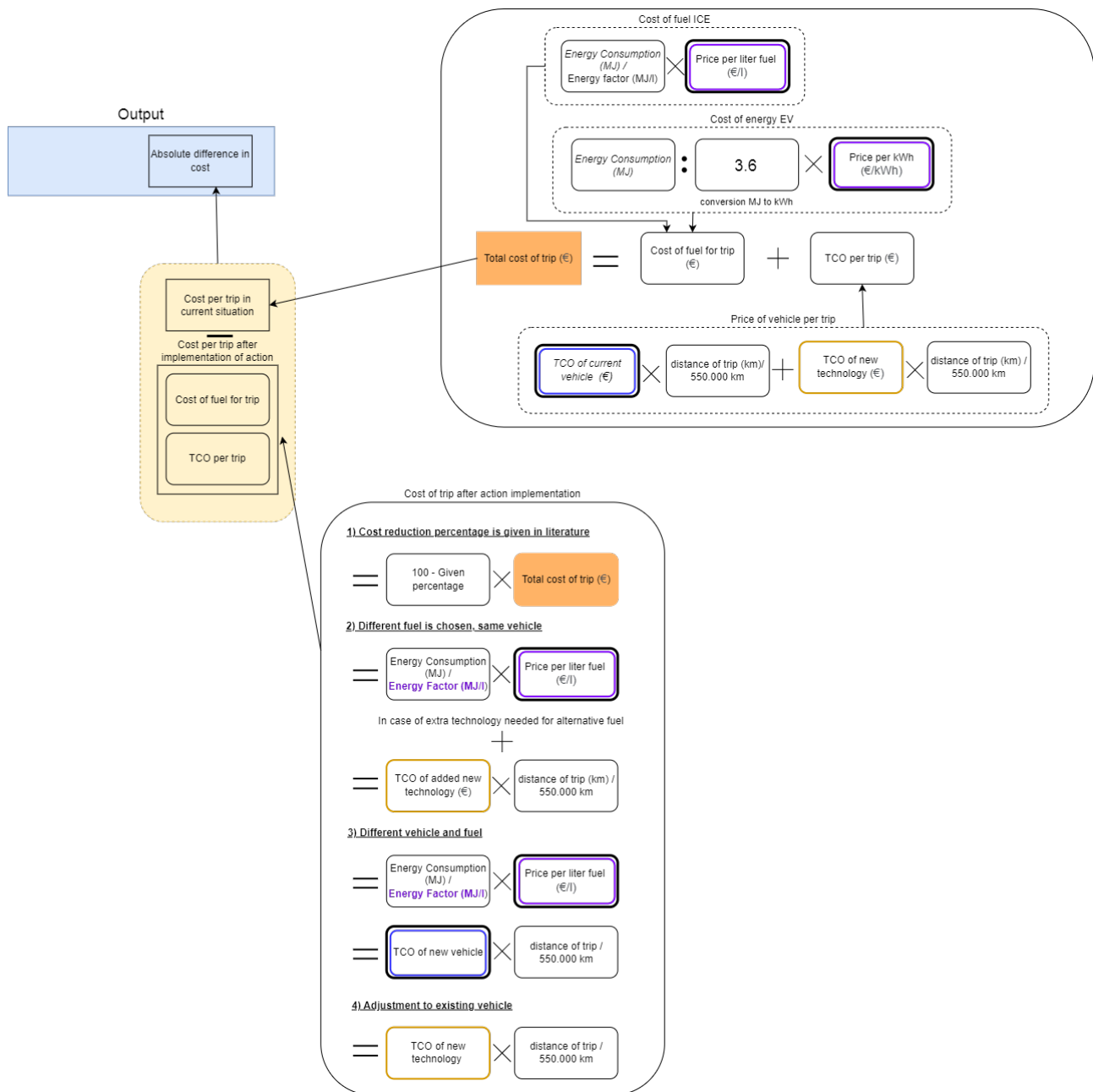


Figure 21: Overview calculations in the tool - right side

5.2 Data in tool

This Section contains the sub-models of the design. This shows the results from the literature study, and the data presented here will be used in the tool. This section starts with the different actions that are present in the tool, their emission reduction potential and cost are displayed in Tables 5, 6 and 7. After the different actions, the chosen calculation method can be seen. The formula's found in literature are used to determine the emissions for a specific trip, the chosen parameters used in these calculations will be shown after. In Section 3.5 determining the cost per trip is first discussed, this together with the cost of carbon is presented in Section 5.2.6. At last the different uncertainties in the data used for the tool are explained and their effect on the outcome of the tool will be discussed.

5.2.1 Actions

The different actions in the figure of A. McKinnon (2018) have been assessed on their compatibility for the purpose of the information tool. The actions that will be included have been studied in literature in Section 3.3, the outcome of this literature study containing the emission reduction potential and the corresponding costs per action will be discussed here.

Increase load

The first solution taken into account to increase the load factor is standardized modules and boxes. This solution is split up into three different actions, changing packaging, high capacity vehicles and double stacking. The second solution is load optimization and the third solution is load consolidation. The reduction potential and corresponding cost can be seen in Table 5. The reduction potential that is used in the tool is an average of the estimated reduction found in literature. By taking the average, the reduction potential is not overestimated. However actions can have a lower reduction than expected after implementation due to various implementation factors.

Table 5: Increase load factor

Intervention	Reduction potential from literature	Cost from literature	Reduction in tool	Cost in tool
<u>Standardized boxes and modules</u>				
high-capacity vehicles	7 % - 15 %	5-11%	11%	8%
Double stacking	0-23%	8-28%	12%	18%
Boxes	31%	8%	16%	4%
Load optimization	10 % - 20%	3-6%	15%	4%
<u>Load consolidation</u>	7 % - 51%	20%	20%	10%

Decrease fuel use

The reduction potential of the actions related to decreasing fuel use are partially discussed in Section 3.3. The reduction potential and the cost of cleaner & efficient technologies and efficient vehicles can be seen in Table 3 and Table 4. The different vehicle categories shown and the differences in values will be used in the calculations by making use of the vehicle type used for the transport. The reduction potential of driving behaviour, fleet management and fleet operation can be seen below in Table 6. Since there are several options under fleet operation and fleet management, an indication has been provided, low, medium or high, to indicate the level of cost. As fleet management entails routing, re timing, maintenance, de-speeding and fuel management, the implementation costs are low. All options have low cost between zero and €1500. Fleet operation entails fleet renewal and planning of use. Planning of use can have zero or low cost, however fleet renewal can be expensive if electric or hydrogen vehicles are purchased. The moment of investment is also of importance, as it depends on strategy of truck replacement. The costs that are taken into account in the tool are presented in the table below and are based on the different options available per solution.

Table 6: Decrease fuel use

	Reduction potential from literature	Cost from literature	Reduction used in tool	Cost used in tool
Driving behaviour	9,40%	Low (€300)	7%	€300
Fleet management	10%	Low	5%	€500
Fleet operation	10% - 20%	Medium - high	15%	€2000

Changing fuel source

Moving to cleaner and lower carbon fuels can reduce emissions based on the blend of fuels used. For hydrogen, the reduction potential is based on the source of energy chosen to produce the hydrogen. The cost of implementing these solutions consists out of two parts, the increase/decrease in TCO and the increase or decrease in fuel cost. Both will be

used to determine the difference in transport cost related to the use of fossil trucks using diesel B5. The cost of fuel can vary with time and between countries. In this overview averages are given of September 2022, for hydrogen the data from Shell has been used (Shell, n.d.).

Table 7: Cleaner and lower carbon fuels

Cleaner and lower carbon fuels	TCO (x TCO of ICEV)		Fuel cost	Reduction potential
	2020	2030		
Bio-diesel	-	-	+/- 3.00 €/l*	>55%
HVO	-	-	2.54 €/l (Fulltank, n.d.)	>65%
CNG/LNG	-	-	> 2.30 €/kg (DirectLease, n.d.)	4-67%
BEV	2,5-4	-	0.26 €/kWh (EUenergy, n.d.)	>100%
Hydrogen (grey)	2-3,5	1,2	10 €/kg (Shell, n.d.)	>100%**

* No exact information was found. As it is in Europe not common to use B100 as a fuel. There is data available for the United States on the website of the US Department of Energy (n.d.). It is known from literature that bio-diesel in Europe is more expensive than regular diesel. Therefore a price of 3€/l was taken for the calculations.

** The reduction potential depends on the energy source, grey hydrogen cannot reduce emissions up to 100%, green hydrogen can.

Table 8: Total Cost of Ownership of vehicles

Total cost of ownership of vehicles	
Diesel	€ 321.750
Hybrid Electric	€ 528.820
Battery Electric	€ 564.820
LNG (Spark ignition)	€ 333.750
CNG (Spark ignition)	€ 347.750
Hydrogen fuel cell	€ 353.820

The Total Cost of Ownership values, used to determine the cost of a trip, can be seen in Table 8. These values are constructed from the information available in the white papers from the International Council on Clean Transportation from Moultaq et al. (2017) and Basma et al. (2021).

5.2.2 Calculations

As mentioned in Section 3.4, there are multiple methods that can be used to calculate emissions. Because this tool is intended for shippers, the shipper must be able to fulfill the input questions of the tool. It is known that specific information of trips is not shared by the carrier with the shipper, so only basic information can be entered into the tool. Therefore the following formulas have been chosen to calculate emissions:

$$Total\ emissions(kgCO_2e) = EC(MJ) \cdot Fuel\ Emission\ Factor(kgCO_2e/MJ) \quad (7)$$

Formula 5, based on the EC factors from HBEFA, has been adjusted. The weight is now incorporated in the EC load, the new formula can be seen below, formula 8.

$$EC(MJ) = (EC\ empty + EC\ load) \cdot distance(km) \quad (8)$$

These formulas rely on the amount of energy consumed (EC) in a trip, which depend on multiple factors as discussed in Section 3.4.2 and Section 3.4.3. In this thesis it is assumed that the user of the tool does not know the exact vehicle and emission class used for the trip. Therefore the vehicles of the same vehicle type but with a different EURO class have been merged into one factor for every vehicle type, valid for an average vehicle of that type if no EURO class is known. The user will only fill in the weight of the shipment and the tool will then take the most likely vehicle type in that category, based on the weight of the load shipped. The energy consumption factors belonging to that vehicle type, shown in Appendix B, will then be used in the calculations.

The energy consumption per vehicle type consist out of two parts. The first part is the energy consumption of the empty vehicle in MJ/km and the second part is the loaded energy consumption in MJ/t-km. HBEFA provides the users with two factors, 0% load and 100% load. The vehicle emission factor (MJ/t-km) used in these calculations are created as follows:

$$EC\ 0\%(MJ/km) = Urban\ share * specific\ urban\ factor\ 0\%\ load + Rural\ share * specific\ rural\ factor\ 0\%\ load + MotorWay\ share * specific\ MW\ factor\ 0\%\ load \quad (9)$$

$$Specific\ load\ factor = (EC\ 100\% - EC\ empty) \cdot \frac{weight(tonne)}{Capacity\ of\ vehicle(tonne)} \quad (10)$$

$$EC\ load(MJ/km) = Urban\ share * specific\ urban\ factor\ load + Rural\ share * specific\ rural\ factor\ load + MotorWay\ share * specific\ MW\ factor\ load \quad (11)$$

It can be seen that the energy consumption factors are dependent on the share of road types urban, rural and motorway of the trip. For the most accurate emission calculation, these shares are filled in by the user for their specific trip. The values from TNO (Verbeek et al., 2018) have been used as a default for the ratio between the three road types. The default values based on the study of TNO are shown later in Section 5.2.5.

The actual emission reduction percentage of a solution is determined with formula 13. This formula makes use of formula 12 for determining the emissions for the base case and for the new situation.

Sub-question 4: How can the effective emission reduction be determined?

The emission reduction of the different actions can be determined in two ways. If the solution is based on a different energy consumption or other fuel with different emission factor, a calculation of the base case and the new situation must be made and compared. When solutions such as more efficient technologies are chosen, the reduction percentage is already provided in literature. By first calculating the base case emissions, the absolute reduction of the action can be determined.

The formula for base case emissions results from formula 7 & 8:

$$Total\ emissions\ base\ case(kgCO_2e) = (EC\ empty + EC\ load) \cdot distance(km) \cdot Fuel\ Emission\ Factor\ base\ case\ (kgCO_2e/MJ) \quad (12)$$

For the emissions related to the solution chosen, the energy consumption can differ, but also the fuel emission factor can differ. The same formula, 12, can be used as for the base case with the changed parameters replaced with the new factors.

The reduction percentage can be determined using formula 13:

$$Reduction\ percentage\ (\%) = \frac{(old\ emissions\ (tCO_2e) - new\ emissions\ (tCO_2e))}{old\ emissions\ (tCO_2e)} * 100 \quad (13)$$

5.2.3 Emission factors

The fuel specific emission factor, mentioned in formula 7, depends on the carbon content of the fuel used. The factors used in this thesis are from the new ISO standard, Table 9. As this standard has not been made public at this time, the ISO is referred to as the ISO 14083 FDIS version (Final Draft International Standard) and small changes can occur in the final ISO standard.

The emission factor for bio-fuels is dependent on the feedstock of the fuel. The exact emission factor for bio-fuels can therefore differ per country. The values in the ISO standard are an average for the European countries and will be used in the tool for all countries with exception of the electricity factor. The electricity emission factor provided by the ISO standard is also an average of the European countries. The grid emission factors for electricity differ strongly per country as these are based on the energy source used to create the electricity. More accurate emission factors for electricity are therefore country specific and the data from Carbon Footprint (2022) has been used in the tool, see Table 10. The electricity emission factor of the ISO standard will only be used as a default for countries that do not occur in the data from Carbon Footprint (2022).

If green electricity is bought by companies, different WTW emission factors are used. If the origin of the electricity is known, the specific factors can be chosen, if this is not known, an average is taken into account based on the data from CO2emissiefactoren (n.d.), see Table 11. The emission factor provided by the ISO is very close to the average of the WTW emission factors of Carbon Footprint (2022), it is assumed that the ISO is therefore based on these values.

Table 9: WTW emission factors (ISO 14083 FDIS version)

	WTW
Fuel type description	<i>gCO₂e/MJ</i>
Gasoline	90,1
Ethanol	48,2
Diesel	87,3
Bio-diesel	38,3
Liquefied Petroleum Gas (LPG)	81,6
Compressed Natural Gas (CNG)	72,7
Liquefied Natural Gas (LNG)	75,5
Bio-LNG	30,4
Hydrogen (grey)	114,4
HVO	28,6
Electricity (EU average)	97
Bio CNG	26,2

5.2.4 Energy consumption

As explained in Chapter 2, the HBEFA tool has been used to determine the energy consumption for the different vehicles and energy sources. From HBEFA the following vehicles were chosen, see Table 12. Every vehicle has a maximum capacity, this information is used in determining the specific load factor from formula 10 and in the base case emission calculations. From this it is assumed that the smallest vehicle is used to for the freight transport.

By executing the method described in Section 2.2.3, the energy consumption factors for heavy goods vehicles, shown in Appendix B, have been derived. These factors are dependent on the energy source used and are therefore divided not only on vehicle type but also on energy source. The different energy sources are CNG, LNG, Battery electric, diesel, petrol, Fuel-cell electric and plug-in hybrid. In the Appendix it can be seen that the energy consumption differs per energy source, as for electric vehicles regenerative braking is taken into account, these values are noticeably lower than for diesel fuelled vehicles. It is also remarkable that for the diesel trucks the energy consumption factors are higher in an urban environment than on the motorway but for the electric vehicles the energy consumption factors are lower in an urban environment in comparison to the motorway, this is a result of the high number of stop and go moments in urban areas where energy is recovered by making use of regenerative braking. The energy consumption factors are in MJ/km and need to be altered according to the weight of the shipment. In both cases this already takes into account the different traffic situations per country. The factors for a 0% load and for 100% load are available for the aggregated traffic situations for MW, urban and rural. By extracting the factors for 0% from the factors for 100%, the additional factor per tonne is given (see Appendix B.2). These factors are still split into the three road types, urban, rural and highway and will be used in formulas 9 & 11.

5.2.5 Parameters in the emission calculation

The parameters used in the emission calculation are partially discussed above, the emission factors and the energy consumption factors. Parameters that are related to solutions have been mentioned in Section 5.2.1, these are the different prices of fuel, the reduction potential of actions and the corresponding costs of actions. The distribution of road types will be discussed here.

As mentioned, TNO provided information on the different distributions of road types for different delivery types, regional delivery and long haul delivery (Verbeek et al., 2018). These different distributions are only indications of how the distribution can look for these delivery types. The actual distribution is unique to every trip and can best be found using a route program. To provide the user with information on how a distribution can look like, the following three profiles have been determined. The regional delivery and long haul delivery are from Verbeek et al. (2018), the profile for delivery between two distribution centres is an estimate based on previously acquired knowledge by the author, see Table 13. The velocity profiles created by TNO only include information on the velocity of the vehicle on different road types and an example of the amount of stop and go moments, no logistics operations are included in these velocity profiles.

5.2.6 Costs

The costs of different actions were already discussed in Section 5.2.1. Other costs that are also relevant are the different carbon taxes in Europe as discussed in Section 3.1.1.

CO₂ tax

Table 10: WTW emission factors of grid electricity per country in Europe (Carbon Footprint, 2022)

Country	WTW emission factor ($kgCO_2e / kWh$)
Austria	0,11118
Belgium	0,20478
Bulgaria	0,37212
Croatia	0,4688
Cyprus	0,642
Czech Republic	0,53244
Denmark	0,42767
Estonia	0,54689
Finland	0,26818
France	0,05852
Germany	0,58883
Greece	0,4904
Hungary	0,27411
Iceland	0,40193
Ireland	0,44647
Italy	0,45857
Latvia	0,42152
Lithuania	0,34019
Luxembourg	0,10136
Malta	0,39092
Netherlands	0,45172
Norway	0,40194
Poland	0,79868
Portugal	0,37538
Romania	0,26516
Russia	0,3102
Serbia	0,81076
Slovakia	0,21823
Slovenia	0,3452
Spain	0,28653
Sweden	0,02314
Switzerland	0,03034
UK	0,316

Table 11: Renewable electricity sources (CO₂emissiefactoren, n.d.)

	WTW emission factor ($kgCO_2e / kWh$)
Wind power	0
Hydro power	0
Nuclear power (World Nuclear Association, 2019)	0.012
Solar power	0
Bio-waste (Climate Neutral Group, n.d.)	0.075
Average	0.024

The price of the carbon tax differs per country as well as the type of GHG that is taxed. Bray (2022) of the Tax Foundation created an overview of the different carbon tax rates in Europe in 2022, see Table 14. The user is asked to check the website of the Tax Foundation to find the taxes in the country where the transport takes place and add this value to the tool.

Carbon pricing

As mentioned, the European ETS does not include transport emissions at this time but it will be included from 2026. The price of these permits is not known, however Germany already has transport emissions included in an ETS, the price of these permits for 2022 are 25€/tCO₂e (Basma et al., 2021).

The average cost of a carbon permit in the current ETS without transport for the period August 1 2022 to August 24 2022 was 88,40€/tCO₂e (Trading Economics, n.d.).

Both prices give an indication of the possible price on carbon when transport is included in the ETS. As it is not clear what the cost of carbon will be in 2026, this data is not intended to serve as an estimate of these costs. However, it can help the

Table 12: Different vehicle categories from HBEFA and capacities

Subsegment	Fuel	Capacity (tonne)
LCV		
LCV BEV 1.7-3.5t	BEV	1,3
LCV BEV N1 3.5t	BEV	1,3
LCV FFV N1 <3.5t	Flex Fuel E85	1,3
LCV CNG/petrol <3.5t	bi-fuel petrol/CNG	1,3
LCV PHEV diesel <3.5t	PHEV diesel	1,3
LCV PHEV petrol <3.5t	PHEV petrol	1,3
LCV diesel <3.5t	Diesel	1,3
LCV petrol <3.5t	Petrol	1,3
HGV		
CNG < 7,5t	CNG	3,5
CNG 7,5-12t	CNG	6
HGV CNG >12t	CNG	6
TT/AT CNG	CNG	26
HGV LNG >12t	LNG	6,2
TT/AT LNG	LNG	26
RigidTruck BEV <=7.5t	BEV	3,5
RT BEV 7,5-12 t	BEV	6
RT BEV > 12 t	BEV	6,2
TT/AT BEV	BEV	26
RT <=7.5t	Diesel	3,5
RT >7,5-12t	Diesel	6
RT >12-14t	Diesel	6,2
RT >14-20t	Diesel	8,4
RT >20-26t	Diesel	13,7
RT >26-28t	Diesel	14,8
RT >28-32t	Diesel	18,4
RT >32t	Diesel	21,2
TT/AT 7,5t	Diesel	3,5
TT/AT >7,5t-14t	Diesel	7
TT/AT >14-20t	Diesel	8,4
TT/AT >20-28t	Diesel	8,8
TT/AT >28-34t	Diesel	18,4
TT/AT >34-40t	Diesel	24,7
TT/AT >40-50t	Diesel	31
TT/AT >50-60t	Diesel	40
TT/AT >60t	Diesel	65
RigidTruck FCEV >12t	FCEV	6,2
TT/AT FCEV	FCEV	26
RT petrol	Petrol	6
RT 7,5t	Plug-in Hybrid diesel/electric	3,5
RT >7,5-12t	Plug-in Hybrid diesel/electric	6
RT >12t	Plug-in Hybrid diesel/electric	6,2
TT/AT PHEV	Plug-in Hybrid diesel/electric	26

user decide on a price for carbon cost for the future. Depending on how expensive the price of carbon will become in the future, decision are made on investing in more efficient vehicles and technology or even zero emission vehicles (Amsen, 2022).

Table 13: Road type distributions

	urban areas	rural roads	motor ways
Regional delivery	28%	46%	27%
DC-DC delivery	-	10%	90%
Long haulage	7%	13%	80%

Table 14: Carbon tax in Europe (Bray, 2022)

	€/tCO₂e
Austria (AT)	30.00
Denmark (DK)	24.04
Estonia (EE)	2.00
Finland (FI)	76.00
France (FR)	45.00
Iceland (IS)	30.93
Ireland (IE)	41.00
Latvia (LV)	15.00
Liechtenstein (LI)	1117.27
Luxembourg (LU)	39.15
Netherlands (NL)	42.00
Norway (NO)	79.12
Poland (PL)	0.07
Portugal (PT)	23.88
Slovenia (SI)	17.27
Spain (ES)	15.00
Sweden (SE)	117.30
Switzerland (CH)	117.27
Ukraine (UA)	0.93
United Kingdom (GB)	21.36

Sub-question 5: What costs and negative effects are involved in the implementation of emission-reducing actions?

The different cost involved in implementing emission reducing actions are:

1. Investment cost of action
2. Increase or decrease of fuel cost
3. Decrease of cost on carbon tax that does not have to be paid (& in the future carbon pricing)

These cost differ per action and the user can decide on the price of carbon, resulting in specific cost and cost reductions per action choice and user preferences entered into the tool.

Sub-question 3: What data do companies need to enter in the tool?

This section provides the answer to sub-question 3, the input questions asked to the user. The questions that need to be answered are:

1. Region of transport
2. Country of origin of transport
3. Current fuel
4. Distance (km or miles)
5. Weight shipped (load, in kg, tonne or pounds)
6. If known: Vehicle used
7. Road type distribution
8. CO_2 cost estimate
9. If preferred: own emission factors and fuel prices

Other aspects that are also of importance but cannot be known by the shipper, will be automatically filled in by the tool. Aspects that are filled in by the tool are:

1. Capacity of the vehicle
2. If not known by user: Vehicle used
3. Top speed

5.2.7 Uncertainty

Uncertainty is present in all the data collected for this thesis. As this study is based on data that can vary based on external factors, the data used is a snapshot and does not reflect the actual situation. Taking into account and explaining the different uncertainties creates a more reliable tool. As mentioned by Kioutsioukis et al. (2010) the uncertainty in the COVERT 4 model, focused on national road transport inventories, exists out of two parts, the uncertainty of the model and the uncertainty in the input data. The energy consumption factors used are also a source of uncertainty. The effect of the different uncertainties on the outcome will be discussed. This section will be concluded with an explanation on how the risks can be determined based on using the input variables.

Model uncertainty

Model uncertainty contains the uncertainty of all the parameters used in the model, the most important one being the energy consumption factors.

Uncertainty in energy consumption factors

Uncertainty in the energy consumption occurs from the set of vehicles that is used to do the tests needed to determine these factors (Kouridis et al., 2010). Each individual vehicle has an emission level, the set of vehicles used to obtain the data is therefore of importance for the uncertainty in the energy consumption factors. In HBEFA, many different vehicles have been presented, for these vehicles energy consumption factors are available with or without load, making the factors less dependent on the vehicle specifics at the time of testing. This generated an average of energy consumption for a certain vehicle type that can be used with certainty for emission calculation, if more accurate data is needed, the emissions of the specific vehicle will need to be monitored during use. It is not expected that using this method will drastically change the outcome of emission calculation. J. Klein (2019) mentions that the uncertainty in energy consumption factors is based on expert judgement and the uncertainty in CO_2 is very small, however the uncertainty of N_2O and CH_4 is large. As the share of these two gasses is very low, the effect of the uncertainty is also very small.

Vehicle choice and travelling speed are two uncertainty factors that are also taken into account by Kouridis et al. (2010). By dividing the speed into three categories, being urban, rural and highway, the uncertainty caused by the speed of the vehicle is reduced in situations with limited vehicle data. Energy consumption factors can also be determined with the exact travelling speed in the function, however a lot of data is needed for this. Again, HBEFA offers the opportunity to make use of the derived averages for traffic situations for the three road types in the different countries. Using these situations provides an energy consumption factor that can be used with certainty, if more accurate information on energy consumption is needed for one specific trip, the fuel consumption of that vehicle needs to be monitored. This outcome will differ from the calculated averages, but the difference in emissions can either be higher or lower than calculated.

Another factor that can influence the certainty of the energy consumption is vehicle age, during the study of Kouridis et al. (2010) not enough data was available to deduct an uncertainty range. Driving behaviour, surrounding temperature and combustion temperature and the time to reach this temperature also play a role in the uncertainty of the actual emission factor per vehicle. All these factors are not known by the shipper, buyer of the transport. Therefore this cannot be used to eliminate uncertainty, the effect of these uncertainties has thus not been researched in this study.

Uncertainty in input data

The user is asked to fill in transport data. These numbers are directly used in emission calculation and are therefore sensitive to uncertainty. The data that is entered here and is used in the calculations relates to the weight and the distance of the transport. Also information on the current situation is asked that is used in emission calculations for the base case.

These uncertainties are seen as the responsibility of the user, because the user will provide the input.

Weight & distance of shipment

Uncertainty in weight and distance of the shipment will have a direct effect on the base line emissions. As this information is also used in determining the emissions of the actions, the effect of this uncertainty is estimated to be rather low.

Vehicle choice

In the tool the user is offered to choose from a list of vehicles that can be used to transport the shipment based on the weight of the load. If this information is not known, the tool will take the truck which fits the weight of the load best. This can result in emissions being underestimated if the load is transported with a larger vehicle. It can also overestimate the emissions as it is not known if the shipments transported are part of load consolidation. It is thus recommended that if the truck size is known by the user, it is filled in in the input cell for vehicle choice.

Road type distribution

As the road type distribution differs per trip, shipment and vehicle used, no average can be given with certainty. In order to provide an indication to the user, the data from TNO has been used. Indicative profiles (overview of shares of different road types for a trip) are provided for companies that do not know their distribution profile. Three examples are given, regional delivery, distribution centre – distribution centre trips and long haul delivery. It is advised to the user to use a route program to determine the shares of the three different road types for the specific trip and enter this into the tool. This distribution will then be used to determine the trip specific energy consumption factor based on both the vehicle choice and the road type distribution. Emission can either be overestimated or underestimated if the indicative values are used. If the share of urban road is overestimated in the distribution, it result in an increase if vehicle emissions. The opposite happens if the share of motorway is overestimated.

Uncertainty in cost

Fuel price

The price of fuel changes every day because it is dependent on many external values. In 2021 and 2022 it was seen that this price can vary significantly. To reduce uncertainty in cost calculations, the user is provided the option to change the fuel prices. Because companies often have negotiated their own fuel prices and because the price of fuel is very changeable over time it is recommended to use this to possibility to avoid estimation errors. The price of fuel can have a large effect on the feasibility of electric vehicles. If the price of fossil fuels is set lower than actually paid for, renewable energy vehicles are rated less attractive than they actually are if looked at the cost per tonne CO_2 emitted. If the price of fuel is higher than actually paid for, the renewable energy vehicles are made to look more positive regarding cost than is actually true. This is because of the difference in the amount of energy needed between ICEVs and BEVs as well as the difference in fuel price.

Total cost of ownership

The feasibility of new technology is also dependent on the total cost of ownership next to the fuel price. As it is uncertain how the prices change over time, only an estimation can be provided. The effect of the TCO on the cost per trip is calculated making use of the first-owner principle, only looking at the first 5 years of service of a vehicle. As this is done to define the price of all actions, it is expected that this uncertainty will not influence the results between actions but can have an influence if the cost of a single action is reviewed.

CO_2 cost

Depending on the regulations per country and the emission measures introduced by the European Commission, the price per tonne of CO_2e differs. As a default value, the average of the CO_2e price in Europe was taken. In 2022 the European Trading System does not include CO_2e of road transport but from 2026 this will be included. The CO_2e tax differs per country and again an average is taken of the European countries as the default in this tool. It is therefore advised to fill in the cells regarding CO_2e cost in the tool to account for the price on GHG emission in the year of implementing the actions. The price per tonne of CO_2e will be used in the abatement curve to draw a red line simulating the carbon price and showing what cost do not have to be paid in the future if a certain action is implemented. The value of this parameter does not influence the uncertainty of the emission calculations.

Determining risk of actions

The success of the different actions in the tool depend on four things: 1. The dependence on price of specific fuel 2. The TCO of the chosen action 3. The road type distribution of the trip 4. The cost of carbon

To simulate the effect of these dependencies for certain actions, the parameters in the tool can be changed. If a solution is in need of a specific fuel which is at this moment more expensive (2022), the price of the fuel can be changed to an expected value in the future where fossil fuels are more expensive than renewables. The same is possible for the expected TCO of vehicles, if these are expected to drop to the same cost of fossil fuels now, the user can change the value of TCO for the chosen vehicle. In Chapter 6, a sensitivity analysis is done to determine the most sensitive parameters and show

the effects of the different uncertainties in the tool.

To account for a higher price on carbon, the values for the Emission Trading System permits and the CO_2 tax can be set higher, showing the new value of these cost in the graph.

Sub-question 6: What are the different uncertainties in the tool and how can this be included in the calculation?

The uncertainty in the tool exists out of three parts, the model uncertainty, the input uncertainty and the cost uncertainty.

The model uncertainty relates to the emission calculation of the current situation and the action choices. As the same values are used in all the calculations, this uncertainty will not effect the comparison of actions. However, the total amount of emissions is effected by the uncertainty in these factors. If a more accurate calculation of the emissions is needed, other methods can be used.

The uncertainty in the input has a larger influence on the results displayed in the tool. The different factors that contain uncertainty are weight and distance of shipment, vehicle choice and road type distribution. Since the first influences current emission calculation as well as the emission calculation of actions, the uncertainty will also not effect the comparison of actions. The vehicle choice and road type distribution do have an influence on the outcome of the tool. As these inputs are related to different factors used in the tool, underestimating or overestimating these factors can impact the comparison of actions.

The uncertainty in cost also has a large effect on the cost effectiveness of the different solutions. As the total cost of actions is made up from the fuel cost and the TCO, both are important. To give the user the opportunity to reduce the deviation from his specific situation, the option is offered to adjust the fuel cost and the TCO in the tool. The cost of carbon can also have an influence on the cost effectiveness of actions but does not influence the calculations as it is not implemented directly. The cost will be shown separately in the same graph to demonstrate the effect. The user can use the input of the carbon cost to see the effect of different carbon prices.

Conclusion of uncertainties

As there are many different uncertainties present in this tool, the tool must be used with awareness of these uncertainties and the results of the tool must be handled with care. By providing the option to the user to change the input of these parameters, the risk can be reduced. If the user is aware of the uncertainties and the risks present, the tool can be used to inform the user of the possible scenario's by making use of the values that can be changed in the tool exploiting these uncertainties.

5.3 Description of Information Tool

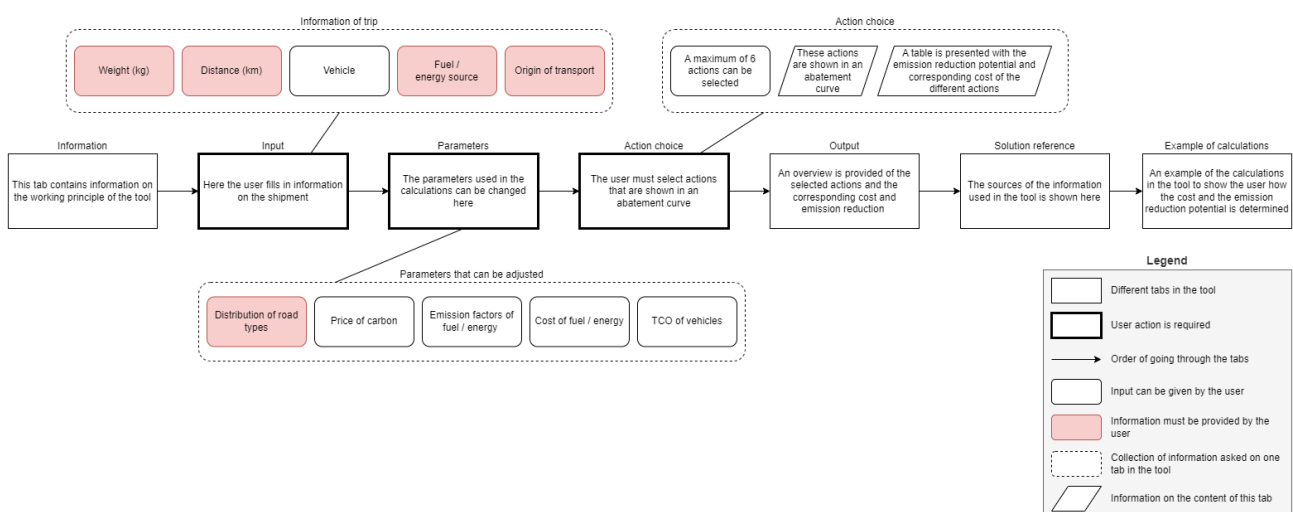


Figure 22: Overview of the different tabs in the tool

The information tool has been build in Excel and contains visible tabs for the user and invisible tabs that contain the calculations. As the tool must be easy to use for shippers and also straightforward in information and calculations, an

introduction is provided in the first tab on the working principle of this tool. The calculations are hidden to ensure the tool is worthy for SFC and to avoid changes made by the user. The parameters used such as the emission factors are also hidden to the user, however users can enter their own emission factors. Parameters that differ a lot between trips and companies such as share of road type are available in a visible and adjustable tab, companies can alter these values if they have more information about the specific trip. The tool has been build in Excel to ensure SFC is able to maintain the tool.

The structure of this section is based on the order in which the user moves through the tool, first the information provided to the user is shown and further explained. Second the information that companies need to enter in the tool will be discussed, this included data of the transport but also action choices. The output that is provided to the user will be presented next. This section will end with describing the invisible tabs, their working principle and the maintenance needed in the future.

5.3.1 Information

The information tab is the first tab the user sees when the tool is opened. In this tab the different steps of the tool are explained and the fields that the user must fill in are elaborated on. It also contains a small glossary explaining the meaning of the terms used in the tool. If the user wants to know more about the working principle of the tool, the accompanying document can be opened, this document is added in Appendix E.

Step 1	Step 2	Step 3	Parameters
Fill in the company data in tab "Input"	Choose the actions of interest in tab "Action choice"	Collect the outcome of the tool in tab "Output"	In this tab it is possible to adjust used parameters if more information about the transport is known.
Make use of the dropdown menu's to fill in your company data. For distance and weight different units can be used. Choose one in the dropdown menu, the tool will automatically determine the amount of t-km shipped based on the input.	Choose the actions that are of interest for your company in the left side menu. The chosen actions will be shown in the abatement curve.	The output of the tool is an abatement curve based on the data entered in Step 1 and Step 2. This curve can be changed by editing the company data in tab "Input" or by choosing different actions in tab "Action choice".	In the tab parameters it is possible to adjust different parameters used in the calculations. It is possible to change the distribution between motorway / urban / rural road per trip and the CO ₂ tax
The base line emissions will be calculated and are shown on the right, this information will be used in step 2, emission reduction of actions		On the left an overview is given of the chosen actions and their reduction / cost ratio per action.	
It is currently not possible in the tool to indicate which actions have already been implemented			Working principle of tool
			This tool provides the user with information about different road freight emission reduction actions
			By finishing the 2 different steps in tabs "Input" and "Action choice" the tool provides an overview of the reduction potential of the chosen actions and the corresponding costs of these actions in "Output"

Glossary	
Abatement curve	An abatement curve is a graph that shows the relation between reduction potential and cost for different emission reducing solutions. If the cost are negative, the company will make a profit if the action is implemented. By multiplying the width of the block with the height of the block x1000, the total cost of the action is given
CO ₂ tax	Price on CO ₂ emitted that differs per country
Emission factor	A GHG emission factor indicates the mass of carbon dioxide equivalent (CO ₂ e) released for a quantity of fuel or electricity used
EU ETS permit price	Current ETS permit price, transport is not included until 2026
Feedstock	The material of which the fuel is made, for electricity the source of the energy
HGV	Heavy goods vehicle
Internal CO ₂ tax	The price of carbon used internally
Road types	The different road types, urban road, rural road and highway, have different characteristics such as speed and stop and go
RT	Rigid truck
TT/AT	Truck Trailer / Articulated Truck
WTT	Well to tank
WTW	Well to Wheel

Information	Input	Parameters	Action choice	Calculations	Output	Data	HBEFA	Solution reference	Example of calculations
-------------	-------	------------	---------------	--------------	--------	------	-------	--------------------	-------------------------

Figure 23: Information tab

Sources

The sources used in this tool have been gathered in the last tab, solution reference. The links to the literature and grey literature used to determine the reduction potential and corresponding costs have been placed here.

5.3.2 Input

The second tab the user will see when the Excel tool is downloaded and opened is the input tab, see Figure 24. In this tab the user (shipper) will insert the information about the transport which is evaluated. This tab includes different roll-out menu's to provide the user with the available options. Because the scope of this research only focuses on Europe, the availability of regions only contains Europe. The possible countries available are all European countries, this is mainly of importance for electric vehicles because the emission factor of electricity differs a lot between countries and the emission factor is based on this input.

The next part of the input tab consist out of questions regarding the trip. The weight of shipments, the distance and current vehicle and fuel. To make the tool as easy to use as possible, the user is offered the possibility to enter the distance in

Step 1: Company data, fill in the yellow cells below				Calculations	
Area information		The yellow cells MUST be filled in		Calculations	
Type in your region:	Europe	The blue cells can be used for a more accurate outcome		Weight shipped	4000 kg
Type in the specific country:	Netherlands	If it is not known the default values in this tool will be used			4,00 tonne
Fuel information				Distance shipped	500 km
Type in current fuel:	Biodiesel_B5 (average)			Amount of tonne-km calculated	2000,00 tonne-km
IF hydrogen / electric, source:				Current emissions	
Shipment information				Total emissions of trip	195,13 kg CO ₂ e
Type in distance:	500 km	Choose a unit			0,20 tonne CO ₂ e
Origin	Netherlands	Fill in origin country for base case emission calculation			
Type in weight shipped (kg):	4000 kg	Choose a unit			
Amount of t-km (if known):		Leave blank if information is not known			
Vehicle used		Leave blank if information is not known			

Figure 24: Input tab

kilometer or miles and the weight in kilograms, tons or pounds. The tool will convert the provided distance and weight into one number, ton-kilometers.

On the right side of the tab a small overview is created. It tells the user the amount of ton-kilometers driven and the corresponding emissions based on the distance, weight, fuel and chosen vehicle. If no vehicle was chosen, the tool automatically chooses the smallest vehicle for that load.

Parameters

The calculations in the tool exist of different parameters that can differ based on vehicle category, fuel, road type, road situation and load. In this tab, the user can alter some of the parameters used in the emission calculation. This option is provided so the user can create the most accurate calculations for their shipment. The parameters that can be changed are:

1. Road type distribution
2. CO₂ tax and ETS pricing
3. Emission factors
4. Price of fuel
5. TCO of vehicles

Possibility to adjust parameters		Information on parameters																																																																											
In this tab it is possible to adjust some parameters if more information about the transport is known. The pink & yellow cells will be used in emission calculation replacing the default values in this tool. The yellow cells MUST be filled in, the blue cells can be changed, if not the default values in this tool will be used. <i>MUST be filled in according to HVC</i> <table border="1"> <thead> <tr> <th>Distribution road types</th> <th>urban area</th> <th>rural road</th> <th>motorway</th> </tr> </thead> <tbody> <tr> <td></td> <td>7%</td> <td>15%</td> <td>88%</td> </tr> </tbody> </table>		Distribution road types	urban area	rural road	motorway		7%	15%	88%	The emission profiles, as created by TNO are used on the Dutch motorway movements, can be seen on the below. Source: TNO-2018-R10214 The profiles are purely intended as a sample of how a truck behaves on a specific road. It is expected that the information will be used to determine the distribution of road type for the chosen trip based on company or product specific transport. In these velocity profiles no specific operations are included. These distributions are provided as an indication, it is therefore in no way a reflection of a chosen trip. It is expected that the user calculated their own distribution of road type based on the velocity profile. Other combinations can be added in the yellow cells on the right. <table border="1"> <thead> <tr> <th>Regional delivery</th> <th>DC-DC delivery</th> <th>Long-haulage</th> </tr> </thead> <tbody> <tr> <td>25%</td> <td>48%</td> <td>27%</td> </tr> <tr> <td>7%</td> <td>10%</td> <td>93%</td> </tr> </tbody> </table>		Regional delivery	DC-DC delivery	Long-haulage	25%	48%	27%	7%	10%	93%																																																									
Distribution road types	urban area	rural road	motorway																																																																										
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CO₂ tax <table border="1"> <tbody> <tr> <td>CO₂ tax</td> <td>1 42,00</td> <td>HHO2p</td> </tr> </tbody> </table> <i>This number has been set at 42 litansso but can be changed per country? An average has been used?</i> <i>If another value is used for internal calculation, please fill in the cells above with this value, this value can be</i> <i>MUST be filled in according to HVC</i> <table border="1"> <thead> <tr> <th>EU ETS carbon pricing</th> <th>HHO2p</th> </tr> </thead> <tbody> <tr> <td>1 906,00</td> <td>HHO2p</td> </tr> </tbody> </table> <i>MUST be filled in according to HVC</i> <table border="1"> <thead> <tr> <th>HHO2p</th> <th>HHO2p</th> </tr> </thead> <tbody> <tr> <td>1 142,00</td> <td>HHO2p</td> </tr> </tbody> </table>		CO ₂ tax	1 42,00	HHO2p	EU ETS carbon pricing	HHO2p	1 906,00	HHO2p	HHO2p	HHO2p	1 142,00	HHO2p	Emission factors ** <table border="1"> <thead> <tr> <th>fuel type</th> <th>CO₂e (g/kWh)</th> <th>CO₂e (g/kWh)</th> </tr> </thead> <tbody> <tr><td>Diesel</td><td>324,750</td><td></td></tr> <tr><td>Gasoline</td><td>298,820</td><td></td></tr> <tr><td>Gasoline/Ethanol blend 95/5</td><td>298,820</td><td></td></tr> <tr><td>Bioethanol E10 (ave)</td><td>298,820</td><td></td></tr> <tr><td>Bioethanol E15</td><td>298,820</td><td></td></tr> <tr><td>Bioethanol E85</td><td>298,820</td><td></td></tr> <tr><td>Diesel</td><td>324,750</td><td></td></tr> <tr><td>Bio-diesel B100</td><td>324,750</td><td></td></tr> <tr><td>Bio-diesel B5 (ave)</td><td>324,750</td><td></td></tr> <tr><td>Bio-diesel B7</td><td>324,750</td><td></td></tr> <tr><td>Bio-diesel B20</td><td>324,750</td><td></td></tr> <tr><td>Bio-diesel B50</td><td>324,750</td><td></td></tr> <tr><td>Liquefied Petroleum Gas (LPG)</td><td>298,820</td><td></td></tr> <tr><td>Compressed Natural Gas (CNG)</td><td>298,820</td><td></td></tr> <tr><td>Liquefied Natural Gas (LNG)</td><td>298,820</td><td></td></tr> <tr><td>Bio-LNG</td><td>298,820</td><td></td></tr> <tr><td>Bio-CNG</td><td>298,820</td><td></td></tr> <tr><td>HVO</td><td>298,820</td><td></td></tr> <tr><td>Electricity</td><td>298,820</td><td></td></tr> <tr><td>Hydrogen (grey)</td><td>298,820</td><td></td></tr> </tbody> </table> <i>** The emission factors from ISO 14063 are implemented in this tool, it is possible to change the emission factors if needed.</i>		fuel type	CO ₂ e (g/kWh)	CO ₂ e (g/kWh)	Diesel	324,750		Gasoline	298,820		Gasoline/Ethanol blend 95/5	298,820		Bioethanol E10 (ave)	298,820		Bioethanol E15	298,820		Bioethanol E85	298,820		Diesel	324,750		Bio-diesel B100	324,750		Bio-diesel B5 (ave)	324,750		Bio-diesel B7	324,750		Bio-diesel B20	324,750		Bio-diesel B50	324,750		Liquefied Petroleum Gas (LPG)	298,820		Compressed Natural Gas (CNG)	298,820		Liquefied Natural Gas (LNG)	298,820		Bio-LNG	298,820		Bio-CNG	298,820		HVO	298,820		Electricity	298,820		Hydrogen (grey)	298,820	
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Hydrogen (grey)	298,820																																																																												

Figure 25: Parameters tab

The road type distribution is different per trip and thus no accurate estimate can be given. An indication is provided to help the user if the distribution is not known, to understand the difference between the three road categories the velocity profiles of Verbeek et al. (2018) for the different road types have been added. The three indications for different types of trips are: Regional delivery, DC-DC delivery and long-haul delivery. It is expected that the user will use this data to decide on the road type distribution of their trip and change the default values accordingly.

The CO₂ tax and ETS pricing can also be altered. As companies can make use of an internal CO₂ tax, this can be entered here. The CO₂ tax can have a different value per country and a link is provided with information on the CO₂ tax per

country. As the ETS pricing is not mandatory for road transport, this can be set either to zero or to a value that is expected from 2026, when the ETS will include road transport. A link is also provided here with the daily price of ETS permits.

The emission factors used in the calculation are the same factors as in the GLEC framework, however if a company wants to use other emission factors it can provide the specific emission factor here.

The price per litre of fuel can be changed to provide the option to companies to fill in the price they agreed on with their carrier or LSP. The price that is used in the tool is the fuel price of September 2022 with taxes. Again a link is provided to the current fuel prices per country so that companies can use the most accurate data if wanted. As the price of fuel varies from day to day, it is advised to adjust the prices.

Actions

In the action tab the user chooses the actions that are of interest. The different actions have been sorted in the same categories as explained in the book of Alan McKinnon and the columns that are being used in the GLEC framework. Because the purpose of the tool is to start and improve collaboration between shippers and carriers, only actions are included that need effort of shippers and carriers.

By clicking the checkbox before an action, the tool will automatically calculate the emission reduction potential and create an abatement curve. In this curve the reduction potential is placed on the x-axis, the cost per tonne CO_2e is placed on the y-axis. Some actions are place in a roll-out menu, this will ensure that no two actions can be chosen at the same time that are actually mutually exclusive. The abatement curve allows a maximum of 6 actions in the curve at the same time. If more actions are clicked, the action with the highest cost will be removed and the six with the lowest cost are displayed. A red line is added in the curve if the user determines a cost on carbon by filling in the related cells in the "parameters" tab.

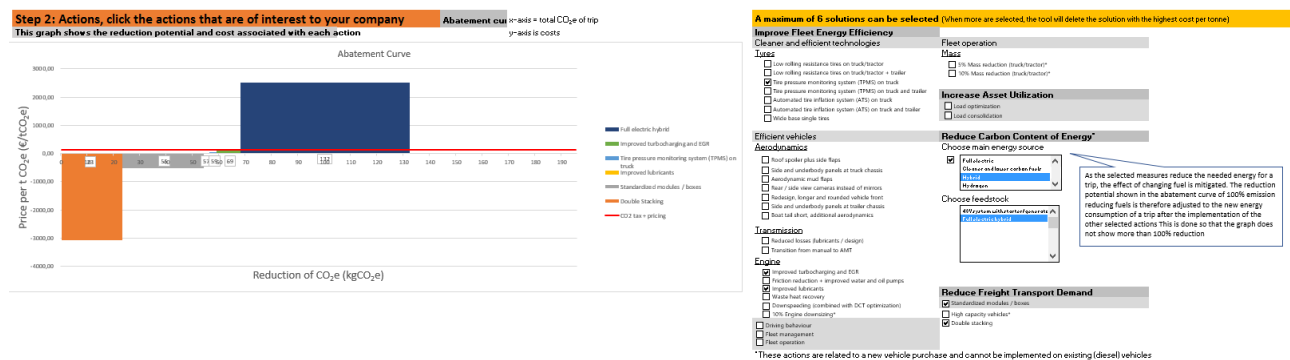


Figure 26: Action tab

Output

In the second-to-last visible tab, the user can see a summary of all the information provided, the chosen actions and related reduction and cost. If the user wants to change something earlier in the tool, the output will also change and the user can see the new conclusions. The total reduction per trip is based on implementing the second action after the first action. This results in an adjusted reduction percentage that is not the same as adding the different reduction potentials.

Example of calculations If the user wants to know more about the calculations done in the tool to determine the emissions and the costs, this tab can be viewed. An overview of the calculations done in the tool is presented here with the formulas that are used. An example is shown that walks through the formulas. If the user is interested in the sources of the data in the tool, the tab "Solution reference" can be viewed.

5.3.3 Background

The tabs that are not visible to the user contain the calculations needed to display the abatement curve and the information on emissions. There is also one tab that is shielded from the user because it is not of interest to the user. This is the tab that contains the information used to create the roll-out menu's and the interface of the tool. Different lists of country names and fuel sorts are located here. This tab only needs to be accessed if more countries or fuels need to be added to the list.

HBEFA

After filling in the input tab, the tool will automatically calculate the current emissions and display them at the input tab. These calculations are done in the HBEFA tab, the energy consumption values based on the fuel and vehicle chosen are used together with the chosen emission factor. All this information is stored in this tab.

After this the parameters can be changed, if the user has made changes, the data in this tab will change accordingly and

Step 3: Output, an abatement curve is created based on the input from step 1 & 2

Current emissions of trip 0,20 t CO₂e

Chosen actions	Reduction potential	Total cost / benefits	Cost / reduction ratio (euro / % reduction)
Double Stacking	12%	€ -72	€ -599
Standardized modules / boxes	16%	€ -16	€ -100
Improved lubricants	1%	€ 0	€ 2
Tire pressure monitoring system (TPMS) on truck	1%	€ 0	€ 11
Improved turbocharging and EGR	5%	€ 1	€ 20
Full electric hybrid	33%	€ 161	€ 491,28

New emissions per trip	0,090 t CO ₂ e
Total reduction per trip	-54% CO ₂ e
Total extra cost per trip	€ -87
Carbon tax savings	€ 15
Total cost savings	€ 102

The total reduction of all actions is determined as if the actions are implemented after one another, not simply adding all reduction percentages

All costs are approximations based on literature, the exact costs depend on many different factors such as implementation order, implementation successfulness, action provider and availability

Information	Input	Parameters	Action choice	Calculations	Output	Data	HBEFA	Solution reference	Example of calculations	+	⋮
-------------	-------	------------	---------------	--------------	--------	------	-------	--------------------	-------------------------	---	---

Figure 27: Output tab

the new values will be used in the current emission calculations as well as in the calculations to determine the emissions after implementation of an action.

When the user moves to the action tab, a solution is chosen. If that entails changing fuels, two other tabs will be also be used. If an electric vehicle is chosen, the tab "Electricity" is used to determine the emission factor of the chosen electricity source for that specific country. This information is then used in the emission calculation in the "Solution cost" tab. If a new fuel is chosen, the calculations to determine the amount of fuel and the corresponding emissions will also take place here. The resulting emissions are then used in the "Data" tab to determine the emission reduction potential. If the user filled in their own emission factors or fuel price, the tool automatically takes these factors into account, if no extra information is provided, the tool uses the default values.

Data

In the "Data" tab, the final data of the different actions is collected. The different emission reductions and costs are calculated in the tab "Solution cost" making use of the information from the tab "HBEFA", the input of the user and information on the TCO of the available vehicles and the cost of fuel. Here, the final data is presented and it is also recorded if an action is clicked. A list is then created of all the actions that are selected and this is presented on this tab.

Calculations

This list is then transferred to a new tab: "Calculations". The list is then sorted on the lowest cost per tonne of CO₂e and from this the input for the abatement curve is created. The information provided by the user on the cost of carbon is used for the red line in the figure.

The list sorted on the lowest cost per tonne is used to create a table with the reduction potential and the cost per tonne. This table is the input for the abatement curve. The last value for the x-axis is the total amount of emissions of the trip, this way the user can see which emissions are reduced and also the amount of emissions that are not reduced.

5.3.4 Use

As mentioned in Section 1.3, the goal of this information tool is to inform shippers about the reduction possibilities in road freight transport with the aim of starting a conversation between shippers and carriers to work together on reducing greenhouse gas emissions. This tool provides the shipper with information on the reduction potential and the corresponding costs of different emission reducing possibilities for their outsourced transport. By using this tool, the shipper gets a clearer picture of the different solutions to reduce their scope 3 emissions.

The shipper can get access to this information tool if it is part of the SFBA initiative at SFC. The tool will be located at the platform for SFBA and it must be downloaded before use. The shipper must be in possession of an Microsoft Excel license in order to open the file, this will not be provided by SFC. When the file has been downloaded, it can be opened and the tool can be used.

Extra information on how this tool can be deployed within SFBA is given in a separate document explaining the usability in more detail, this document is added in Appendix D.

5.3.5 Maintenance

As mentioned, the tool has been build in Excel and can therefore be easily maintained. A document (See Appendix C) has been created with an elaborate explanation of the working principle of the background of the tool. This document contains explanations on all different calculations used in the tool, how they work, which data they use and where that data comes from. The document will be password protected to make sure that users do not change text, values or calculation that should not be changed. The password itself will also be in this maintenance document. Because the tool relies on the accuracy of the data used for the calculations and the actions, it is recommended to maintain the tool regularly. On the one hand to make sure the actions included are available and to ensure that new emission reducing techniques are taken into account in the tool and the emission factors and costs data are up to date.

The most variable parameters in the tool are the cost of the different fuels, it is advised to alter these values every six months. The default values available in the tool for the cost of the different actions and their availability should be checked and updated every year together with the emission factors for electricity generation in the different European countries. As the cost of the different vehicles technologies can also be changed by the user, this must be checked every year to make sure it does not deviate much from the current costs of these vehicles, but changing these values can be done every other year. The provided distribution profiles of road types in the tool are based on existing literature, as not much research has been done on this topic yet, it is advised to keep an eye out for new studies and adjust or elaborate more on this when more information becomes available. Finally, it is recommended to change the emission factors and the energy consumption factors at the same time that the GLEC factors are being updated, to maintain the same values across SFC as well as keeping the tool up to date. The emission factors are currently from the ISO 14083, these numbers are valid until a new update will occur. As the GLEC will also stay up to date with the latest emission factors available, no extra update moment is needed.

Since the tool was created within SFBA, it is expected that the tool will be maintained by someone working on this initiative. Due to the extent to which technical information is used in the tool, it is recommended to assign someone from the technical team to maintain the tool. This person must read the maintenance document, after which a recurring moment is scheduled in the agenda in which the updates and checks for the tool are carried out so that they are not forgotten.

6 Substantive Analysis of the Tool

The use of this tool is tested in this chapter. In the first section, two examples are given in which the use of this tool is demonstrated. In the first example it can be seen what the different outputs are of the tool and how the actions chosen are presented in the abatement curve. In the second example, some of the parameters are changed and the effect on the different actions can be seen. The next section of this chapter shows the effect of the different uncertainties in this tool. The different parameters that contain uncertainty are varied and the response of the output can be seen below. This section also contains a sensitivity analysis of the user input. This analysis provides the user with knowledge on the inputs that more sensitive to a large effect on the output and which inputs are less important.

6.1 Examples of use

For this example the following transport data has been used in the tool as the base case:

- Country: Iceland
- Current fuel: Bio-diesel B5 (average)
- Distance: 500 km
- Country of Origin: Iceland
- Weight of shipment: 2500 kg
- Vehicle choice: No vehicle is selected

In the parameter tab, the road type distribution (RTD) is set to the long haul distribution and the CO_2 tax is set to 100€/t. The fuel price and TCO were not changed for the base case situation.

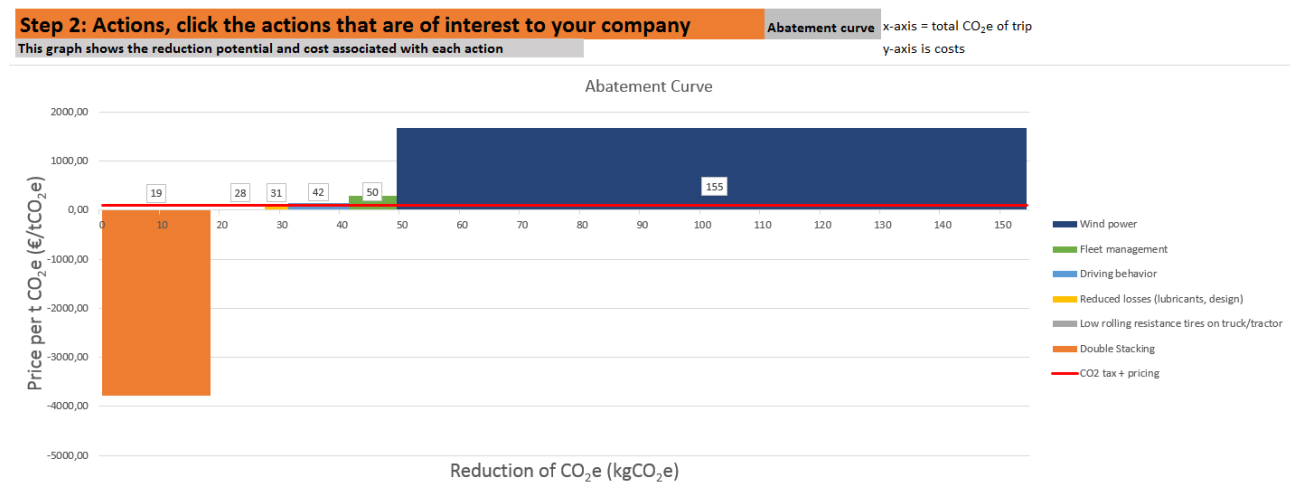


Figure 28: Base case example

In the action tab, the following actions are selected:

- Low rolling resistance tires
- Driving behaviour
- Fleet management
- Double stacking
- Reduced losses (lubricants or design)
- Full Electric - Wind power

In the figure, it can be seen that 100% of the emissions are reduced if all actions are implemented. In Figure 26, it was mentioned that for the vehicles that reduce 100% of the emissions, the abatement curve is adjusted so that no more than 100% of the emissions is reduced. The energy consumption reduction from other actions is already taken into account. In Figure 28, the actions on and below the red line will not cost the carrier money to implement. The other actions do require an investment. Implementing electric vehicles is the most expensive action shown, where the three actions on the left do not require an investment.

If the price of diesel is altered to 3.50€/l and the road type distribution is changed to a more urban environment, the abatement curves changes and looks like this.

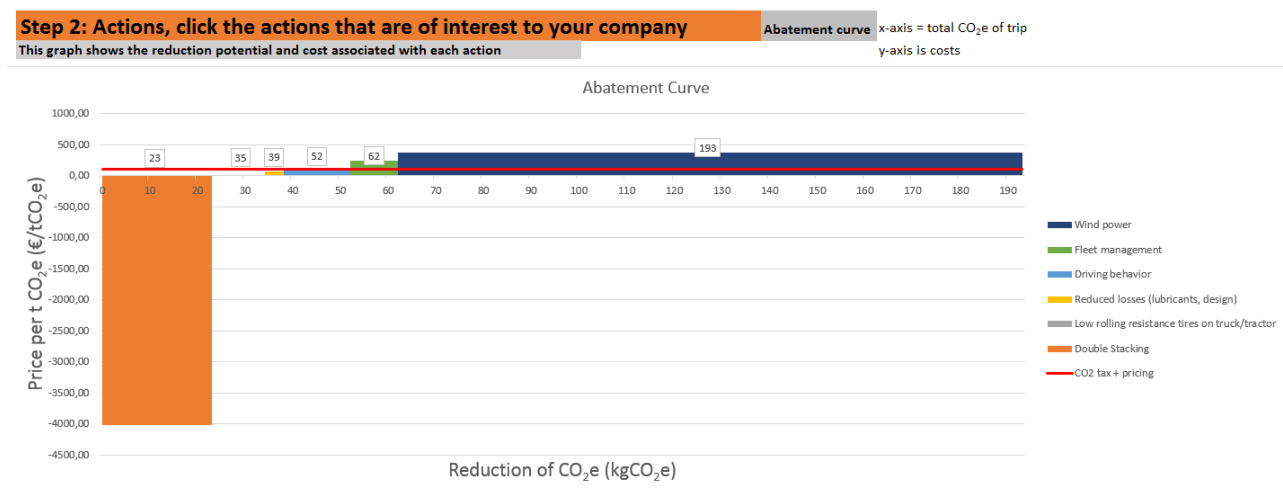


Figure 29: Abatement curve after changing parameters

The reduction potential of the actions stays the same but the cost of the actions is changed. Driving behaviour is now almost as expensive as the carbon price and double stacking reduced even more than in the base case. The biggest change can be seen for the electric vehicles, it is still more expensive but the difference is a lot smaller.

6.1.1 Output

The overview of the output of the base case can be seen in Figure 30. It shows the 100% emission reduction and the total cost savings per trip are negative. This indicated that the cost of the trip will be more expensive if all actions are implemented. This overview can be used to find the actions that result in a savings per trip.

Step 3: Output, an abatement curve is created based on the input from step 1 & 2

Current emissions of trip 0,15 t CO₂e

Chosen actions	Reduction potential	Total cost / benefits	Cost / reduction ratio (euro / % reduction)
Double Stacking	12%	€ -70	€ -585
Low rolling resistance tires on truck/tractor	6%	€ 0	€ 2
Reduced losses (lubricants, design)	2%	€ 0	€ 11
Driving behavior	7%	€ 2	€ 21
Fleet management	5%	€ 2	€ 45
Wind power	100%	€ 176	€ 176,23

New emissions per trip	0,000 t CO ₂ e
Total reduction per trip	-100% CO ₂ e
Total extra cost per trip	€ 110
Carbon tax savings	€ 15
Total cost savings	€ -95

Figure 30: Overview of the output of the base case

In the overview of the output of the altered base case, the cost are positive. This means that if all actions are implemented the cost of the trip will be less than in the current situation. This shows that the viability of the action choice relies heavily on the fuel price and the trip specifications such as the road type distribution.

Step 3: Output, an abatement curve is created based on the input from step 1 & 2

Current emissions of trip 0,19 t CO₂e

Chosen actions	Reduction potential	Total cost / benefits	Cost / reduction ratio (euro / % reduction)
Double Stacking	12%	€ -93	€ -776
Low rolling resistance tires on truck/tractor	6%	€ 0	€ 2
Reduced losses (lubricants, design)	2%	€ 0	€ 11
Driving behavior	7%	€ 2	€ 21
Fleet management	5%	€ 2	€ 45
Wind power	100%	€ 49	€ 49,12

New emissions per trip	0,000 t CO ₂ e
Total reduction per trip	-100% CO ₂ e
Total extra cost per trip	€ -40
Carbon tax savings	€ 19
Total cost savings	€ 59

Figure 31: Overview of the output of the altered base case

6.2 Effect of uncertainties

In Section 5.2.7, the different parameters of the tool are mentioned and it is explained which parameters contain uncertainty. In this section, the different parameters in the tool that are entered by the user are varied and the tool itself is used to perform a sensitivity analysis. By changing the values of the base case with an estimated magnitude of uncertainty, the sensitivity of these parameters is shown.

6.2.1 Sensitivity analysis of user input

The parameters mentioned in Section 5.2.7 that are entered by the user and contain uncertainty are:

- Weight of shipment
- Distance
- Vehicle choice
- Road type distribution
- Fuel price
- Total cost of ownership

The estimated magnitude of uncertainty is based on the differences per country, the differences with time or an estimate of the order of magnitude in which the user may have entered his transport data incorrectly. For the weight and the distance of the shipment this is estimated to be 10% lower or higher. For the vehicle choice the default option is chosen and a commonly used larger vehicle was used. The road type distribution is first estimated as the default and then changed to contain a little more urban and rural and for the second run to contain 100% more urban and 50% more rural. As the fuel price can vary significantly between countries, a price +0.50€/l and a price -0.50€/l was tested. The total cost of ownership was varied for an electric vehicle with +50.000€ and -50.000€.

Base case

For this evaluation, the same base case is used as for the examples in Section 6.1, only the country is changed to Germany.

Effect on emission calculations and base costs

First, the effect that the changes have on the emission calculations and cost estimate of the base case was examined. The estimated magnitudes of uncertainty were used and the emission calculations are compared as well as the cost for the base case.

In Table 15 it can be seen that varying the different parameters has different effects on the outcome. Changing the weight of the shipment does not have a big effect on the emissions as well as the cost. Varying the distance of the trip with

Table 15: Sensitivity analysis of the user input

	Base case	Weight		Distance		Vehicle	RTD		Fuel price	
Weight (kg)	2500	2250 (-10%)	2750 (+10%)	2500	2500	2500	2500	2500	2500	2500
Distance (km)	500	500	500	450 (-10%)	550 (+10%)	500	500	500	500	500
Vehicle type	Default	Default	Default	Default	Default	RT 20-26t	Default	Default	Default	Default
RTD (MW/R/U)	80/13/7	80/13/7	80/13/7	80/13/7	80/13/7	80/13/7	76/15/9	63/23/14	80/13/7	80/13/7
Fuel price (€/l)	Default	Default	Default	Default	Default	Default	Default	Default	1.40 (-0.5)	2.40 (+0.5)
Output (kg CO_{2e})	154.64	152.39 -1.45%	156.90 1.46%	139.18 -10%	170.10 10%	315.65 204%	170.22 10%	218.35 41.2%	154.64 0%	154.64 0%
Cost (€)	390.10	388.86 -0.3%	391.52 0.4%	351.09 -10%	429.11 10%	491.72 26%	399.93 2.5%	430.30 10.3%	364.42 -6.6%	415.78 6.6%

10% also changes the outcome of the cost as well as the emissions with 10%. This is because the distance of the trip is used in the emission calculations as well as the fuel consumption and the cost of the trip, as this is based on the first ownership principle. The vehicle choice contains the biggest uncertainty as a change in vehicle can impact the emissions enormously. The costs are also higher but it is not as different as the emissions. Changing the road type distribution is also of importance, the difference in emissions is large when looked at the small changes in distribution. The cost are also higher but not in the same proportions as the emissions. It can be seen that changing the fuel price directly impacts the trip costs. However a large deviation of >30% relates to a smaller increase or decrease in total costs. The two parameters that are the most sensitive to change are the vehicle choice and the road type distribution.

Effect on actions

After this, the effect on the chosen actions is examined. In this part of the sensitivity analysis also the TCO is changed to investigate the effects. The chosen actions are full electric hybrid vehicles on a grid and diesel mix, low rolling resistance tires on truck and double stacking.

In Table 16 it can be seen that the three chosen actions react differently to the changes in parameters. The emission reduction potential of the full electric hybrid vehicle only changes when the vehicle type is changed or the road type distribution. Both parameters change the energy consumption of the trip and impact the emission reduction potential of the action. The costs of this action vary between €49 and €197, again the vehicle choice has an influence as well as the TCO of the vehicles. For the action low rolling resistance tires on truck, no change in emission reduction potential or costs can be seen. As this action will reduce the emissions of trucks in every situation, this was expected. The effect of double stacking on the emissions also stays the same for all parameter changes. This action is based on improving the load factor of a vehicle and this stays the same for all parameter changes. The decrease in transport cost varies a little because of the amount of fuel used for the transport, but the changes are not mayor.

When looked at the total emission reduction potential of the three actions combined, the same can be seen as for the full hybrid electric vehicles. As these emission reduction potentials are the only ones that change with different parameter changes, this is as expected. The most emission reduction potential can be reached when a larger vehicle is used. If the vehicle from the base case is used, no parameter influences the total emission reduction potential drastically. In Table 16 it can be seen that the cost associated with these actions are heavily influenced by the parameter changes.

Using the outcome of the sensitivity analysis, an assumption can be done on the viability of zero emission vehicles in the future. As the prices are expected to move towards each other, the gap between the TCO's will become very small or even zero. The cost of fuel is expected to differentiate further and thus make alternative fuels more attractive.

Table 16: Sensitivity effect on actions

Action	Parameter change		Emissions reduction potential	Cost (€)
Full electric hybrid	Base		41%	150
	Weight change	-10%	41%	151
		+10%	41%	150
	Distance	-10%	41%	136
		+10%	41%	165
	Vehicle	RT 20-26t	71%	49
	RTD	Small	41%	148
		Medium	40%	139
	Fuel price	-0.50	41%	165
		+0.50	41%	135
	TCO diesel	-50.000	41%	189
		+50.000	41%	98
Low rolling resistance tires on truck	TCO hybrid	-50.000	41%	106
		+50.000	41%	197
	Base		6%	+/- 0
	Weight change	-10%	6%	+/- 0
		+10%	6%	+/- 0
	Distance	-10%	6%	+/- 0
		+10%	6%	+/- 0
	Vehicle	RT 20-26t	6%	+/- 0
	RTD	Small	6%	+/- 0
		Medium	6%	+/- 0
	Fuel price	-0.50	6%	+/- 0
		+0.50	6%	+/- 0
Double stacking	TCO diesel	-50.000	6%	+/- 0
		+50.000	6%	+/- 0
	Base		12%	-70
	Weight change	-10%	12%	-70
		+10%	12%	-70
	Distance	-10%	12%	-63
		+10%	12%	-77
	Vehicle	RT 20-26t	12%	-88
	RTD	Small	12%	-72
		Medium	12%	-77
	Fuel price	-0.50	12%	-65
		+0.50	12%	-75
	TCO diesel	-50.000	12%	-63
		+50.000	12%	-80

Table 17: Total emission reduction after the implementation of the three actions

Parameter change		Total emission reduction
Base		52%
Weight change	-10%	52%
	+10%	52%
Distance	-10%	52%
	+10%	52%
Vehicle	RT 20-26t	76%
RTD	Small	51%
	Medium	50%
Fuel price	-0.50	52%
	+0.50	52%
TCO diesel	-50.000	52%
	+50.000	52%
TCO hybrid	-50.000	52%
	+50.000	52%

7 Verification & Validation

In this chapter the design is tested against the requirements, verification, and the tool is validated. The validation of the tool took place in different stages of designing the tool, only the last validation will be discussed. Validating the tool included several tests that focused on the correct execution of the different formula's used in the tool and included interviews with employees of SFC and an associated consultant with previous work experience at shipper companies.

7.1 Verification

The design of the tool was checked using the requirements developed in Section 4.3. The functional requirements that were drawn up were used to develop the design. All the functional requirements have been implemented and met. The non functional requirements have been test by sending the tool to potential users and employees of SFC. Since there has been no response from any potential users, the verification of the non-functional requirements relies on the employees of SFC. Below the different non-functional requirements are shown with the summarized reactions from the interviewed employees.

1. The tool should be easy to use
The information in the tool is clear and provides the user with the needed knowledge to use the tool. The questions asked on the "input" tab are very easy, these can be answered by shipper companies
2. The tool should include information on the working principle of the tool
The working principle of the tool is clear from the information provided in the tool itself. The extra information provided in accompanied manual was not needed to make use of the tool, however it offers interesting insights in the working principle
3. The tool should be understandable for users with a road freight logistics background
The information in the tool made it easy to understand, some extra information can be added on the "action choice" tab on how the chosen actions are sorted. Also more information on the output tab can be added to explain the total emission reduction
4. The tool should present the emission reduction possibilities in a meaningful way to shippers
This was checked during a second set of interviews, the result can be seen below
5. The tool should display the outcome in a clear way
See above
6. The tool should be possible to download
The tool was send via email and was downloaded, all the functions of the tool worked
7. The tool should be accessible on the SFBA platform
This could not be tested and is handed over to the commissioner of the tool
8. The tool should be available as a MS Excel download file
As the tool is build in Excel, the tool is only available in Excel
9. The tool should have a size that is downloadable
The size of the tool is quite small and thus easy to download
10. The tool should work with all versions of MS Excel
See the answer to requirement 5
11. The tool should be easy to maintain (C)
The maintenance document added in Appendix C provides a clear overview of how the tool can be maintained by SFC in the future. The layout of the tool is simple, by adding more informative headings in the hidden tabs, it will be easier to locate all the specific data

7.2 Validation

The validation of the tool exist out of two parts, first it is checked that the tool provides the right output, the calculations to provide this result are correct and that there are no mistakes made with units and conversion of units. The second part checks whether the tools meets the needs of the commissioner and the other stakeholders.

7.2.1 Validation of calculations used in tool

To see if the emission calculation of the current state is working correctly, the origin of transport, weight of shipment, fuel and distance have been entered in the tool. The vehicle choice was left to the tool and the distribution of road types was left in a default state. The outcome of the calculations done by the tool on the "input" tab correspond to the calculations done by hand. The tool is executing the current state emission calculation formula's correctly. When checking the units of the data provided in the tool, the different steps calculations steps were walked through and it was seen that the right units were presented to the user of the tool.

Second the emission calculations of actions has been done. The factors corresponding to the emission reduction actions have been entered at the "Data" tab and the emission calculation is done on this tab as well. When an action is clicked, the tool automatically calculates the corresponding emission reduction and cost. The costs corresponding to the action are scaled using the distance filled in in the "input" tab and the average amount of kilometres driven in the first 5 years from the first user principle. This works correctly in the tool and is done for every action. The emission reduction calculations differ per action, it was tested if selecting a more polluting fuel created an increase in emissions. This did occur, however the complete graph started to look different. When a fuel was chosen with a lower carbon content, the graph did work and showed the emission reduction potential of the chosen action. All the actions and their corresponding emission reduction potential and costs are also shown in a table below the abatement curve, showing the percentage reduction and an estimation of the cost increase or decrease.

7.2.2 Validation of tool by commissioner

During a second set of interviews with employees of SFC and an associated consultant, the tool was validated to see if it satisfied the needs of the commissioner and it is checked if they expect the tool to be meaningful for the intended users. The interviews were conducted with the technical manager of SFBA, the director of SFBA and with a consultant associated with SFBA who has previous work experience at shipper companies. The outcome of the different interviews is presented below, the answers are paraphrased and then checked by the interviewees.

James: Technical manager Sustainable Freight Buyers Alliance

Question 1: "What makes a decarbonization tool for road freight logistics meaningful for shippers?"

The tool must be easy to use and it must be possible to use own parameters and data. Making it possible for the user to adjust the calculations by making use of their own values will make the tool more valuable to shippers. Shippers look for information that is specific to their transport and not high level information, by adjusting parameters this can be achieved. The output of the tool must be clear and the method and calculations used to determine this should be provided. The cost calculations are especially of interest for shippers, the sources of information are of importance as well as a detailed overview of which costs are taken into account and how the calculations are done.

Question 2: "Is this tool considered meaningful and what can be added to increase the use of this tool?"

Yes, this tool is meaningful for shippers. It is very useful to be able to change parameters, making it possible to also change the Total Cost of Ownership of the different vehicles increases the value of the tool. The different velocity profiles in the parameter tab are clear and can help the user in defining the distribution of road types for the chosen trip. Including information on road type distribution for distinct trips can make it easier for the user. Another addition could be showing the user the ease of implementing the actions, which actions take more time to implement or require bigger changes in the operating strategy of the company.

Question 3: "How is the tool useful for shippers?"

The tool empowers the shippers to start a conversation with their carriers with well-founded data and insights. It can also help the shipper in creating insights in improvements in their own supply chain. By providing the user with the sources of all the information used, the user can follow up on that information to verify it before talking to the shipper, providing certainty on the data used in the tool.

Question 4: "Are all the requirements met?"

The requirements that were drawn up are almost all met, some do have improvements for the future. Functional requirement 7 only applies to the electric vehicles, but is met for these vehicles. Functional requirement 8 regards to the list of actions in the tool, this requirement is met but a future improvement can be to explain all the different actions in the tool. Functional requirement 11, the tool shall show the different actions in an abatement curve, explain better why only 6 actions are chosen in the tool so the user understands the importance of this, however the requirement is met. Non-functional requirement 2, information on the working principle of the tool, make this more clear by adding an example in the tool to make users understand the calculations made in the tool to increase the usefulness of the tool.

John: Sustainable Logistics and Supply Chain Management Consultant

Question 1: "What makes a decarbonization tool for road freight logistics meaningful for shippers?"

The tool must be easy to understand, logical in its use, clear and concise. The questions asked must also be easy to answer. A clear overview of the actions must be given and the if visuals are used, these must be intuitive. Extra explanations should be available for all aspects of the tool that are not common knowledge and calculations done by the tool that are not visible must be explained.

Question 2: "Is this tool considered meaningful and what can be added to increase the use of this tool?"

This tool has all the demands of a meaningful tool. Some things can be better explained, such as the difference between actions for their own gain, for example creating the opportunity for double stacking and the actions that must be implemented by carriers. If a better explanation is given of why these other actions are also of interest to a shipper, the value of this tool will be increased. It was also not completely clear to me how an abatement curve works, if more information can be provided on this in the glossary, the figure will make more impact. Other improvements are mainly to create a better layout of the tool, make it more sexy and intuitive to use.

Question 3: "How is the tool useful for shippers?"

In the tool shippers can see the different options clearly to reduce carbon emissions of their transport. This will definitely drive the shippers to start a conversation in-house and can make a difference in moving from talking about emission reduction to starting to make plans.

Eszter: Director of the Sustainable Freight Buyers Alliance

Question 1: "What makes a decarbonization tool for road freight logistics meaningful for shippers?"

Most of the shippers outsource their road freight activities. But there are shippers which do own some assets. A meaningful tool should probably provide help for both groups, meaning that it should support making decarbonization decisions for own fleets and also should support the discussion with logistics service provider and carriers about their choices. A meaningful tool for road freight decarbonization should include information on all main decarbonization actions and this data should be up to date. New or extra information should be added regularly and updates should be done if more information is available from the industry or literature. A meaningful tool also makes use of current practice information to create a more accurate estimation of reduction potential and costs. Road freight decarbonization solutions and technologies are evolving in a fast pace and so does their availability and cost as well, the tool can remain meaningful if it reflects these changes and updates.

Question 2: "Is this tool considered meaningful and what can be added to increase the use of this tool?"

This tool is definitely meaningful. If the data in the tool is kept up to date and new information is added in the future, the tool will stay meaningful. Real time experiences from projects of SFBA and other SFC activities should be added as well. In the future the tool can be made more accessible by rebuilding it and making it a web-based tool instead of Excel, although that might create barriers concerning data. To eliminate data issues, the shippers could purchase the program of the tool, while SFC would give the program and the updates to it. Just to mention a possible way forward, but we will possibly need to do further testing and planning before deciding on these functional solutions.

Question 3: "How is the tool useful for shippers?"

It is a great tool to play with and calculate and estimate the impacts of different actions. Both for direct interventions and as a base/intelligence for discussion with logistics service providers. I am not sure if this tool will generate projects for SFBA, but it can help companies to see and pre-calculate the potential impact of the interventions linked to the projects. It can also be used to estimate the emission reduction of potential projects and play a useful role in SFBA in that way.

7.3 Process environment

The tool created in this thesis will be used by SFC and added to their knowledge sharing platform. During the second set of validation interviews, the role that this tool can play within SFC and SFBA was discussed as well as how this tool contributes to the already existing tools and initiatives. In this section the context in which this tool can be used in the future is discussed as well as how it is related to the existing tools and information available.

7.3.1 Usability in SFBA

During the validation interviews with SFC employees, the question was asked how this tool fits within SFBA. The following answers were given:

James: Technical manager Sustainable Freight Buyers Alliance

The tool is one of the levers that shippers have in order to create insights into decarbonization to enable more confidence in conversations with service providers. The SFBA fuel benchmarking tool (other tool created by SFBA) intends to provide a global coverage of the impact that fuel (and feedstock) choices can have on operational emissions (and within the fuel supply chain). This tool takes the analysis to a much deeper level for a more narrow band of (European) country cases. An attempt is made to quantify the associated costs and so enable the user to have an informed discussion with service providers about which interventions make the most sense considering the nature of the logistics lanes and the age/status of the fleet. This can help to form the basis for prioritizing actions (which is absent from the other fuel emissions benchmark tool). This information also provides a context for the advice that SFBA is preparing for members on how procurement as a strategic tool can be used to decarbonize outsourced freight services. In some cases it may perhaps also contribute to how members consider which SFBA projects they may wish to participate in. Cost is a sensitive and critical element of these types of decisions and this tool aims to provide a baseline cost of CO_2 . However, it will be important to provide clear disclosure of how the costs are put together in order to gain a high level of trust from users.

Eszter: Director of the Sustainable Freight Buyers Alliance

This tool is very educational and is therefore very useful for the current Solutions Hub of SFBA. In the future the tool should be available to all SFC members so they can play with the tool and see the impact of the different actions. It can also be used to determine the impact of SFBA projects and the outcome of these projects can again be used to improve the information in the tool. The cost estimate that is provided in the tool is a big bonus for the companies as there is not a lot of data available about this. At the same time this also makes the tool sensitive to market changes and developments. The tool could be a good additional service of existing tool providers, there is currently little available with this kind of information on actions and cost in one tool.

SFBA contains different tools, all with their own purpose and properties. With this knowledge platform, SFBA wants to provide the user with helpful information and knowledge on reducing scope 3 emissions. This tool will be an addition to the other tools available within SFBA as it brings together costs and emission reduction potential. The benchmarking tool provides an overview of the impact of fuel choice and both tools can be used together. The initiatives map shows the user the existing initiatives that companies can join and the collaboration catalyzer helps companies find projects that are of interest. Within the collaboration catalyzer the tool can provide insight in the associated costs and emission reduction potential of the projects. The GLEC Framework can be used to provide more insight in the calculation and reporting of emissions, next to the calculations done in the tool.

7.3.2 Contribution to existing literature, tools and initiative

From the literature research on the state of the art of existing tools and initiatives, a map was created. This map consists out of 4 parts, calculations methods, initiatives with information on actions, tools and collaboration initiatives. The existing tools and programs are shown in this map, Figure 32. The tool created in this thesis is, as said, a tool which contains a calculation method and also information on the actions presented in the tool. The big red dot represents where the tool fits in this map and also shows that it is connected to the smaller dots located in the parts that are also fitting. Combining a calculation method with the information on actions in one tool is what makes it unique and shows how it is an addition to the tools and initiatives that already exist.



Figure 32: Overview of existing tools and initiatives

8 Conclusion & Recommendations

In this chapter the conclusion of the research as well as the discussion and the recommendations are presented. In the conclusion, the research question and the sub-question will be answered. The discussion includes uncertainties and elaborates on the influence of the scope of this research. At last recommendations are given for further research and for further improvements of the tool.

8.1 Conclusion

From this research, it can be concluded that insights in emission reduction potential for road freight can help shippers reduce their transport emissions. With the help of the tool created for this thesis, shippers are provided the opportunity to see the impacts of possible emission reducing solutions on their supply chain in emission reduction and cost.

According to the requirements of the client, Smart Freight Centre, the tool uses the same calculation methods and values as used in the GLEC framework. The tool is built in Excel and a maintenance document is provided in the appendix to help keep the tool up to date.

From Chapter 6, it can be concluded that the vehicle choice and the road type distribution have the greatest effect on the outcome of the tool. In order to obtain the most reliable results from the tool, the shipper is encouraged to fill in their own data in the 'parameters' tab in the tool and select the vehicle that fits best on the 'input' tab as every trip is different. The provided averages in the tool serve as possible values for the parameters based on average European numbers. They are not specified according to the input given by the shipper on the tab 'input' and are therefore not representative for the trip.

The answer to the main research question and the sub-questions are:

1. Which aspects are of importance for companies when deciding on the ultimate choice for projects that reduce emissions?
From the interviews it was clear that cost is the most important aspect. The ratio between reduction potential and cost plays a distinct role when decisions regarding less polluting transport are being made.
2. Which information must the tool provide in order to inform the shipper?
The tool must provide an indication of emission reduction potential based on the current practice and the increase or decrease in transport cost.
3. What data do companies need to enter in the tool?
In order to determine the current emissions for a trip, a shipper must answer the following questions:
 - (a) Region of transport
 - (b) Country of origin of transport
 - (c) Current fuel
 - (d) Distance (km or miles)
 - (e) Weight shipped (load, in kg, tonne or pounds)
 - (f) If known: Vehicle used

(g) *The distribution of road types (urban, rural and motorway)*

(h) *CO₂ cost estimate*

(i) *If preferred: own emission factors and fuel prices*

4. How can the effective emission reduction be determined?

The equations mentioned in Section 5.2.2 have been used to determine current emissions and future emissions, formula's 9, 11 & 12. A basic reduction percentage calculation was done to determine the reduction, formula 13.

5. What costs and negative effects are involved in the implementation of emission-reducing actions?

Implementing emission reducing actions can have a large effect on the carrier. Depending on the action, new infrastructure is needed and vehicles can have less capacity. Other effects are a lower heating value and energy content of fuel, resulting in a lower range with the new fuel and higher or lower fuel prices

6. What are the different uncertainties in the tool and how can this be included in the calculation?

The uncertainty in the tool exists out of three parts, the model uncertainty, the input uncertainty and the cost uncertainty. The input uncertainty contains the biggest risk because the vehicle choice and the road type distribution have a large effect on the outcome of the tool. If this information is not known, the uncertainty of the outcome is high. The user must be aware of these uncertainties and the results of the tool must be handled with care.

The main research question of this study is:

How can emission reduction possibilities be meaningfully presented to shippers?

The answer to this question is to present shippers with information on emission reduction possibilities in an interactive way. This requires the design of a tool. This tool can provide meaningful information on the effect of emission reduction possibilities on the supply chain of shippers. With the help of a tool, shippers can see both the emission reducing effect of emission reducing actions as well as the cost associated with these actions. As shippers can also use the tool to simulate various scenario's, information can be extracted that can influence the logistics choices of the company in the future and not only for one trip.

8.2 Discussion

With this research, a practical tool was developed that can be used to gain insights in the emission reduction potential of different solutions in road freight transport and the corresponding costs. In literature, no large review of existing emission reducing measures existed before this study. With this tool, also a practical interpretation has been given to this knowledge. In this study, the focus was on decarbonizing road freight transport in Europe and looking into actions that need collaboration from shippers and carriers. As this eliminates a lot of actions that can be implemented by either the carrier or the shipper, a lot of reduction potential is not included in this design.

The many different solutions that are included in the tool affect the level of detail of the calculations. Using HBEFA, a lot of the factors that influence energy consumption are generalized in average energy consumption numbers generated by this tool. As these can have a large impact on the energy consumption, it is possible that the emissions calculated by this tool are underestimated or overestimated compared to reality.

The corresponding cost of the actions in this tool are calculated based on the prices found in literature and based on the reduction of fuel. The estimation of these costs are not based on the shipper's specific transport requirements and therefore only provides a rough estimation of the costs. The relation between the shipper and the carrier is also not taken into account, nor the methods used by carriers to determine their transport costs. The prices of technology as well as fuel change with time, making it impossible to provide exact pricing information. The technology and the price of fuel are dependent on external factors such as the world market, the price of oil and taxes that differ per country. In the beginning of 2022 it was seen that a war can result in oil prices soaring resulting in all goods to become more expensive. It is therefore recommended that prices of fuel are changed by the user based on the prices that are agreed upon by the shipper and carrier or to use more recent data of fuel prices at the time the tool is used.

8.3 Recommendations

This section will elaborate more on the aspects encountered during this study that could not be reviewed in this research and are recommended for further research. After the recommendations for further research also recommendations for the tool are given.

During the literature research, choices had to be made because of time limitations. Subjects that were not reviewed have been marked as further research. First of all the energy efficiency of fuel distribution, this differs between different fuels

as they need different forms of transportation. Where liquid fuels can be transported to refuelling stations with trucks, electricity for BEV's is transported using the energy grid. Hydrogen needs a different form of transportation because of the properties of hydrogen. The efficiency of all these different distributions plays a role in the complete energy efficiency of fuels and is advised for further research.

Next to CO_2e also other gasses are emitted during transport. The effect of these gasses on the environment and health is not taken into account in this study. As the amount of other gasses emitted during transport differ per fuel it is recommended that this is studied in further research.

In the interviews, it was mentioned by shippers that the necessities of transport differ per shipment and sector. Refrigerated shipments and time sensitive shipments are two examples of special needs transportation and differ from regular shipments. These aspects were not taken into account in this study and they are recommended for further research.

When multiple actions are being implemented at the same time, this can have an effect on the complete emission reduction potential. Currently, the emission reduction of actions is calculated using the current situation, not taking into account the effect between different actions. The output calculations in the tool do use the reduced amount of emissions after the first action to determine the absolute reduction of the second action and so on. This does not include the effect the action might have on the potential of other actions, as information on this was not found in literature, a research gap for further research was found.

8.3.1 Recommendations for tool

During the design of this tool, choices were made due to the time limit of this study. This resulted in recommendations for further improvements for the tool and possible extensions of the tool. In addition to possible improvements and additions that were thought of during the course of this thesis, points for improvement have also emerged during the last validation step. All improvements are discussed here and are recommended to implement in the future.

Due to the time limit of this research, the tool is limited to Europe, collaboration actions and road transport. This tool can therefore be extended in different ways, more modes can be added, different collaboration structures can be added and the regions can be extended. At this stage the tool is only deployable for road transport, it would be most useful if more research would be done into the other modes, air transport, sea transport, inland waterways, rail transport and also logistics sites. Next to this, the focus of the tool is now on the collaboration between shipper and carrier, in order to take all different emission reduction solutions into account, it will be useful to extend the tool with actions that require a different collaboration or require no collaboration at all and can be executed by only a shipper or only a carrier. Thirdly, the tool can also be extended for different continents and countries, making intercontinental transportation possible to address in the tool.

Improving the tool can also entail more accurate and detailed calculation. A trade-off must be made here between usefulness and difficulty. Extended research can be done on the availability of technology in different countries, vehicle availability and empty rides per vehicle segment. These last two relate to the specific energy consumption calculation. One last improvement of calculations can be done on the cost of the different solutions, providing the user with a more accurate estimation of the different costs per action.

Other choices that were made during this design rely on certain assumptions. Currently, the tool will pick the smallest vehicle based on the weight of the shipment to transport the shipment if the user did not select a vehicle. In order to prevent an underestimation of emissions, another method for vehicle choice can be implemented, for example the method of EcoTransIT (n.d.) which is based on most common used trucks. Further research is required to determine a more accurate method for automatic vehicle selection. Another assumption that was made is that the weight of a shipment would not exceed the maximum capacity of the largest vehicle. At this point, the tool cannot divide the load into multiple shipments. If a heavy load is entered as an input, the tool will take the largest truck but does not split the load. This can be an useful improvement if the tool is used for larger shipments or complete trade routes. The last assumption was made with regard to the current situation. At this moment, it is not possible to indicate which actions are already implemented. It would be useful to be able to show this in the tool.

During the last set of validation interviews, three improvements were mentioned. The first addition is to show the user the ease of implementation of the different actions. This can make the user more aware of the impact of the action on the carrier. Secondly, it would be helpful to have more information available through out the tool to make it more clear to users if they have no logistics background. Lastly, it was advised to create a visually more attractive tool and possibly re-build the tool to make it available on a web-page.

Alter emission calculation

First of all the energy consumption calculations, in the previous section two improvements have been mentioned related to the energy consumption factors. Second, there are several external and internal factors that can have an influence on the total amount of emissions that are not taken into account in HBEFA. For example the age of the motor has an impact on the amount of CO_2 produced. This is not taken into account in this thesis and can be done in further research. The

surroundings of the transport are also not specifically taken into account, meaning specific traffic situations for a route or gradients (hills). An average has been taken of different external traffic factors in this thesis, studying the effect of traffic situations is recommended for further research.

Finally, in the current emission calculations, the vehicle chosen depends on the weight. However, the metric volume of a shipment can also effect the vehicle choice. Volumetric weight calculators are available to determine if a correction factor is needed to account for extra space. If this information is known by the shipper, it would be a good improvement of the tool if the volumetric weight is taken into account instead of only the weight of the shipment.

Other

This tool has been developed using current values and information. It is therefore not directly viable for future decision making. By making use of probability and statistics and a discount rate for costs, the tool can be adjusted for future decision making.

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A Scientific Paper

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An information tool for shippers concerning the cost effectiveness of emission reduction measures in road freight transport

Hannah de Regt (4386760)

Abstract: This paper describes the design of an information tool, created as an addition to the knowledge platform of the Smart Freight Buyers Alliance initiative of Smart Freight Centre. This tool was created for shippers to inform themselves on the emission reducing actions available to reduce road freight transport emissions. Different emission reducing actions for road freight transport are researched and compared based on emission reducing potential and cost. A calculation method to determine emissions and cost per trip form the basis for an informational tool for shippers. As shippers buy road freight transport from logistic service providers, third-party logistics or directly from the carrier, they do not have a direct influence on the amount of emissions emitted during transport. However, by making use of collaboration, shippers can influence emission reduction by working together on implementing emission reducing solutions and influencing the corresponding decrease or increase in the price of transport. This tool has the goal to inform shippers on the possibilities for emission reduction, their reduction potential and costs.

Keywords: Road transport emission reduction, road freight transport emission calculation, road freight transport, CO_2e mitigating actions information tool, cost and emission reduction potential of actions in road freight transport

1 Introduction

Emission reduction and climate change are two frequently heard words in the past years and even more often in 2022. Due to the increasing knowledge about climate change and the effects of emissions on nature and the livability of our planet, the voice that change is needed became louder and stronger. Different governments, UN climate conferences and experts came to the same conclusion, that emission reduction is needed in all different aspects of society. To limit the effects of climate change, the Paris agreement was adopted in 2015. This climate accord has the goal to limit global warming with a maximal increase of 2 degrees Celsius [1], and even trying to limit it to 1.5 degrees Celsius, resulting in many plans and treaties with targets to reduce emissions. One main polluter is transport, people as well as freight. With transport being responsible for over 25% of emissions in Europe and road transport being responsible for 72% of that in 2019 [2], road freight transport became one of the major sectors for change [3]. It resulted in a strategy in Europe, the European Green Deal [4], that greenhouse gas (GHG) emissions must be reduced by at least 60% in 2050 compared to 1990 [5].

As part of the European Green Deal, the European Commission has decided that from 2026 the transport sector will also participate in the Emissions Trading System (ETS) [6]. This measure puts a price on transport emissions making traditional (fossil fuelled) transport more expensive, which is expected to stimulate the use of cleaner fuels and increase investments in cleaner technologies. As a result, carriers as well as shippers need to decide on their transport strategy. As road freight transport is often purchased by shippers either directly from the carrier or through a logistic service provider (LSP) or third-party logistics (3PL), collaboration is needed in order to create change in the road freight sector. As carriers are responsible for their operational fleet, the change to vehicles and fuels used needs to take place here. However, a change of mindset is also necessary for shippers as they purchase the freight transport and currently base their decision purely on cost and reliability. To implement emission reducing solutions, collaboration between shippers and carriers is needed.

Several studies were found that study emission reduction in road freight transport. This research has mostly been done on finding a solution for a specific situation, such as city logistics, long haul or multi-modal logistics. [7] researched the measurements of CO_2 emissions in the UK for road freight transport, [8] looked into city emissions in Dublin and [9] developed a calculation method to determine emissions of transport in the Netherlands. These studies are often focused on passenger transport and inner city logistics because of the direct impact on the health of people living in the city.

Little work has been put into creating an overview of the different solutions available, which would allow companies to see which options fit their supply chain best. The Global Logistics Emissions Council Framework (GLEC), created by Smart Freight Centre (SFC), tried to capture all different categories of solutions into one table based on the book of [10] next to offering companies a method for emission calculation and reporting. By creating these kind of overviews, companies, shippers as well as LSP, can see what their options are with regard to implementing emission reduction solutions. However, only an overview of the options does not provide information on the emission reduction potential of these solutions or other factors that are related to implementing a solution, such as costs.

To fill in this gap, some organizations created tools which do compare options or solutions such as EcoTransIT [11], which compares different modes for the same origin-destination pair. The International transport forum [12], they created an overview of mitigation measures for passenger as well as freight transport, it includes emission reduction potential and cost information but lacks in number of solutions that are in need of collaboration. Vecto, a tool created by the European Commission to help calculate emissions of heavy-duty vehicles (HDV) above 3,5t, but does not contain information on mitigation measures [13]. And initiatives such as Science Based Targets [14], that help their clients to set targets for emission reduction but do not provide information on how the emission reduction can be achieved.

In literature, only a low number of studies focus on comparing the different possible solutions and their impact on emission reduction and costs. The reviews that were found often only compared two different solutions so a large overview was not created. In grey literature

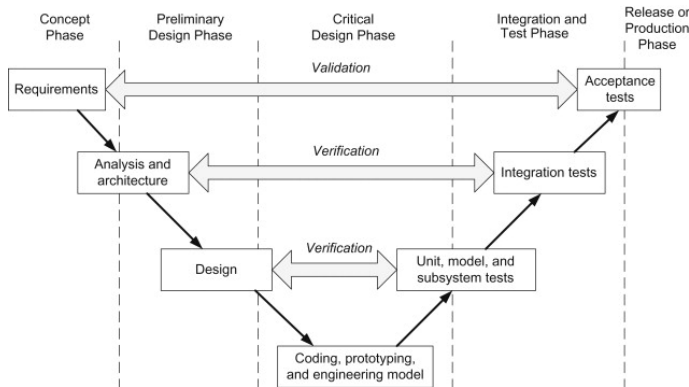
no tool was located that combined information on cost and emission reduction of actions to reduce emission in road freight transport into one tool. With this study, the gap between companies and information that can be found in literature on different solutions for reducing emission in road freight transportation is closed by creating an information tool that takes into account not only emission reduction but also costs. With the study, the following research question was answered:

How can emission reduction possibilities be meaningfully presented to shippers?

2 Methodology

As this is a design study, the methodology used in this research was based on a design method, the V-model. This model exist out of five phases from requirement analysis to final design. Some validation and verification steps were added to ensure error were spotted quickly.

Fig. 1: V-model [15]



The first part of the design process, the concept phase, consisted of determining the goal of the tool. This was determined through interviews with shippers, the future users of the tool. These interviews were also used to learn more about the process environment of decision making with regard to sustainable transport and to find the requirements for an information tool. This phase also included a literature research on the state-of-the-art of existing decarbonization tools. The phase was concluded with the list of requirements.

During the preliminary design phase a conceptual model was constructed and from this the architecture of the tool was determined. The different sub-models of the tool were designed and literature was used to find the data and the calculation methods needed for the tool. From the different sub-models, the tool was actually built in Excel in the critical design phase.

In the next phase, the integration and test phase, the tool was tested and a first round of validation interviews was done. Several employees of Smart Freight Centre tested the tool and provided feedback. This was then used to improve the tool before a second set of validation interviews was done. During the integration and test phase, also a sensitivity analysis was conducted to examine the effect of the uncertainties of the different parameters used.

After verifying and validating the tool some last improvements were made before entering the final design step, the release phase.

3 Literature review

Two separate literature reviews have been conducted in this study. First the state-of-the-art of existing decarbonization tools was studied. Different initiatives, programs and tools were searched using literature as well as grey literature as tools are mostly available on the internet. The second literature study was done to collect the data needed for the information tool. Different emission reducing actions were studied to determine their cost and emission reduction potential. The main search engines used were Google Scholar and Scopus. By making use of different keywords related to the decarbonization of road freight transport in Europe, many papers were found. These papers were filtered based on their publication date, no older than 2018, and the title. If the title of the paper sounded promising with relation to road freight decarbonization, the abstract was read. For the actions that were not mentioned many times, the publication date was altered to 2014. During this study the emission calculation methods were also determined.

State-of-the-art of existing decarbonization tools

The existing tools on the decarbonization of road freight were studied and an overview was created, see Table 6. Most of the available initiatives and tools focused on calculating and reporting emissions, same as the GLEC Framework [16]. Other initiatives focused more on specific targets, like Science Based Targets and EV100+ [14]. Only a few tools included multiple actions and their emission reduction potential such as EcoTransIT [11] and Greenrouter [17].

Actions

By providing the shipper with information on the reduction potential and the corresponding costs of different emission reducing possibilities for their outsourced transport, responsible for scope 3 emissions, the shipper gets a clearer picture of where the solutions to reducing these emissions lie. With this in mind, this research focuses on the actions that need collaboration between shippers and carriers to make the change happen, actions that can be performed by only shippers are therefore not included. Also actions with regard to mode switch have not been taken into account, while this research solely focuses on road freight transportation.

Because the emissions (scope 1, scope 2 and scope 3) that need to be reported are calculated in CO_2e , in this study the same pollutants are taken into account for emission reduction potential. CO_2e includes, CO_2 , N_2O , CH_4 and fluorine-containing gases, these are converted into a CO_2 equivalent using the Global Warming Potential (GWP), that is the extent to which a gas contributes to the greenhouse effect.

The actions that meet the scope and are taken into account in the tool are shown in Table 1.

Table 1 Actions included in information tool

Increase load	Decrease fuel use	Changing energy source
Load optimization	Cleaner & efficient technologies	Cleaner & lower carbon fuels
Load consolidation	Efficient vehicles	Electrification
Standardized modules & boxes	Driving behaviour	Hydrogen
	Fuel management	
	Fleet operation	

Data collection

For these actions the emission reduction and costs are determined from literature. In Table 7, 8, 9, 11 and 10 an overview is provided of the actions and the data that is used in the tool.

The first category, increase load, is based on a higher load factor. This can be done by load optimization, load consolidation, standardized boxes, high-capacity vehicles and double stacking. The reduction potential of these actions is shown in Table 7 and is based on [18] [19] [20] [21][22][23] and [24].

For the actions related to Cleaner & Efficient technologies and Efficient Vehicles, the data from a study done by TNO in combination with TU Graz, CE Delft and ICCT has been used [25]. The emission reduction potential of both solutions can be seen in Table 11 and 10. Driving behaviour [26] [27], fuel management [18] and fleet operation [28] [29] [30] are shown in Table 8. Actions that are related to fleet operation are fuel efficiency, ecodriving, lightweight equipment (trailers), planning of vehicles and routing. As fuel efficiency from a fleet operation standpoint, fuel management and ecodriving are very intertwined, the reduction potential of these three is combined into one factor for fleet management together with routing and maintenance. All actions of this category have in common that they reduce the amount of fuel use of a trip. Not all actions can be implemented on existing trucks, adding solutions to existing vehicles is called retrofitting.

The last category is based on changing the energy source of vehicles. This solution relies on the carbon content of energy and therefore the emission factors of the different fuels play a large role [31][32]. Table 9 shows the effect of the different fuels. The different investment costs of the vehicles are shown in Table 2, [33] and [34].

4 Requirements

By making use of different requirement trawling techniques [35] during meetings of SFBA, a preliminary list of requirements was created. During the interviews conducted as part of the concept phase, these requirements were discussed and more requirements were discovered. This led to the final list of requirements. This list was divided into functional requirements, things a system has to do, and non-functional requirements, such as qualities, performance and usability. The requirements that are imposed by SFC are marked with (C) for commissioner.

The functional requirements are:

FR 1: The tool shall only take actions into account for road transport

FR 2: The tool shall provide a location where the user can enter their transport data

FR 3: The tool shall calculate the emissions of the current situation by using the data provided by the user

FR 4: The tool shall use calculation methods found in literature to determine the emissions

FR 5: The tool shall take into account the weight of the shipment in either kg, lb or tonne

FR 6: The tool shall take into account the distance of the shipment in either km or miles

FR 7: The tool shall take into account the origin of the shipment for determining the emission factor

FR 8: The tool shall provide the user with opportunity to choose from the list of actions which are of interest and which are not

FR 9: The tool shall determine the emission reduction potential of the different actions that are chosen by the user

FR 10: The tool shall determine the cost of emission reduction actions per trip

FR 11: The tool shall show the different actions in an abatement curve

FR 12: The tool shall adjust the abatement curve within 10 seconds after changing the input

FR 13: The tool shall provide an overview of the outcome separately from the abatement curve

FR 14: The tool shall provide information on the uncertainty of the calculations in the tool

FR 15: The emission calculation in the tool shall be in line with the GLEC Framework (C)

FR 16: The emission factors used in the tool shall be in line with the GLEC Framework (C)

FR 17: The energy consumption calculations shall be based on the HBEFA tool (C)

The non-functional requirements are:

NFR 1: The tool should be easy to use

NFR 2: The tool should include information on the working principle of the tool

NFR 3: The tool should be understandable for users with a road freight logistics background

NFR 4: The tool should present the emission reduction possibilities in a meaningful way to shippers

NFR 5: The tool should display the outcome in a clear way

NFR 6: The tool should be possible to download

NFR 7: The tool should be accessible on the SFBA platform

NFR 8: The tool should be available as a MS Excel download file

NFR 9: The tool should have a size that is downloadable

NFR 10: The tool should work with all versions of MS Excel

NFR 11: The tool should be easy to maintain (C)

5 Model Components

Conceptual model

The conceptual model of the tool can be seen in Figure 3. This conceptual model consists of two main parts, the emission reduction potential and the cost estimation. Both parts contain a set of calculations to determine the emissions and cost of the current situation. To determine the emission reduction potential and cost increase or decrease of the action, alterations to these calculations must be made. In the figure an overview of the different alterations for the emission calculation as well as the cost calculations is shown. Depending on the action, the calculations are altered and the corresponding emissions of a trip with the included action are calculated as well as the cost. This information is then used in the tool to create a visual overview of the chosen actions.

Calculations

The data used in the tool is determined from the literature research and shown in the Tables 7, 8, 9, 11 and 10. This information is used in calculating the emissions, which is done in the way that is described in the conceptual model, Figure 3. The formulas used for the emission calculation are:

$$TE = (EC_e + EC_l) \cdot d \cdot EF \quad (1)$$

$$\text{Reduction percentage (\%)} = \frac{(TE_{bc} - TE_n)}{TE_{bc}} \cdot 100 \quad (2)$$

$$EC_e = U \cdot UF_0 + R \cdot RF_0 + MW \cdot MWF_0 \quad (3)$$

$$LF = EC_{100} - EC_e \cdot \frac{w}{C} \quad (4)$$

$$EC_l = U \cdot UF_{LF} + R \cdot RF_{LF} + MW \cdot MWF_{LF} \quad (5)$$

- TE: Total emissions ($kgCO_2e$)
- TE_{bc} : Total emissions base case ($kgCO_2e$)
- TE_n : Total emissions new ($kgCO_2e$)
- EC_e : Energy consumption empty (MJ/km)
- EC_l : Energy consumption load (MJ/km)
- d: Distance (km)
- EF: Fuel Emission Factor ($kgCO_2e/MJ$)
- U: Urban share
- UF_0 : Specific urban energy consumption factor 0% load (MJ/km)
- R: Rural share
- RF_0 : Specific rural energy consumption factor 0% load (MJ/km)
- MW: Motorway share
- MWF_0 : Specific motorway energy consumption factor 0% load (MJ/km)
- LF: Specific load factor
- w: Weight of shipment (tonne)
- C: Capacity of vehicle (tonne)
- UF_{LF} : Specific urban energy consumption factor with specific load (MJ/km)
- RF_{LF} : Specific rural energy consumption factor with specific load (MJ/km)
- MWF_{LF} : Specific motorway energy consumption factor with specific load (MJ/km)

The associated cost of the actions are described in Figure 3 and are determined with formula 6 & 7.

$$Cost_v = TCO \cdot \frac{d}{ad} \quad (6)$$

$$Cost_t = Cost_v + Cost_f \quad (7)$$

- $Cost_v$: Cost of vehicle per trip (€)
- TCO: Total Cost of Ownership (€)
- ad: average distance travelled in the first 5 years (km)
- $Cost_t$: Cost of trip (€)
- $Cost_f$: Cost of fuel per trip (€)

This calculation uses the first ownership principle [36]. This method calculated the cost of a new vehicle in the first 5 years and relates the cost to the average amount of kilometres travelled in this period. The average amount of kilometres travelled is determined at 550,000 km in the first 5 years.

The Total Cost of Ownership values, used to determine the cost of a trip, can be seen in Table 2. These values are constructed from the information available in the white papers from the International Council on Clean Transportation from [33] and [34].

Table 2 Total Cost of Ownership of vehicles

Total cost of ownership of vehicles	
Diesel	€ 321.750
Hybrid Electric	€ 528.820
Battery Electric	€ 564.820
LNG (Spark ignition)	€ 333.750
CNG (Spark ignition)	€ 347.750
Hydrogen fuel cell	€ 353.820

Parameters

It can be seen that many different parameters are used in the emission calculation and costs calculation. Some of the parameters need to be filled in by the user such as weigh and distance of the shipment. Others are implemented in the tool, these are: - Emission Factors

- Energy Consumption
- Road type distribution
- TCO of vehicles
- Cost of fuel

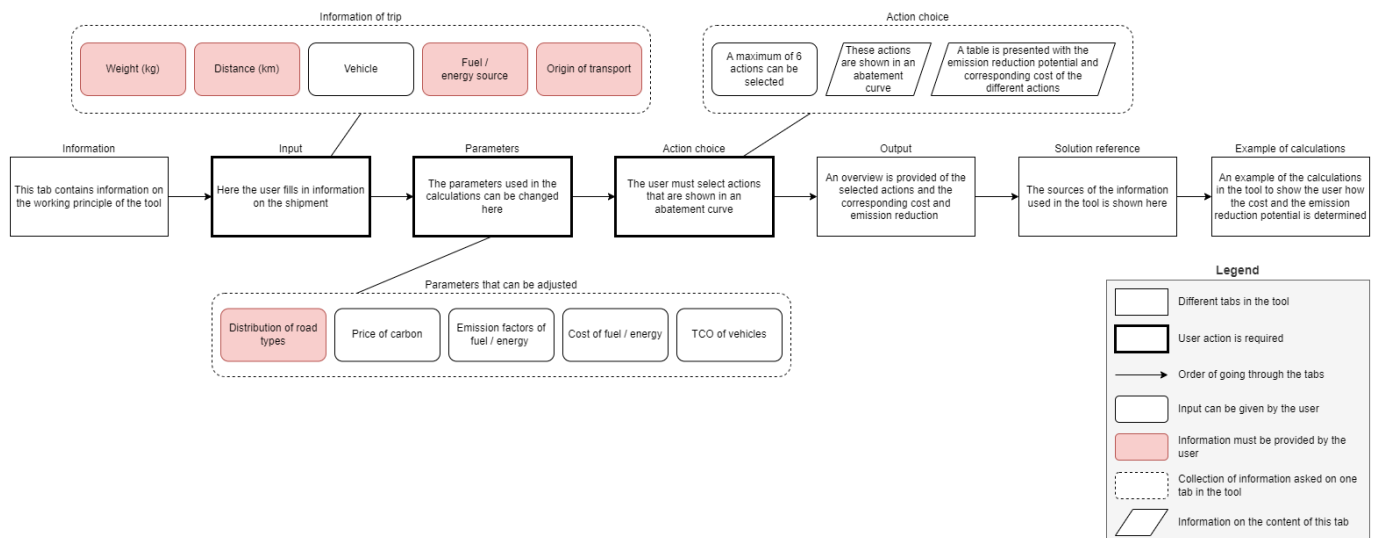
The emission factors used in the tool are the factors from the new ISO standard, ISO14083 [31], see Table 3

Table 3 WTW emission factors (ISO 14083 FDIS version)

Fuel type description	WTW gCO_2e/MJ
Gasoline	90,1
Ethanol	48,2
Diesel	87,3
Bio-diesel	38,3
Liquefied Petroleum Gas (LPG)	81,6
Compressed Natural Gas (CNG)	72,7
Liquefied Natural Gas (LNG)	75,5
Bio-LNG	30,4
Hydrogen (grey)	114,4
HVO	28,6
Electricity (EU average)	97
Bio CNG	26,2

The energy consumption was determined by making use of the Handbook Emission Factors for Road Transport (HBEFA) [37]. These values were based on the vehicle type and fuel and are divided into three categories, motorway, urban and rural road. By making use of the road type distribution of the trip and the vehicle class, the energy consumption of the trip can be determined.

Fig. 2: Overview of the different tabs in the tool



TNO provided information on the different distributions of road types for different delivery types, regional delivery and long haul delivery [25]. These different distributions are only indications of how the distribution can look for these delivery types. The actual distribution is unique to every trip and can best be found using a route program. The regional delivery and long haul delivery are from [25], the profile for delivery between two distribution centres is an estimate based on previously acquired knowledge by the author, see Table 4.

Table 4 Road type distributions

	urban areas	rural roads	motor ways
Regional delivery	28%	46%	27%
DC-DC delivery	-	10%	90%
Long haulage	7%	13%	80%

Description of information tool

In Figure 2, the structure of the Excel Workspace is explained. When the user opens the Excel-file, the information tab is shown. This contains explanations on the different steps of the tool and informs the user of the information that the user must provide in order

for the tool to work. The next tab contains the questions on the shipment information. The country of origin, weight of shipment, distance as well as current fuel and vehicle are asked. When these questions are answered, the user will see the emissions of the current situation. The next step is to determine if the parameters used in the cost and emission calculations need to be changed. The default values available in the tool are an average of the European countries and this information is not specific to the trip entered in the input tab. To create a more accurate estimation of reduction potential and cost, it is advised that the parameter tab is used to fill in extra information about the trip.

After the user has answered the questions and possibly altered the parameters. The user can select the actions of interest in the action choice tab. A list of actions is shown and a maximum of 6 can be clicked. If an action is selected, the tool will show the action in the abatement curve. In this curve the reduction potential of the action is shown on the x-axis and the cost of the action is located on the y-axis. This curve will automatically sort the selected actions based on the cost of the action.

The complete width of the abatement curve shows the total emissions of the trip, if the graph is not completely filled with colored blocks, some emissions are still not reduced after implementing the actions.

In the output tab of the tool, an overview is provided of the different selected actions, their emission reduction potential and associated costs. The complete emission reduction potential is calculated as if the actions were implemented after one another, creating a more accurate result for the total amount of reduced emission if all actions were actually implemented.

If the user is then interested in the sources of the data, the solution references tab can be viewed. An explanation on the emission calculation methods is provided in the example of calculations tab.

6 Analysis with tool

The tool was used to perform a sensitivity analysis to determine which parameters have the greatest influence on the outcome of the tool. By varying the different input parameters and evaluating the difference in outcome of the tool, the effect of the parameters was determined. In Table 5 the different parameters that were varied can be seen. For this test, a base case was used:

- Country: Germany
- Current fuel: Bio-diesel B5 (average)
- Distance: 500 km
- Country of Origin: Germany
- Weight of shipment: 2500 kg
- Vehicle choice: No vehicle is selected

In the parameter tab, the road type distribution (RTD) is set to the long haul distribution and the CO_2 tax is set to 100€/t. The fuel price and Total Cost of Ownership were not changed for the base case situation.

From this analysis, it was found that the road type distribution and the vehicle choice have a large impact on the outcome. It was seen that changing the vehicle from the smallest vehicle possible to a commonly used truck, rigid truck 20-26 tonne, had a great impact. It resulted in twice the amount of emissions as for the smaller truck. The road type distribution was also found to be very sensitive to the different shares of road type, while the distance and weight of the shipment did not have a large effect.

Table 5 Sensitivity analysis of the user input

	Base case	Weight		Distance		Vehicle	RTD		Fuel price	
Weight (kg)	2500	2250 (-10%)	2750 (+10%)	2500	2500	2500	2500	2500	2500	2500
Distance (km)	500	500	500	450 (-10%)	550 (+10%)	500	500	500	500	500
Vehicle type	Default	Default	Default	Default	Default	RT 20-26t	Default	Default	Default	Default
RTD (MW/R/U)	80/13/7	80/13/7	80/13/7	80/13/7	80/13/7	80/13/7	76/15/9	63/23/14	80/13/7	80/13/7
Fuel price (€/l)	Default	Default	Default	Default	Default	Default	Default	Default	1.40 (-0.5)	2.40 (+0.5)
Output (kg CO₂e)	154.64	152.39 -1.45%	156.90 1.46%	139.18 -10%	170.10 10%	315.65 204%	170.22 10%	218.35 41.2%	154.64 0%	154.64 0%
Cost (€)	390.10	388.86 -0.3%	391.52 0.4%	351.09 -10%	429.11 10%	491.72 26%	399.93 2.5%	430.30 10.3%	364.42 -6.6%	415.78 6.6%

7 Validation & Verification

A verification and validation of the tool was done as part of the V-model, the integration and test phase. During the verification the different requirements of the tool were tested. The list of functional requirement was checked and all requirements were met. For the non-functional requirements the tool was tested by employees of Smart Freight Centre. To test if the tool met the non-functional requirements, the employees were asked several questions to determine if and to what extent the requirements were met. From this it was concluded that the tool met all non-functional requirements except for the maintenance requirement, NFR 11. This could not be tested at the time.

The validation of the tool existed out of two separate phases. To check if the calculations in the tool were executed in the right way, a test case was designed. The calculations were also done by hand to see if the outcome of the tool matches the results. The different calculations were also checked on the use of units.

After this, a validation by the commissioner tool place. During three interviews, the working principle of the tool was discussed. These interviews took place partly online and partly face to face. The goal of these interviews was to check whether the tool meets the demands and wishes of the commissioner, to collect further improvements and to gain insight of the role of this tool in the context of SFBA. From the interviews it was clear that the tool provides the user with meaningful information on the existing emission reducing possibilities. As the tool is in line with the other tools of SFC, the needs and wishes of the commissioner were therefore met.

This tool will be made available next to the other available information and tools on the knowledge platform of SFBA. All different tools have with their own purpose and properties. This tool will be an addition to the other tools available within SFBA as it brings together costs and emission reduction potential. The benchmarking tool provides an overview of the impact of fuel choice and both tools can be used together. The initiatives map shows the user the existing initiatives that companies can join and the collaboration catalyzer helps companies find projects that are of interest. Within the collaboration catalyzer the tool can provide insight in the associated costs and emission reduction potential of the projects. The GLEC Framework can be used to provide more insight in the calculation and reporting of emissions, next to the calculations done in the tool.

8 Conclusion

The answer to the research question is to develop an information tool that provides the user with an overview of the reduction potential and corresponding cost of action with little effort. By providing the tool with formulas found in literature and data that is used in the industry, the tool can determine estimations of the current emissions of users and the reduction potential of the chosen actions. The uncertainty present in the tool can be limited by making the user aware of the different uncertainties present and providing the opportunity to

the user to decrease the uncertainty if data specific to the trip is used in the calculations. To ensure that the tool contains the most recent data, a maintenance plan was developed that provides the commissioner with a manual to keep the tool up to date.

It must be noted that due to scope limitations of this research, other modes of transport have not been taken into account. Including these in the tool will provide the user with more options to reduce emissions including the option of mode switch, which can have an impact on the actions for road freight. Different emission reducing actions that can be implemented by shippers or carriers alone are also not taken into account. These actions can help reduce emissions in other parts of the supply chain, which can affect the emissions of transport. Additionally, the calculations done in the tool are simplified deliberately, which means that by performing more detailed emission calculations, the tool can also be used to determine current emissions that can be used in reporting.

9 Discussion

The created tool is dependent on the accuracy of the data in the tool. Parameters regarding energy consumption, emission factors and costs of actions should therefore be updated regularly to maintain the value of the tool. As these values can also differ based on the contracts between carriers and shippers, providing the opportunity to change these values is important. If more actions are added in the future, this opportunity should be extended to the new actions. This option ensures the value of the tool for companies that do have a lot of information on their shipments.

The calculations done in the tool for emission calculation are based on a simplification of the situation. As shippers do not have detailed information on their shipments, the data asked from shippers on their shipments is very basic. If more accurate calculations are required, the amount of information also becomes higher, however this can result in a more suitable solution for trip.

10 Recommendation

-The tool provides insight in the emission reducing actions for road freight transport. Due to time limitations, only actions that require collaboration between shippers and carriers are taken into account. Looking into all different actions and extending the tool can improve the value of the tool.

This can also be done with more modes. By adding air transport, sea transport, inland waterways, rail transport and logistics sites, more solutions are possible to reduce emissions and modal shift and synchromodality are made possible.

Furthermore, it is recommended that more research is done on the costs of transport and the methods that carriers use to determine the cost. In this tool the cost calculations are based on the total cost of ownership and the fuel cost but no research was done on how carrier determine their pricing.

Finally, it is advised to look deeper in the different prices of fuel and possibly create an overview of the different cost per country. With this the availability of the different fuels is examined and the cost of fuel per country creates a more accurate estimation of the fuel cost.

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Fig. 3: Conceptual model

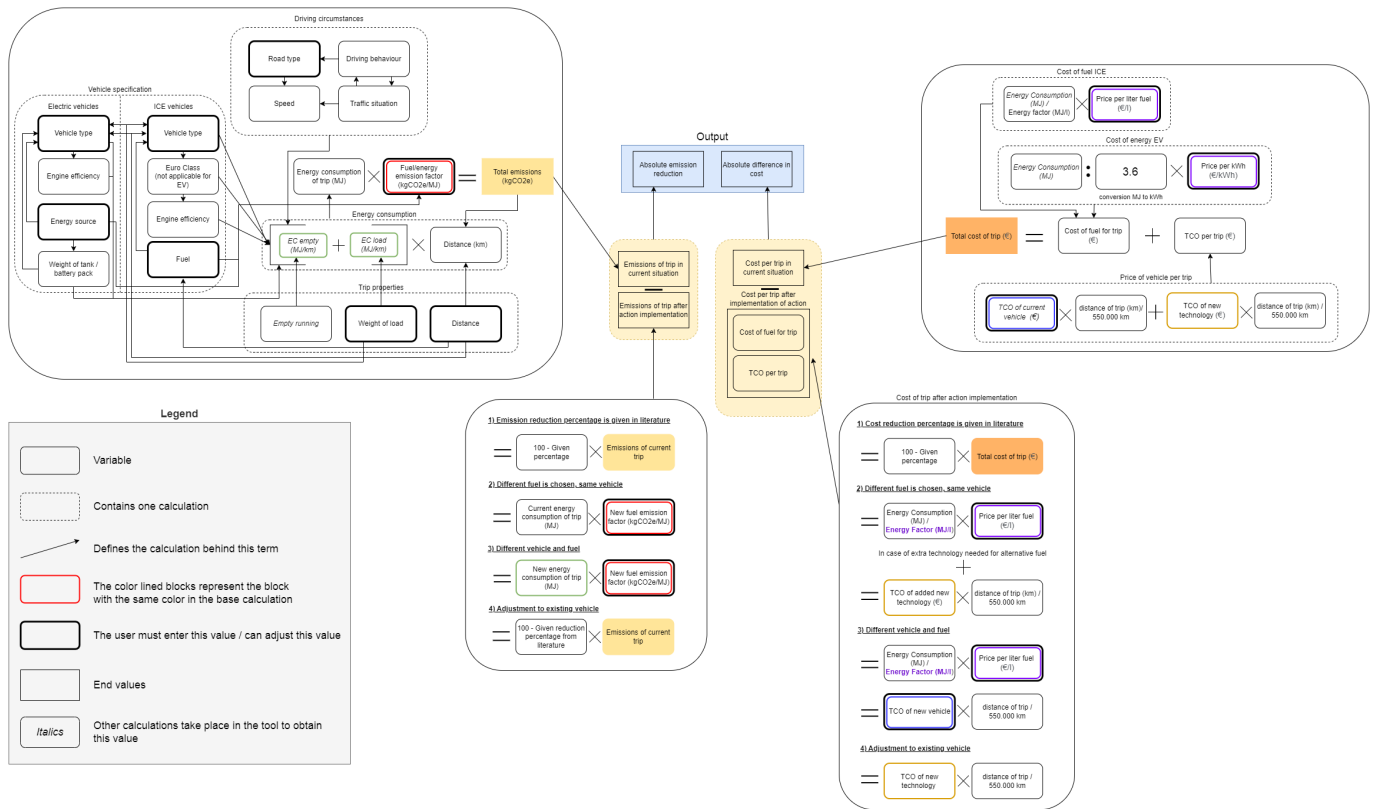


Table 6 State-of-the-art existing tools

Name	Lacks	T O O L	I N F O	C A L C U L A T E	R E P O R T	T A R G E T S	O T H E R
Transport climate action directory [12]	Has very few mitigation measures for road freight transport, only 1 solution that needs collaboration		X				
Truck Ecodriving Toolkit [26]	More mitigation measures		X				
The Global Fuel Economy Initiative toolkit [38]	Information on reduction possibilities	X	X				
Vecto [13]	Practical comparisons between actions	X					
GLEC [16]	Information about reduction possibilities, other than an overview of the possibilities			X			
Emission calculator [11]	Only offers mode switch solutions, no other road specific options	X		X			
AMBITIOUS CORPORATE CLIMATE ACTION [14] (Science Based Targets)	No specific solution information					X	
LEARN [39]	Information about reduction possibilities				X		
European Matchmaking Platform [40]	No information on solutions, only offers platform to collaborate						X
The logistics Emissions Calculator [41]	Information about reduction possibilities			X	X		
Reff Assessment Tool [42]	Focussed on logistics site, no information on emission reducing solutions				X		
TK Blue [43]	Compares existing carriers, does not provide information on emission reducing solutions				X		
Bigmile [44]	No specific solution information			X			
ECOEMISSION [45]	No specific solution information			X			
Greenrouter [17]	Includes a few solutions and their emission reduction potential, no cost analysis	X					
Pledge [46]	No specific solution information				X		
Tracks [47]	No specific solution information				X		
Smartway [48]	No specific solution information				X		
Calculator Tool [49]	Information on all sectors in the UK, not only road and no specific solutions	X	X				
SRF optimizer [50]	Needs very detailed information from user, emission calculations are based on DEFRA carbon emission factors 2015	X					

Table 7 Increase load factor

Intervention	Reduction potential from literature	Cost from literature	Reduction in tool	Cost in tool
Standardized boxes and modules				
high-capacity vehicles	7 % - 15 %	5-11%	11%	8%
Double stacking	0-23%	8-28%	12%	18%
Boxes	31%	8%	16%	4%
Load optimization	10 % - 20%	3-6%	15%	4%
Load consolidation	7 % - 51%	20%	20%	10%

Table 8 Decrease fuel use

	Reduction potential from literature	Cost from literature	Reduction used in tool	Cost used in tool
Driving behaviour	9,40%	Low (€300)	7%	€300
Fleet management	10%	Low	5%	€500
Fleet operation	10% - 20%	Medium - high	15%	€2000

Table 9 Cleaner and lower carbon fuels

Cleaner and lower carbon fuels	TCO (x TCO of ICEV)		Fuel cost	Reduction potential
	2020	2030		
Bio-diesel	-	-	+/- 3.00 €/l*	>55%
HVO	-	-	2.54 €/l [51]	>65%
CNG/LNG	-	-	> 2.30 €/kg [52]	4-67%
BEV	2,5-4	-	0.26 €/kWh [53]	>100%
Hydrogen (grey)	2-3,5	1,2	10 €/kg [54]	>100%**

* No exact information was found. As it is in Europe not common to use B100 as a fuel. There is data available for the United States on the website of the [55]. It is known from literature that bio-diesel in Europe is more expensive than regular diesel. Therefore a price of 3€/l was taken for the calculations.

** The reduction potential depends on the energy source, grey hydrogen cannot reduce emissions up to 100%, green hydrogen can.

Table 10 Cleaner and efficient technologies

CO ₂ reducing technologies	TNO-2018-R10214	Vehicle group 4		Vehicle group 5		Vehicle group 9		Vehicle group 10	
	TNO code	%	€	%	€	%	€	%	€
Tyres									
Low rolling resistance tyres on truck/tractor	TYRES1	-6,10	140,00	-5,10	350,00	-6,40	210,00	-5,20	420,00
Low rolling resistance tyres on truck/tractor + trailer	TYRES2	-	-	-8,50	350,00	-	-	-8,50	420,00
Tyre pressure monitoring system (TPMS) on truck	TYRES3	-1,20	140,00	-1,90	350,00	-1,40	210,00	-2,00	420,00
Tyre pressure monitoring system (TPMS) on truck and trailer	TYRES4	-	-	-2,00	350,00	-	-	-2,10	420,00
Automated tyre inflation system (ATIS) on truck	TYRES5	-1,20	1.080,00	-1,90	1.080,00	-1,40	1.080,00	-2,00	1.080,00
Automated tyre inflation system (ATIS) on truck and trailer	TYRES6	-	-	-2,00	1.350,00	-	-	-2,10	1.350,00
Wide base single tyres	TYRES7	-1,20	-35,00	-1,9	-70,00	-1,40	-35,00	-2,00	-70,00

Table 11 Efficient vehicle solutions

CO2 reducing technologies	TNO-2018-R10214	Vehicle group 4		Vehicle group 5		Vehicle group 9		Vehicle group 10	
	TNO code	%	€	%	€	%	€	%	€
<u>Aerodynamics</u>									
Roof spoiler plus side flaps	AERO1	0,00	2.000,00	-2,20	2.000,00	0,00	2.000,00	-2,10	2.000,00
Side and underbody panel at truck chassis	AERO2	-1,40	750,00	-1,50	750,00	-1,10	750,00	-1,50	750,00
Aerodynamic mud flaps	AERO3	-3,00	1.000,00	-3,20	1.000,00	-2,40	1.000,00	-3,20	1.000,00
Rear/side view cameras instead of mirrors	AERO4	-0,80	3.078,00	-0,90	1.539,00	-0,70	3.078,00	-0,90	1.539,00
Redesign, longer and rounded vehicle front	AERO5	-0,80	40,00	-0,90	100,00	-0,70	60,00	-0,90	120,00
Side and underbody panels at trailer chassis	AERO6	-	-	-1,10	200,00	-	-	-1,10	200,00
Boat tail short, additional Aerodynamics	AERO7	-	-	-1,30	3.000,00	-	-	-1,30	3.000,00
<u>Mass</u>									
5% Mass reduction (truck/tractor)	MASS1	-2,20	794,00	-3,20	1.416,00	-2,90	1.402,00	-3,30	1.416,00
10% Mass reduction (truck/tractor)	MASS2	-3,30	1.588,00	-4,70	2.831,00	-4,50	2.805,00	-4,80	2.831,00
<u>Transmission</u>									
Reduced losses (lubricants, design)	TRANS1	-2,00	250,00	-2,60	250,00	-2,20	250,00	-2,80	250,00
Transition from manual to AMT	TRANS2	-2,90	2.661,00	-3,50	3.288,00	-3,10	2.661,00	-3,60	3.288,00
<u>Engine</u>									
Improved turbocharging and EGR	ENG1	-4,80	1.050,00	-4,80	1.050,00	-4,80	1.050,00	-4,80	1.050,00
Friction reduction + improved water and oil pumps	ENG2	-2,40	309,00	-2,40	309,00	-2,40	309,00	-2,40	309,00
Improved lubricants	ENG3	-1,20	23,00	-1,20	23,00	-1,20	23,00	-1,20	23,00
Waste heat recovery	ENG4	-2,40	5.000,00	-2,40	5.000,00	-2,40	5.000,00	-2,40	5.000,00
Downspeeding (combined with DCT optimization)	ENG5	-0,20	1.250,00	-0,20	1.250,00	-0,20	1.250,00	-0,20	1.250,00
10% Engine downsizing	ENG6	-1,00	-400,00	-1,20	-640,00	-1,10	-560,00	-1,30	-700,00
<u>Hybridisation</u>									
48V system with starter/generator	HYBRID1	-1,70	4.184,00	-2,60	6.694,00	-2,00	5.857,00	-2,80	7.321,00
Full electric hybrid	HYBRID2	-2,50	8.367,00	-3,70	13.387,00	-3,00	11.714,00	-4,00	14.642,00

B HBEFA values

B.1 Guide to determine emission factors using HBEFA

The emission calculation, base emissions and emission reduction, depends on emission factors. As this thesis is written at Smart Freight Centre, the same emission factors shall be used as within the GLEC framework and the other programs of SFC. The GLEC framework energy consumption factors for the 2023 update were determined in collaboration and the following method to determine the factors was used.

First the program needs to be downloaded from the website of HBEFA. When the program is opened the tool provides the option to create a specific case for which emission factors will be calculated. The tool offers different input boxes but before a new case can be created, the country needs to be chosen. If you want to switch countries, the program has to be closed and opened again. The different inputs in the HBEFA tool are:

1. Vehicle categories
2. Components (Pollutants)
3. Years
4. Fleet composition
5. Parameters for HOT emissions factors
6. Aggregation level of output

An overview of the choices in the HBEFA tool is provided in Figure 33. The first column can only be chosen when opening the program, the rest can therefore only be changed within one country.

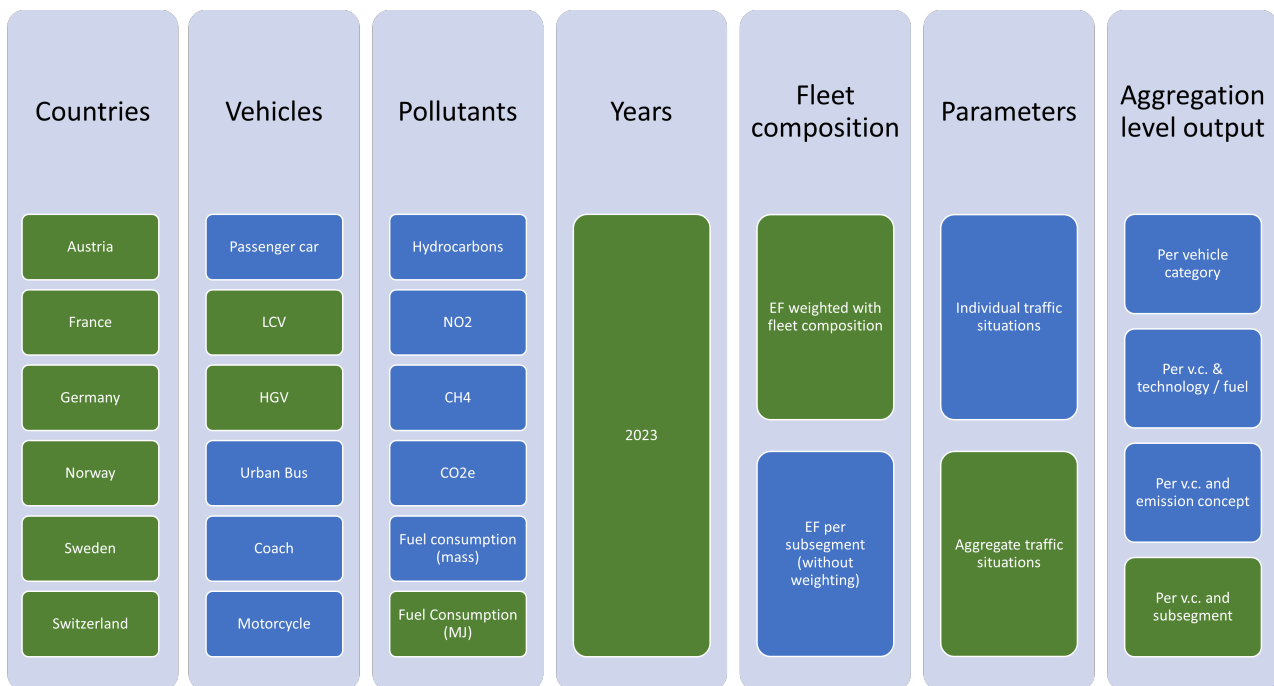


Figure 33: Choices HBEFA tool

First a country needs to be chosen, HBEFA offers the following six countries:

- Austria
- France
- Germany
- Norway
- Sweden
- Switzerland

After choosing the country of interest, the HBEFA tool presents a new case and the input can be chosen. The first input that needs to be given is the vehicle choice:

- Passenger Car
- Light Commercial Vehicle
- Heavy Goods Vehicle

- Urban Bus
- Coach
- Motorcycle

The different vehicles that can be used to transport freight will be included in the GLEC framework and are therefore also of importance for this research. The different vehicles are divided into weight classes and into different emission classes (EURO III, IV, V, VI etc). For road freight transport the LCV, light commercial vehicles, and HGV, heavy goods vehicles, are of interest and are selected in the tool.

After the vehicle choice, the different pollutants can be selected. HBEFA offers many different pollution components to choose from. For the purpose of this thesis and calculating new GLEC emission factors, only the fuel consumption in MJ is of importance because the emission factors per fuel / feedstock will be created using the CO_2e/MJ factors per fuel. With the use of an extra menu, as many options as needed can be selected. The different pollutants in the tool are:

- Total hydrocarbons (HC)
- Carbon Monoxide (CO)
- Nitrogen oxides (NOx, in NO2 equivalents)
- Fuel consumption (mass)
- Particulate matter (PM, mass)
- Particle number (PN)
- CO2(rep), carbon dioxide (reported / fossil)
- CO2(total) carbon dioxide (total / ultimate)
- Nitrogen dioxide (NO2)
- Methane (CH4)
- Non-Methane hydrocarbons (NMHC)
- Lead (Pb)
- Sulfur dioxide (SO2)
- Nitrous Oxide (N2O)
- Ammonia (NH3)
- **Fuel Consumption (FC_MJ in MJ)**
- PM10 (non-exhaust / total)
- Benzene
- PM2.5 (exhaust)
- Black Carbon (BC, exhaust)
- PM2.5 (non exhaust / total)
- Black Carbon (non exhaust)
- CO2e (CO2 equivalents)

Next to the vehicle choice and the different pollutants, the user can also choose the year for which the emission factors are wanted, the program offers all the years between 1990-2050. This year will also have an impact on the available fleet and the average fleet used in the next step, aggregate traffic situations. In order to create values for the update of GLEC the year 2019 has been chosen as this provides an overview of the average vehicles in Europe instead of the six countries that are in HBEFA.

The next input field includes the fleet composition. There are two choices, EF (emission factor) weighted with fleet composition and EF per subsegment (without weighting). The first takes into account the complete fleet of the chosen country in the chosen year, the second does not use the year but just provides emission factors for the chosen subsegment. In order to only include vehicle segments and emission classes that are actually in use, the EF weighted with fleet composition has been chosen.

For the parameters for hot emission factors, two options are presented. First individual traffic situations where you can choose the area, level of service and the speed and separately the gradient. Second, aggregate traffic situations (including the gradient distribution), here the average traffic situations per country are already provided with pre-defined road types, level of service, speed and gradients. The different definitions of the shown traffic situations can be seen when the box information on defined aggregate traffic situations is clicked. It provides the user with the actual combination of traffic situations for the chosen definition. The aggregate traffic situation options differ per country and differ in base year and added gradient or not. The traffic situations chosen can be seen in Table 18.

Austria only offers these three options and one with all road categories. France offers many different traffic situations that differ in taking into account the corresponding highways. To keep the speeds of the different options closest to the other country options, these three traffic situations have been selected. It is remarkable that France does not take into account gradients in the provided options. Germany offers just one current option for MW, Rural and Urban and also provides outdated data and two options for all road categories. Norway offers the choice between average data, no gradients or with gradients. Sweden has data for all different years. The most recent traffic situations were chosen. Switzerland provides not only the option for previous years but also has the possibility to choose from future years, again the most actual year

Table 18: Chosen traffic situations in HBEFA

	Urban	Rural	MW
Austria	Ø-Urban	Ø-Rural	Ø-MW
France	Urban-All	Rural-All	Mway_excl_Mway-City
Germany	D Ø-Urban UBA 2021	D Ø-Rural UBA 2021	D Ø-MW UBA 2021
Norway	Urban(Avg)	Rural (avg)	Motorway(avg)
Sweden	URB_NMW_19	RUR_NMW_19	MW_19
Switzerland	CH Ø-Urban 2020 HB41	CH Ø-Rural 2020 HB41	CH Ø-MW 2020 HB41

data has been used.

The last choice in the HBEFA tool is the level of output. 4 different options are provided by HBEFA depending on the level of aggregation. With the aggregated traffic situations, the road category has been chosen and the emission factors will depend on that information as well as the different choices stated below.

1. *Per vehicle category* All the different sized HGV's are averaged for all different fuel possibilities and a combined emission factor is created
2. *Per vehicle category and technology / fuel type* All HGV's are averaged per fuel type, one emission factor for diesel and one for petrol is given.
3. *Per vehicle category and emission concept* All different sized HGV's are combined per EURO class, an averaged emission factor per EURO class is given, also one emission factor for all the different petrol HGV's is provided.
4. *Per vehicle category and subsegment* The emission factors are calculated per size, per fuel and per EURO class.

Because it is desired to obtain emission factors per vehicle type, the last and most detailed option has been chosen. To analyze the data from HBEFA, 6 files (one per country) were downloaded with the energy consumption data (MJ/km) for the aggregated traffic situation divided into motorway, urban and rural. From this data, one emission factor per vehicle type has been constructed. This has been done using the different emission factors for the same vehicle type (for example: RT 14-20t) but different Euro-class and taking an average based on the % vehicle share for that country provided by HBEFA and the total goods vehicles available in that country presented in the data from Eurostat (Eurostat, 2021). Using the amount of vehicles of a specific vehicle type and Euro-class and taking an average of all the vehicles from the six countries with the same vehicle type but different Euro-class using the amount of vehicles derived from Eurostat, one average emission factor per vehicle type for the three different road types was constructed. The distribution of road types differ per trip and trip purpose and therefore only an indication can be provided. This indication is explained in Section 3.4.3, using the velocity profiles of TNO.

B.2 Overview of Energy Consumption factors from HBEFA - CONFIDENTIAL

This appendix is confidential as it is not allowed by HBEFA to make their data public. This appendix will only be shown to the supervising committee and is absent in the public version of this thesis.

C Maintenance document thesis tool

The purpose of this document is to guide the maintenance of the information tool after my thesis. This document contains information on the structure of the Excel file containing my tool, the data & parameters and information on how the abatement curve in Excel is build as this is not a function of Excel, but is created from different graph styles present in Excel.

1. Structure of the Excel tool

The Excel file exist out of visible and invisible tabs, where the visible tabs are meant to be seen and used by the user (yellow) and the invisible tabs contain the background data to structure the tool and the different calculations (blue and green). In this chapter the use and needed maintenance of every tab will be discussed separately, ending with an overview of maintenance tasks.

Information

The information tab explains the different steps in the tool and the actions expected from the user. This tab also only needs to be altered if the working principle of the tool changes or more/other actions are expected from the user in this tool. The information tab also provides the user with a word list of used concepts in the tool and the working principle of the tool.

Input

The input tab is step 1 for the user. The data needed from the company on their road freight transport needs to be filled in here. This tab relies on the tab “Menu data” for the different roll-outs. The bright yellow cells are the cells that need to be filled out by the user, the grey cells on the right are the calculations related to the emissions of the current situation. These calculations rely on the tab “HBEFA” for the emission factors and the energy consumption factors. Every year a check needs to be done on this tab to see if the links between the tabs are still working correctly and if the calculations are still working. If changes are made to either the “Menu data” tab or the “HBEFA” tab, the working principle of the “Input” tab also needs to be checked.

Parameters

The tab parameters provides the user with the opportunity to use their own information in the calculations. If other values are used for energy consumption, fuel emission factors, cost of fuel or TCO of vehicles, this can be changed here. These cells are linked to the calculation in the “HBEFA” tab to make sure the entered data of the user is used instead of the pre-defined values of the “HBEFA” tab. If more options are added in the parameters list for emission factors or cost, it needs to be checked if these cells are then correctly linked to the emission calculation and are also prioritized over the pre-defined values. The distribution of road types and CO2 costs are also defined here and must be filled in by the user, if other default values are used, these need to be changed here and the new sources also need to be added. To check if the new values are then used in the calculations, the formula’s in the “Calculations” tab can be checked. It is advised to check every 6 months if the CO2 tax or ETS is changed on average in Europe and to change the values in the tool accordingly. The distribution of road types also need to be entered by the user as this distribution differs highly per trip and shipment, the offered indications should be changed if more information on the average distribution of road types is available. It is advised to do a quick literature check every 2 years to see if more research is available.

Action choice

At the action choice tab, the user chooses that actions that are of interest. After clicking the tick-off box in front of the action, the action should appear in the abatement curve if no more than 6 actions are selected. The list of actions can be seen on the right were the actions that are mutually exclusive are found in a drop-down menu. The figure of the abatement curve is created using different graph styles together in one graph, if new actions are added or data of these actions is changes in the “Data” tab, the reaction of the abatement curve in the “Action choice” tab needs to be checked. If new actions are added to the tool, also a tick-off box must be created which is linked to a cell on the “data” tab in the section Information on actions, here the cost and reduction potential of the action can be filled in.

Output

The output tab provides the user with an overview of the chosen actions and a summary of the total reductions and cost for the new trip. It is important to notice that the output is constructed on a per trip basis, the data previously used in the action choice tab must therefore be changed into a per trip number. Every year it needs to be checked if the formula’s in this tab work correctly based on the input tab and the action choice tab.

Solution reference

To provide the user with the sources of the used information, a special tab is created with the different sources used per topic in the tool. The user can have a look themselves at the data user if more information is wanted on the uncertainty or the origin of the information. As more data is entered in the tool, the sources used must also be entered on the “Solution reference” tab.

Calculations

The calculations tab is an invisible tab responsible for the input of the abatement curve and the output tab. First the calculations in B2:J24 are used to determine the data for the abatement curve in the right order. It is sorted on the lowest

price per tCO₂. This data is linked to the calculations done on the data tab. The calculations in L3:Y14 are the actual input for the graph, this data is linked to the list of actions on the left side. This data needs to be entered in this stepwise manner to create the abatement curve look with different rectangles. If a higher or lower amount of actions must be allowed in the abatement curve, the amount of cells in the 3rd row can be altered accordingly. Row 11 is used to enter the CO₂ tax and ETS pricing. This value is linked to the entered values on the “Parameters” tab and uses the same x-values as the chosen actions. Below the first set of calculations the output calculations are done based on the values above. This small list determines the absolute emission reduction of the chosen actions by calculating the emission reduction of the next action after the previous one has been implemented and thus eliminating double counting in the emission reduction calculations for the output. These cells are then linked to the output of the tool.

Electricity

As the electricity source differs per country and the availability of green energy sources also differ per country, a separate tab is used to gather all the information on electricity sources of different countries in the EU. The corresponding emission factors are gathered and the different sources are mentioned in column H. The WTW emission factors are always found in kgCO₂/kWh and are transformed into MJ by using the conversion factor of 3.6. In cell D1 a filter is placed that searches for the right emission factor if electric vehicles are chosen in the action choice tab. This value is based on the country chosen in the input tab and the energy source chosen in the action choice tab. If certain energy sources were not available in a country, they were not added to the list and that entry thus does not exist. It is advised to adjust these parameters every year according to the new values of the carbonfootprint website. Also an availability study needs to take place every other year to investigate the availability of the different energy sources in the available countries in the tool.

Data

The data tab is also an invisible tab and the heart of this document. In the columns B:H the data of the different actions can be seen. This list is adjusted according to the tick-boxes ticked in the “Action choice” tab. In column J:O an overview is given of the selected actions and this is sorted on their absolute costs. This tab needs to be checked every year, the cost and reduction potential of these actions can change due to change in technologies. It needs to be checked if actions are still relevant and if the cost of these actions did not go down.

Menu data

All the different roll-out menu’s need to be fed with information that needs to be in that specific menu. These lists can be found here. If something needs to be added to a list, it needs to be checked if this value is also added in the selection. This can be done in the Formula menu -> Manage names. To remove an option from a menu, just delete the entry in the list on the Menu Data tab.

HBEFA

In the HBEFA tab, the emission consumption factors of the different vehicles are stored. These are the same energy consumption factors as are being used in the GLEC framework and thus also need to be updated with every update of the GLEC Framework. Below the energy consumption factors the emission factors of ISO14083 are placed to determine the actual emissions of a trip. From these values also emission values for blends are created. An indication of the cost per litre fuel is also provided next to the emission factors of fuels, these factors are based on averages in Europe and were determined in September 2022. These values must be updated every year as the price of fuel fluctuates. On the right side on this tab the emission calculation for bio-fuels is placed. On top this calculated the emissions for the used vehicle but changed fuel to cleaner and lower carbon fuel, below the calculations are done on electric vehicles using the emission factor retrieved from the “Electricity” tab.

Base cost To determine the base cost of transportation with ICEV, an overview of the different cost reported by the ICCT is used. This table offers the opportunity to compare ICEV with LNG or CNG vehicles, Hybrid vehicles, BEV and fuel cell vehicles. Based on this table the cost for a trip was determined. This table offers an estimation of the cost now and in 2030, however if more accurate data can be found, this section of the tool can be replaced. It is advised to check the cost of transport technology every two years.

Solution cost

The cost of the different solutions for more efficient vehicles and cleaner and efficient technologies have been based on absolute investment costs. These need to be changed into cost per trip. This is done in this tab. If the cost or reduction potential of these actions is changed, this can be done here. The calculations into a per trip factor then need to be checked and used for the new numbers. These cells are then linked to the related cells in the Data tab.

2. Data & parameters

The data used in the tool changes over time. The energy consumption of vehicles as well as the emission factor of fuels will go down as processes become more energy efficient. The data on costs of fuel is highly dependent on the prices of oil as bio-fuel prices also go up when the oil price rises. The cost of reducing actions will go down if techniques become more common and the amount of production is higher. It is therefore recommended to review the indicated cost of fuel in the tool every 6 months and to review the cost of actions every year. The parameters used for energy consumption and emission factors only need to change if the values in the ISO14083 change or when the GLEC Framework factors change as this tool is compliant with both.

3. Abatement curve

The abatement curve in the Excel tool is created using

this link: <https://nl.extendoffice.com/excel/excel-charts/excel-variable-width-column-chart.html> As Excel does not offer the possibility to create an abatement curve, this is done by hand combining two different graph types and multiple steps to recreate an abatement curve. If changes need to be made to this curve, it is advised to first try to alter the current graph and the data sets used before building a new graph. No updates are needed to this graph as the data in the tool should automatically be transferred to this graph.

Table 19: Overview of recommended updates

Subject	Updated every
Default values for cost of fuel	Every 6 months
Default values for cost of actions	Every year
Available actions	Every year
Electricity emission factors	Every year
Default values for cost of vehicle technologies	Every two years
Overview of possible distribution profiles of road types	Every two years
Energy consumption factors	With GLEC update
Emission factors	With GLEC update

D Usability for SFBA

Usability of information tool

Subject: Thesis Hannah - Information tool to inform shipper companies on emission reduction in road freight transport

Date: September 2022

Author: Hannah de Regt

1 Introduction

The purpose of this document is to explain why this tool was build, what the value of this tool is for SFBA and how this tool can be used in the daily work of SFBA.

This tool was build as part of completing the Master's program Transport, Infrastructure and Logistics at the TU Delft as part of graduating. From November 2021 till February 2022 I sat in on meetings of the SFBA founders circle to determine a useful contribution within SFBA that could also serve as a graduation assignment. A combination between contributing to literature, sufficient academic relevance and relevance to SFBA was found in creating an information tool to inform shippers on the emission reducing possibilities in road freight transport in Europe. This tool compares different possibilities to reduce emissions in road freight transport on emission reduction potential and costs per trip. As collaboration is the main focus of SFBA, the emission reducing actions in this tool can be implemented as a result of collaboration between shippers and carriers.

As collaboration projects regarding decarbonizing logistics is the main focus of SFBA, sparking the conversation with shippers and carriers is key to starting new projects. It was found that shippers are mainly focused on keeping the cost of transport low and are therefore less interested in joining a project of which the main goal is to eliminate emissions instead of low cost. To inform these shippers on the actual cost and corresponding emission reduction of collaboration projects this tool was build. It is expected that shippers will be more interested in collaborating to reduce emissions of road freight transport when given insight in the low or even negative cost.

In order to ensure more collaboration projects, it is advised to make the information tool available to the public. By doing so it can both get more companies involved with SFBA and result in more collaboration projects.

2 Recommendations

As this tool was build as part of a thesis, it is recommended that the tool will be elaborated on in the future to ensure the usefulness of the tool for a larger public. After graduation, a prototype was delivered to SFC that is focused on road freight transport in Europe. This can be extended with more modes of transport and different regions. Also the amount of actions included in the tool can be extended as with more modes, different and more solutions become available. Adjusting the tool to also provide information for the total freight distribution of a company in a specific region can also be part of elaborating the tool, however different calculations and properties of transport must then be taken into account. These adjustment are expected to increase the value for the shipper companies as well as carrier companies connected to SFBA.

E Tool Guide

The goal of this document is to explain the uncertainties in the information tool. Also solutions are offered to determine the risk of actions. The calculations in this tool are based on averages valid for Europe. As no trip specific data and vehicle specific data is used, the uncertainty of this tool will be explained.

If a company makes use of the indicative values in the tool, such as vehicle choice, road type distribution, the CO2 cost and the fuel price, the outcome of the calculations are more uncertain than if own values are entered. However, the tool can be used to simulate what happens if the prices go up or if other vehicles are used. Per parameter that can be changed, it will be explained what the uncertainty entails. A description is given how the tool can be used to determine risks for the actions that can be chosen in the tool.

Uncertainty

Vehicle choice

The user is offered to choose from a list of vehicles that can be used to transport the shipment based on the weight of the load. If this information is not known, a default truck will be used being a 26-40t Truck Trailer. If the weight of the load is higher than the capacity of this type of truck, the most fitting Truck Trailer size will be chosen. For shipments less heavy than the capacity of the 26-40t TT, the emissions can be overestimated. For shipments heavier, it can be that the emissions are under estimated in case a larger truck was actually used than chosen in the tool. If the truck size is known by the user, it is advised to use the input cell for vehicle choice.

Road type distribution

As the road type distribution differs per trip, shipment and vehicle used, no average can be given with certainty. In order to provide an indication to the user, the data from TNO has been used for trip distribution. Indicative profiles (overview of shares of different road types for a trip) are provided for companies that do not know their distribution profile. Three examples are given, regional delivery, distribution centre – distribution centre trips and long haul delivery. It is advised to the user to use a route program to determine the shares of the three different road types for the specific trip and enter this data in the tab “Parameters”. This distribution will be used to determine the trip specific energy consumption factor based on both the vehicle choice and the road type distribution. Emission can either be overestimated or underestimated if the indicative values are used.

CO2 cost

Depending on the regulations per country and the emission measures introduces by the European Commission, the price per tonne of CO2e differs. As a default value, the average of the CO2e price in Europe was taken. In 2022 the European Trading System does not include CO2e of road transport but from 2026 this will be included. The CO2e tax differs per country and again an average is taken of the European countries as the default in this tool. It is therefore advised to fill in the cells regarding CO2e cost in the tool to account for the price on GHG emission in the year of implementing the actions. The price per tonne of CO2e will be used in the abatement curve to draw a red line simulating the carbon price and showing what cost do not have to be paid in the future if a certain action is implemented. The value of this parameter does not influence the uncertainty of the emission calculations.

Fuel price

The price of fuel can be altered in the tab “Parameters”. This option is provided as companies often have negotiated their own fuel prices and because the price of fuel is very changeable over time. The default value for fuel prices is based on the fuel price in Europe over the first six months of 2022. If the price of fuels is set lower than actually paid for, renewable energy vehicles are rated less attractive than they actually are if looked at the cost per tonne CO2. If the price of fuel is higher than actually paid for, the renewable energy vehicles are made to look more positive than actually true.

Determining risk of actions

The success of the different actions in the tool depend on four things: 1. The dependence on price of specific fuel 2. The TCO of the chosen action 3. The road type distribution of the trip 4. The price on carbon To simulate the effect of these dependencies for certain actions, the parameters in the tool can be changed. If a solution is in need of a specific fuel which is at this moment more expensive (2022), the price of fuels in the “Parameter” tab can be changed to an expected value in the future where fossil fuels are more expensive than renewables. The same is possible for the expected TCO of vehicles, if these are expected to drop to the same cost of fossil fuels now, the actions “Lower carbon content of fuels” can be used with the input of a fossil fuelled vehicle. To account for a higher price on carbon, the values for the Emission Trading System permits and the CO2 tax can be set higher, showing the new value of these cost in the graph.

An information tool for shippers concerning the cost effectiveness of emission reduction measures in road freight transport

Hannah de Regt (4386760)

Abstract: This paper describes the design of an information tool, created as an addition to the knowledge platform of the Smart Freight Buyers Alliance initiative of Smart Freight Centre. This tool was created for shippers to inform themselves on the emission reducing actions available to reduce road freight transport emissions. Different emission reducing actions for road freight transport are researched and compared based on emission reducing potential and cost. A calculation method to determine emissions and cost per trip form the basis for an informational tool for shippers. As shippers buy road freight transport from logistic service providers, third-party logistics or directly from the carrier, they do not have a direct influence on the amount of emissions emitted during transport. However, by making use of collaboration, shippers can influence emission reduction by working together on implementing emission reducing solutions and influencing the corresponding decrease or increase in the price of transport. This tool has the goal to inform shippers on the possibilities for emission reduction, their reduction potential and costs.

Keywords: Road transport emission reduction, road freight transport emission calculation, road freight transport, CO_2e mitigating actions information tool, cost and emission reduction potential of actions in road freight transport

1 Introduction

Emission reduction and climate change are two frequently heard words in the past years and even more often in 2022. Due to the increasing knowledge about climate change and the effects of emissions on nature and the livability of our planet, the voice that change is needed became louder and stronger. Different governments, UN climate conferences and experts came to the same conclusion, that emission reduction is needed in all different aspects of society. To limit the effects of climate change, the Paris agreement was adopted in 2015. This climate accord has the goal to limit global warming with a maximal increase of 2 degrees Celsius [1], and even trying to limit it to 1.5 degrees Celsius, resulting in many plans and treaties with targets to reduce emissions. One main polluter is transport, people as well as freight. With transport being responsible for over 25% of emissions in Europe and road transport being responsible for 72% of that in 2019 [2], road freight transport became one of the major sectors for change [3]. It resulted in a strategy in Europe, the European Green Deal [4], that greenhouse gas (GHG) emissions must be reduced by at least 60% in 2050 compared to 1990 [5].

As part of the European Green Deal, the European Commission has decided that from 2026 the transport sector will also participate in the Emissions Trading System (ETS) [6]. This measure puts a price on transport emissions making traditional (fossil fuelled) transport more expensive, which is expected to stimulate the use of cleaner fuels and increase investments in cleaner technologies. As a result, carriers as well as shippers need to decide on their transport strategy. As road freight transport is often purchased by shippers either directly from the carrier or through a logistic service provider (LSP) or third-party logistics (3PL), collaboration is needed in order to create change in the road freight sector. As carriers are responsible for their operational fleet, the change to vehicles and fuels used needs to take place here. However, a change of mindset is also necessary for shippers as they purchase the freight transport and currently base their decision purely on cost and reliability. To implement emission reducing solutions, collaboration between shippers and carriers is needed.

Several studies were found that study emission reduction in road freight transport. This research has mostly been done on finding a solution for a specific situation, such as city logistics, long haul or multi-modal logistics. [7] researched the measurements of CO_2 emissions in the UK for road freight transport, [8] looked into city emissions in Dublin and [9] developed a calculation method to determine emissions of transport in the Netherlands. These studies are often focused on passenger transport and inner city logistics because of the direct impact on the health of people living in the city.

Little work has been put into creating an overview of the different solutions available, which would allow companies to see which options fit their supply chain best. The Global Logistics Emissions Council Framework (GLEC), created by Smart Freight Centre (SFC), tried to capture all different categories of solutions into one table based on the book of [10] next to offering companies a method for emission calculation and reporting. By creating these kind of overviews, companies, shippers as well as LSP, can see what their options are with regard to implementing emission reduction solutions. However, only an overview of the options does not provide information on the emission reduction potential of these solutions or other factors that are related to implementing a solution, such as costs.

To fill in this gap, some organizations created tools which do compare options or solutions such as EcoTransIT [11], which compares different modes for the same origin-destination pair. The International transport forum [12], they created an overview of mitigation measures for passenger as well as freight transport, it includes emission reduction potential and cost information but lacks in number of solutions that are in need of collaboration. Vecto, a tool created by the European Commission to help calculate emissions of heavy-duty vehicles (HDV) above 3,5t, but does not contain information on mitigation measures [13]. And initiatives such as Science Based Targets [14], that help their clients to set targets for emission reduction but do not provide information on how the emission reduction can be achieved.

In literature, only a low number of studies focus on comparing the different possible solutions and their impact on emission reduction and costs. The reviews that were found often only compared two different solutions so a large overview was not created. In grey literature

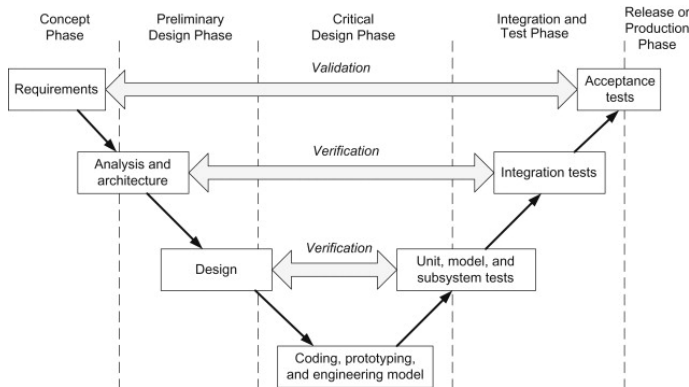
no tool was located that combined information on cost and emission reduction of actions to reduce emission in road freight transport into one tool. With this study, the gap between companies and information that can be found in literature on different solutions for reducing emission in road freight transportation is closed by creating an information tool that takes into account not only emission reduction but also costs. With the study, the following research question was answered:

How can emission reduction possibilities be meaningfully presented to shippers?

2 Methodology

As this is a design study, the methodology used in this research was based on a design method, the V-model. This model exist out of five phases from requirement analysis to final design. Some validation and verification steps were added to ensure error were spotted quickly.

Fig. 1: V-model [15]



The first part of the design process, the concept phase, consisted of determining the goal of the tool. This was determined through interviews with shippers, the future users of the tool. These interviews were also used to learn more about the process environment of decision making with regard to sustainable transport and to find the requirements for an information tool. This phase also included a literature research on the state-of-the-art of existing decarbonization tools. The phase was concluded with the list of requirements.

During the preliminary design phase a conceptual model was constructed and from this the architecture of the tool was determined. The different sub-models of the tool were designed and literature was used to find the data and the calculation methods needed for the tool. From the different sub-models, the tool was actually built in Excel in the critical design phase.

In the next phase, the integration and test phase, the tool was tested and a first round of validation interviews was done. Several employees of Smart Freight Centre tested the tool and provided feedback. This was then used to improve the tool before a second set of validation interviews was done. During the integration and test phase, also a sensitivity analysis was conducted to examine the effect of the uncertainties of the different parameters used.

After verifying and validating the tool some last improvements were made before entering the final design step, the release phase.

3 Literature review

Two separate literature reviews have been conducted in this study. First the state-of-the-art of existing decarbonization tools was studied. Different initiatives, programs and tools were searched using literature as well as grey literature as tools are mostly available on the internet. The second literature study was done to collect the data needed for the information tool. Different emission reducing actions were studies to determine their cost and emission reduction potential. The main search engines used were Google Scholar and Scopus. By making use of different keywords related to the decarbonization of road freight transport in Europe, many papers were found. These papers were filtered based on their publication date, no older than 2018, and the title. If the title of the paper sounded promising with relation to road freight decarbonization, the abstract was read. For the actions that were not mentioned many times, the publication date was altered to 2014. During this study the emission calculation methods were also determined.

State-of-the-art of existing decarbonization tools

The existing tools on the decarbonization of road freight were studied and an overview was created, see Table 6. Most of the available initiatives and tools focused on calculating and reporting emissions, same as the GLEC Framework [16]. Other initiatives focused more on specific targets, like Science Based Targets and EV100+ [14]. Only a few tools included multiple actions and their emission reduction potential such as EcoTransIT [11] and Greenrouter [17].

Actions

By providing the shipper with information on the reduction potential and the corresponding costs of different emission reducing possibilities for their outsourced transport, responsible for scope 3 emissions, the shipper gets a clearer picture of where the solutions to reducing these emissions lie. With this in mind, this research focuses on the actions that need collaboration between shippers and carriers to make the change happen, actions that can be performed by only shippers are therefore not included. Also actions with regard to mode switch have not been taken into account, while this research solely focuses on road freight transportation.

Because the emissions (scope 1, scope 2 and scope 3) that need to be reported are calculated in CO_2e , in this study the same pollutants are taken into account for emission reduction potential. CO_2e includes, CO_2 , N_2O , CH_4 and fluorine-containing gases, these are converted into a CO_2 equivalent using the Global Warming Potential (GWP), that is the extent to which a gas contributes to the greenhouse effect.

The actions that meet the scope and are taken into account in the tool are shown in Table 1.

Table 1 Actions included in information tool

Increase load	Decrease fuel use	Changing energy source
Load optimization	Cleaner & efficient technologies	Cleaner & lower carbon fuels
Load consolidation	Efficient vehicles	Electrification
Standardized modules & boxes	Driving behaviour	Hydrogen
	Fuel management	
	Fleet operation	

Data collection

For these actions the emission reduction and costs are determined from literature. In Table 7, 8, 9, 11 and 10 an overview is provided of the actions and the data that is used in the tool.

The first category, increase load, is based on a higher load factor. This can be done by load optimization, load consolidation, standardized boxes, high-capacity vehicles and double stacking. The reduction potential of these actions is shown in Table 7 and is based on [18] [19] [20] [21][22][23] and [24].

For the actions related to Cleaner & Efficient technologies and Efficient Vehicles, the data from a study done by TNO in combination with TU Graz, CE Delft and ICCT has been used [25]. The emission reduction potential of both solutions can be seen in Table 11 and 10. Driving behaviour [26] [27], fuel management [18] and fleet operation [28] [29] [30] are shown in Table 8. Actions that are related to fleet operation are fuel efficiency, ecodriving, lightweight equipment (trailers), planning of vehicles and routing. As fuel efficiency from a fleet operation standpoint, fuel management and ecodriving are very intertwined, the reduction potential of these three is combined into one factor for fleet management together with routing and maintenance. All actions of this category have in common that they reduce the amount of fuel use of a trip. Not all actions can be implemented on existing trucks, adding solutions to existing vehicles is called retrofitting.

The last category is based on changing the energy source of vehicles. This solution relies on the carbon content of energy and therefore the emission factors of the different fuels play a large role [31][32]. Table 9 shows the effect of the different fuels. The different investment costs of the vehicles are shown in Table 2, [33] and [34].

4 Requirements

By making use of different requirement trawling techniques [35] during meetings of SFBA, a preliminary list of requirements was created. During the interviews conducted as part of the concept phase, these requirements were discussed and more requirements were discovered. This led to the final list of requirements. This list was divided into functional requirements, things a system has to do, and non-functional requirements, such as qualities, performance and usability. The requirements that are imposed by SFC are marked with (C) for commissioner.

The functional requirements are:

FR 1: The tool shall only take actions into account for road transport

FR 2: The tool shall provide a location where the user can enter their transport data

FR 3: The tool shall calculate the emissions of the current situation by using the data provided by the user

FR 4: The tool shall use calculation methods found in literature to determine the emissions

FR 5: The tool shall take into account the weight of the shipment in either kg, lb or tonne

FR 6: The tool shall take into account the distance of the shipment in either km or miles

FR 7: The tool shall take into account the origin of the shipment for determining the emission factor

FR 8: The tool shall provide the user with opportunity to choose from the list of actions which are of interest and which are not

FR 9: The tool shall determine the emission reduction potential of the different actions that are chosen by the user

FR 10: The tool shall determine the cost of emission reduction actions per trip

FR 11: The tool shall show the different actions in an abatement curve

FR 12: The tool shall adjust the abatement curve within 10 seconds after changing the input

FR 13: The tool shall provide an overview of the outcome separately from the abatement curve

FR 14: The tool shall provide information on the uncertainty of the calculations in the tool

FR 15: The emission calculation in the tool shall be in line with the GLEC Framework (C)

FR 16: The emission factors used in the tool shall be in line with the GLEC Framework (C)

FR 17: The energy consumption calculations shall be based on the HBEFA tool (C)

The non-functional requirements are:

NFR 1: The tool should be easy to use

NFR 2: The tool should include information on the working principle of the tool

NFR 3: The tool should be understandable for users with a road freight logistics background

NFR 4: The tool should present the emission reduction possibilities in a meaningful way to shippers

NFR 5: The tool should display the outcome in a clear way

NFR 6: The tool should be possible to download

NFR 7: The tool should be accessible on the SFBA platform

NFR 8: The tool should be available as a MS Excel download file

NFR 9: The tool should have a size that is downloadable

NFR 10: The tool should work with all versions of MS Excel

NFR 11: The tool should be easy to maintain (C)

5 Model Components

Conceptual model

The conceptual model of the tool can be seen in Figure 3. This conceptual model consists of two main parts, the emission reduction potential and the cost estimation. Both parts contain a set of calculations to determine the emissions and cost of the current situation. To determine the emission reduction potential and cost increase or decrease of the action, alterations to these calculations must be made. In the figure an overview of the different alterations for the emission calculation as well as the cost calculations is shown. Depending on the action, the calculations are altered and the corresponding emissions of a trip with the included action are calculated as well as the cost. This information is then used in the tool to create a visual overview of the chosen actions.

Calculations

The data used in the tool is determined from the literature research and shown in the Tables 7, 8, 9, 11 and 10. This information is used in calculating the emissions, which is done in the way that is described in the conceptual model, Figure 3. The formulas used for the emission calculation are:

$$TE = (EC_e + EC_l) \cdot d \cdot EF \quad (1)$$

$$\text{Reduction percentage (\%)} = \frac{(TE_{bc} - TE_n)}{TE_{bc}} \cdot 100 \quad (2)$$

$$EC_e = U \cdot UF_0 + R \cdot RF_0 + MW \cdot MWF_0 \quad (3)$$

$$LF = EC_{100} - EC_e \cdot \frac{w}{C} \quad (4)$$

$$EC_l = U \cdot UF_{LF} + R \cdot RF_{LF} + MW \cdot MWF_{LF} \quad (5)$$

- TE: Total emissions ($kgCO_2e$)
- TE_{bc} : Total emissions base case ($kgCO_2e$)
- TE_n : Total emissions new ($kgCO_2e$)
- EC_e : Energy consumption empty (MJ/km)
- EC_l : Energy consumption load (MJ/km)
- d: Distance (km)
- EF: Fuel Emission Factor ($kgCO_2e/MJ$)
- U: Urban share
- UF_0 : Specific urban energy consumption factor 0% load (MJ/km)
- R: Rural share
- RF_0 : Specific rural energy consumption factor 0% load (MJ/km)
- MW: Motorway share
- MWF_0 : Specific motorway energy consumption factor 0% load (MJ/km)
- LF: Specific load factor
- w: Weight of shipment (tonne)
- C: Capacity of vehicle (tonne)
- UF_{LF} : Specific urban energy consumption factor with specific load (MJ/km)
- RF_{LF} : Specific rural energy consumption factor with specific load (MJ/km)
- MWF_{LF} : Specific motorway energy consumption factor with specific load (MJ/km)

The associated cost of the actions are described in Figure 3 and are determined with formula 6 & 7.

$$Cost_v = TCO \cdot \frac{d}{ad} \quad (6)$$

$$Cost_t = Cost_v + Cost_f \quad (7)$$

- $Cost_v$: Cost of vehicle per trip (€)
- TCO: Total Cost of Ownership (€)
- ad: average distance travelled in the first 5 years (km)
- $Cost_t$: Cost of trip (€)
- $Cost_f$: Cost of fuel per trip (€)

This calculation uses the first ownership principle [36]. This method calculated the cost of a new vehicle in the first 5 years and relates the cost to the average amount of kilometres travelled in this period. The average amount of kilometres travelled is determined at 550,000 km in the first 5 years.

The Total Cost of Ownership values, used to determine the cost of a trip, can be seen in Table 2. These values are constructed from the information available in the white papers from the International Council on Clean Transportation from [33] and [34].

Table 2 Total Cost of Ownership of vehicles

Total cost of ownership of vehicles	
Diesel	€ 321.750
Hybrid Electric	€ 528.820
Battery Electric	€ 564.820
LNG (Spark ignition)	€ 333.750
CNG (Spark ignition)	€ 347.750
Hydrogen fuel cell	€ 353.820

Parameters

It can be seen that many different parameters are used in the emission calculation and costs calculation. Some of the parameters need to be filled in by the user such as weigh and distance of the shipment. Others are implemented in the tool, these are: - Emission Factors

- Energy Consumption
- Road type distribution
- TCO of vehicles
- Cost of fuel

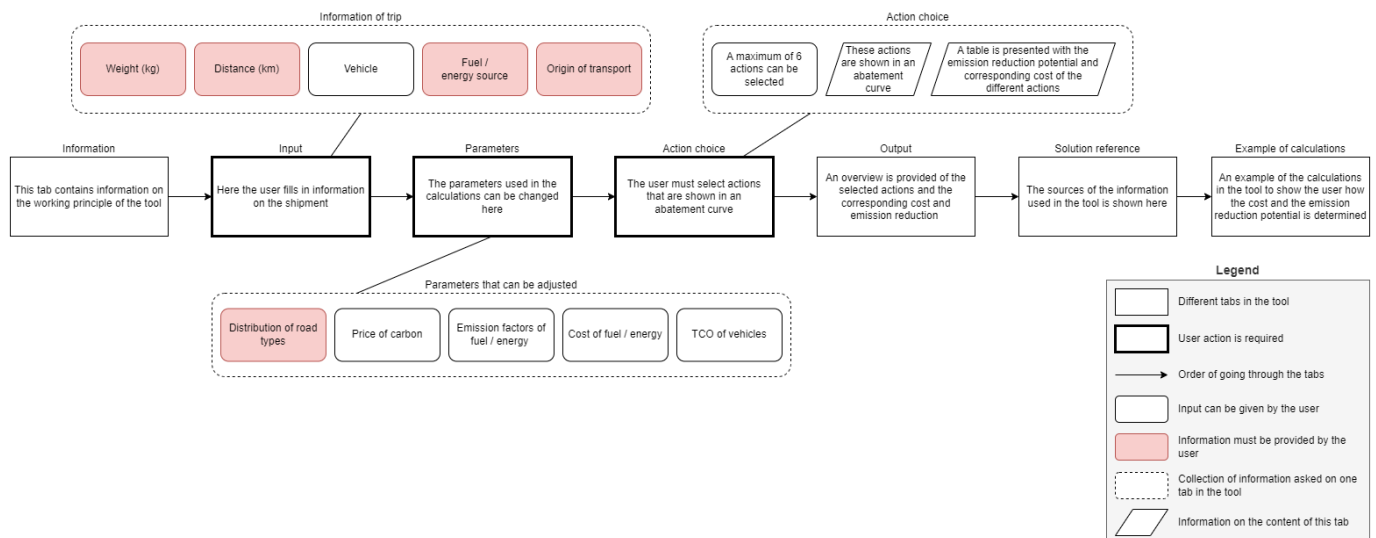
The emission factors used in the tool are the factors from the new ISO standard, ISO14083 [31], see Table 3

Table 3 WTW emission factors (ISO 14083 FDIS version)

Fuel type description	WTW gCO_2e/MJ
Gasoline	90,1
Ethanol	48,2
Diesel	87,3
Bio-diesel	38,3
Liquefied Petroleum Gas (LPG)	81,6
Compressed Natural Gas (CNG)	72,7
Liquefied Natural Gas (LNG)	75,5
Bio-LNG	30,4
Hydrogen (grey)	114,4
HVO	28,6
Electricity (EU average)	97
Bio CNG	26,2

The energy consumption was determined by making use of the Handbook Emission Factors for Road Transport (HBEFA) [37]. These values were based on the vehicle type and fuel and are divided into three categories, motorway, urban and rural road. By making use of the road type distribution of the trip and the vehicle class, the energy consumption of the trip can be determined.

Fig. 2: Overview of the different tabs in the tool



TNO provided information on the different distributions of road types for different delivery types, regional delivery and long haul delivery [25]. These different distributions are only indications of how the distribution can look for these delivery types. The actual distribution is unique to every trip and can best be found using a route program. The regional delivery and long haul delivery are from [25], the profile for delivery between two distribution centres is an estimate based on previously acquired knowledge by the author, see Table 4.

Table 4 Road type distributions

	urban areas	rural roads	motor ways
Regional delivery	28%	46%	27%
DC-DC delivery	-	10%	90%
Long haulage	7%	13%	80%

Description of information tool

In Figure 2, the structure of the Excel Workspace is explained. When the user opens the Excel-file, the information tab is shown. This contains explanations on the different steps of the tool and informs the user of the information that the user must provide in order

for the tool to work. The next tab contains the questions on the shipment information. The country of origin, weight of shipment, distance as well as current fuel and vehicle are asked. When these questions are answered, the user will see the emissions of the current situation. The next step is to determine if the parameters used in the cost and emission calculations need to be changed. The default values available in the tool are an average of the European countries and this information is not specific to the trip entered in the input tab. To create a more accurate estimation of reduction potential and cost, it is advised that the parameter tab is used to fill in extra information about the trip.

After the user has answered the questions and possibly altered the parameters. The user can select the actions of interest in the action choice tab. A list of actions is shown and a maximum of 6 can be clicked. If an action is selected, the tool will show the action in the abatement curve. In this curve the reduction potential of the action is shown on the x-axis and the cost of the action is located on the y-axis. This curve will automatically sort the selected actions based on the cost of the action.

The complete width of the abatement curve shows the total emissions of the trip, if the graph is not completely filled with colored blocks, some emissions are still not reduced after implementing the actions.

In the output tab of the tool, an overview is provided of the different selected actions, their emission reduction potential and associated costs. The complete emission reduction potential is calculated as if the actions were implemented after one another, creating a more accurate result for the total amount of reduced emission if all actions were actually implemented.

If the user is then interested in the sources of the data, the solution references tab can be viewed. An explanation on the emission calculation methods is provided in the example of calculations tab.

6 Analysis with tool

The tool was used to perform a sensitivity analysis to determine which parameters have the greatest influence on the outcome of the tool. By varying the different input parameters and evaluating the difference in outcome of the tool, the effect of the parameters was determined. In Table 5 the different parameters that were varied can be seen. For this test, a base case was used:

- Country: Germany
- Current fuel: Bio-diesel B5 (average)
- Distance: 500 km
- Country of Origin: Germany
- Weight of shipment: 2500 kg
- Vehicle choice: No vehicle is selected

In the parameter tab, the road type distribution (RTD) is set to the long haul distribution and the CO_2 tax is set to 100€/t. The fuel price and Total Cost of Ownership were not changed for the base case situation.

From this analysis, it was found that the road type distribution and the vehicle choice have a large impact on the outcome. It was seen that changing the vehicle from the smallest vehicle possible to a commonly used truck, rigid truck 20-26 tonne, had a great impact. It resulted in twice the amount of emissions as for the smaller truck. The road type distribution was also found to be very sensitive to the different shares of road type, while the distance and weight of the shipment did not have a large effect.

Table 5 Sensitivity analysis of the user input

	Base case	Weight		Distance		Vehicle	RTD		Fuel price	
Weight (kg)	2500	2250 (-10%)	2750 (+10%)	2500	2500	2500	2500	2500	2500	2500
Distance (km)	500	500	500	450 (-10%)	550 (+10%)	500	500	500	500	500
Vehicle type	Default	Default	Default	Default	Default	RT 20-26t	Default	Default	Default	Default
RTD (MW/R/U)	80/13/7	80/13/7	80/13/7	80/13/7	80/13/7	80/13/7	76/15/9	63/23/14	80/13/7	80/13/7
Fuel price (€/l)	Default	Default	Default	Default	Default	Default	Default	Default	1.40 (-0.5)	2.40 (+0.5)
Output (kg CO₂e)	154.64	152.39 -1.45%	156.90 1.46%	139.18 -10%	170.10 10%	315.65 204%	170.22 10%	218.35 41.2%	154.64 0%	154.64 0%
Cost (€)	390.10	388.86 -0.3%	391.52 0.4%	351.09 -10%	429.11 10%	491.72 26%	399.93 2.5%	430.30 10.3%	364.42 -6.6%	415.78 6.6%

7 Validation & Verification

A verification and validation of the tool was done as part of the V-model, the integration and test phase. During the verification the different requirements of the tool were tested. The list of functional requirement was checked and all requirements were met. For the non-functional requirements the tool was tested by employees of Smart Freight Centre. To test if the tool met the non-functional requirements, the employees were asked several questions to determine if and to what extent the requirements were met. From this it was concluded that the tool met all non-functional requirements except for the maintenance requirement, NFR 11. This could not be tested at the time.

The validation of the tool existed out of two separate phases. To check if the calculations in the tool were executed in the right way, a test case was designed. The calculations were also done by hand to see if the outcome of the tool matches the results. The different calculations were also checked on the use of units.

After this, a validation by the commissioner tool place. During three interviews, the working principle of the tool was discussed. These interviews took place partly online and partly face to face. The goal of these interviews was to check whether the tool meets the demands and wishes of the commissioner, to collect further improvements and to gain insight of the role of this tool in the context of SFBA. From the interviews it was clear that the tool provides the user with meaningful information on the existing emission reducing possibilities. As the tool is in line with the other tools of SFC, the needs and wishes of the commissioner were therefore met.

This tool will be made available next to the other available information and tools on the knowledge platform of SFBA. All different tools have with their own purpose and properties. This tool will be an addition to the other tools available within SFBA as it brings together costs and emission reduction potential. The benchmarking tool provides an overview of the impact of fuel choice and both tools can be used together. The initiatives map shows the user the existing initiatives that companies can join and the collaboration catalyzer helps companies find projects that are of interest. Within the collaboration catalyzer the tool can provide insight in the associated costs and emission reduction potential of the projects. The GLEC Framework can be used to provide more insight in the calculation and reporting of emissions, next to the calculations done in the tool.

8 Conclusion

The answer to the research question is to develop an information tool that provides the user with an overview of the reduction potential and corresponding cost of action with little effort. By providing the tool with formulas found in literature and data that is used in the industry, the tool can determine estimations of the current emissions of users and the reduction potential of the chosen actions. The uncertainty present in the tool can be limited by making the user aware of the different uncertainties present and providing the opportunity to

the user to decrease the uncertainty if data specific to the trip is used in the calculations. To ensure that the tool contains the most recent data, a maintenance plan was developed that provides the commissioner with a manual to keep the tool up to date.

It must be noted that due to scope limitations of this research, other modes of transport have not been taken into account. Including these in the tool will provide the user with more options to reduce emissions including the option of mode switch, which can have an impact on the actions for road freight. Different emission reducing actions that can be implemented by shippers or carriers alone are also not taken into account. These actions can help reduce emissions in other parts of the supply chain, which can affect the emissions of transport. Additionally, the calculations done in the tool are simplified deliberately, which means that by performing more detailed emission calculations, the tool can also be used to determine current emissions that can be used in reporting.

9 Discussion

The created tool is dependent on the accuracy of the data in the tool. Parameters regarding energy consumption, emission factors and costs of actions should therefore be updated regularly to maintain the value of the tool. As these values can also differ based on the contracts between carriers and shippers, providing the opportunity to change these values is important. If more actions are added in the future, this opportunity should be extended to the new actions. This option ensures the value of the tool for companies that do have a lot of information on their shipments.

The calculations done in the tool for emission calculation are based on a simplification of the situation. As shippers do not have detailed information on their shipments, the data asked from shippers on their shipments is very basic. If more accurate calculations are required, the amount of information also becomes higher, however this can result in a more suitable solution for trip.

10 Recommendation

-The tool provides insight in the emission reducing actions for road freight transport. Due to time limitations, only actions that require collaboration between shippers and carriers are taken into account. Looking into all different actions and extending the tool can improve the value of the tool.

This can also be done with more modes. By adding air transport, sea transport, inland waterways, rail transport and logistics sites, more solutions are possible to reduce emissions and modal shift and synchromodality are made possible.

Furthermore, it is recommended that more research is done on the costs of transport and the methods that carriers use to determine the cost. In this tool the cost calculations are based on the total cost of ownership and the fuel cost but no research was done on how carrier determine their pricing.

Finally, it is advised to look deeper in the different prices of fuel and possibly create an overview of the different cost per country. With this the availability of the different fuels is examined and the cost of fuel per country creates a more accurate estimation of the fuel cost.

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Fig. 3: Conceptual model

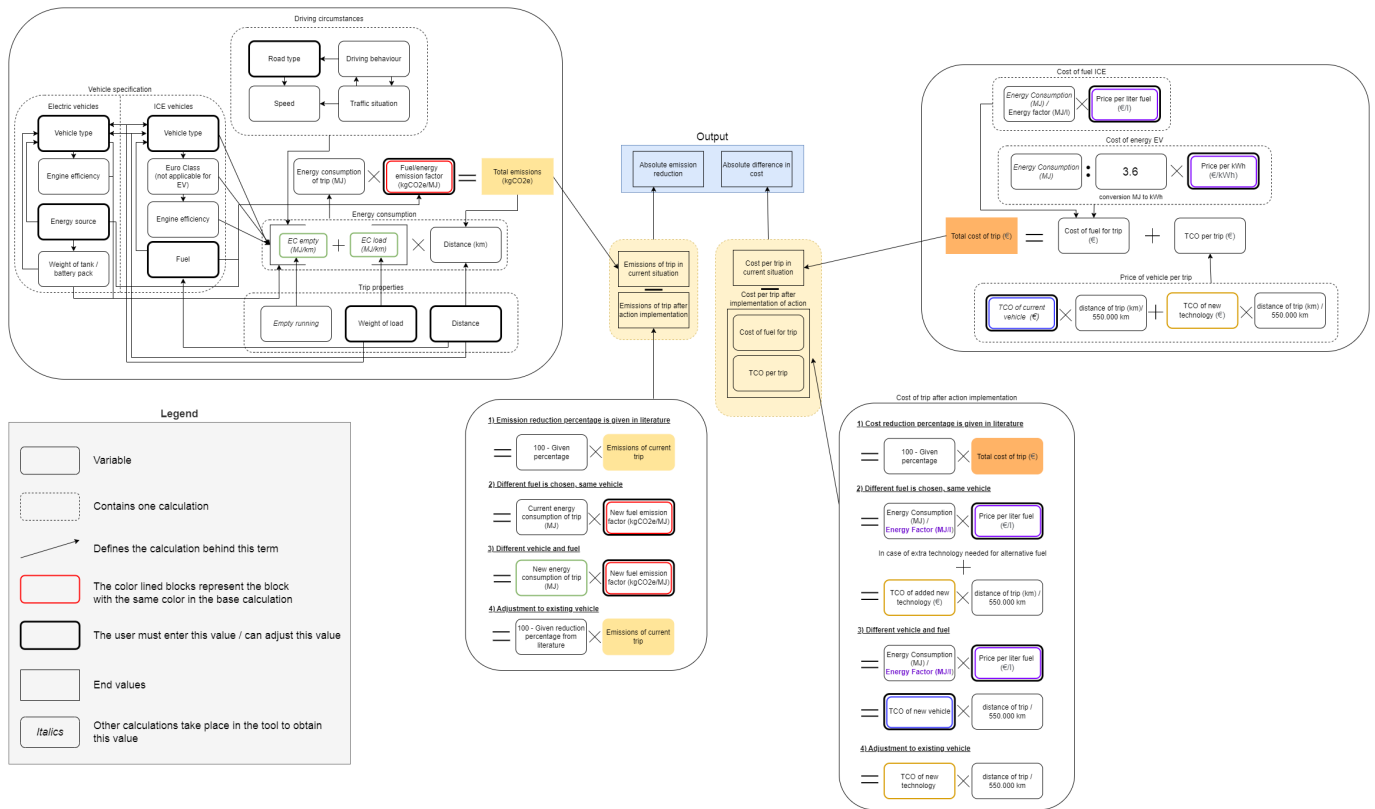


Table 6 State-of-the-art existing tools

Name	Lacks	T O O L	I N F O	C A L C U L A T E	R E P O R T	T A R G E T S	O T H E R
Transport climate action directory [12]	Has very few mitigation measures for road freight transport, only 1 solution that needs collaboration		X				
Truck Ecodriving Toolkit [26]	More mitigation measures		X				
The Global Fuel Economy Initiative toolkit [38]	Information on reduction possibilities	X	X				
Vecto [13]	Practical comparisons between actions	X					
GLEC [16]	Information about reduction possibilities, other than an overview of the possibilities			X			
Emission calculator [11]	Only offers mode switch solutions, no other road specific options	X		X			
AMBITIOUS CORPORATE CLIMATE ACTION [14] (Science Based Targets)	No specific solution information					X	
LEARN [39]	Information about reduction possibilities				X		
European Matchmaking Platform [40]	No information on solutions, only offers platform to collaborate						X
The logistics Emissions Calculator [41]	Information about reduction possibilities			X	X		
Reff Assessment Tool [42]	Focussed on logistics site, no information on emission reducing solutions				X		
TK Blue [43]	Compares existing carriers, does not provide information on emission reducing solutions				X		
Bigmile [44]	No specific solution information			X			
ECOEMISSION [45]	No specific solution information			X			
Greenrouter [17]	Includes a few solutions and their emission reduction potential, no cost analysis	X					
Pledge [46]	No specific solution information				X		
Tracks [47]	No specific solution information				X		
Smartway [48]	No specific solution information				X		
Calculator Tool [49]	Information on all sectors in the UK, not only road and no specific solutions	X	X				
SRF optimizer [50]	Needs very detailed information from user, emission calculations are based on DEFRA carbon emission factors 2015	X					

Table 7 Increase load factor

Intervention	Reduction potential from literature	Cost from literature	Reduction in tool	Cost in tool
Standardized boxes and modules				
high-capacity vehicles	7 % - 15 %	5-11%	11%	8%
Double stacking	0-23%	8-28%	12%	18%
Boxes	31%	8%	16%	4%
Load optimization	10 % - 20%	3-6%	15%	4%
Load consolidation	7 % - 51%	20%	20%	10%

Table 8 Decrease fuel use

	Reduction potential from literature	Cost from literature	Reduction used in tool	Cost used in tool
Driving behaviour	9,40%	Low (€300)	7%	€300
Fleet management	10%	Low	5%	€500
Fleet operation	10% - 20%	Medium - high	15%	€2000

Table 9 Cleaner and lower carbon fuels

Cleaner and lower carbon fuels	TCO (x TCO of ICEV)		Fuel cost	Reduction potential
	2020	2030		
Bio-diesel	-	-	+/- 3.00 €/l*	>55%
HVO	-	-	2.54 €/l [51]	>65%
CNG/LNG	-	-	> 2.30 €/kg [52]	4-67%
BEV	2,5-4	-	0.26 €/kWh [53]	>100%
Hydrogen (grey)	2-3,5	1,2	10 €/kg [54]	>100%**

* No exact information was found. As it is in Europe not common to use B100 as a fuel. There is data available for the United States on the website of the [55]. It is known from literature that bio-diesel in Europe is more expensive than regular diesel. Therefore a price of 3€/l was taken for the calculations.

** The reduction potential depends on the energy source, grey hydrogen cannot reduce emissions up to 100%, green hydrogen can.

Table 10 Cleaner and efficient technologies

<i>CO₂</i> reducing technologies	TNO-2018-R10214	Vehicle group 4		Vehicle group 5		Vehicle group 9		Vehicle group 10	
	TNO code	%	€	%	€	%	€	%	€
Tyres									
Low rolling resistance tyres on truck/tractor	TYRES1	-6,10	140,00	-5,10	350,00	-6,40	210,00	-5,20	420,00
Low rolling resistance tyres on truck/tractor + trailer	TYRES2	-	-	-8,50	350,00	-	-	-8,50	420,00
Tyre pressure monitoring system (TPMS) on truck	TYRES3	-1,20	140,00	-1,90	350,00	-1,40	210,00	-2,00	420,00
Tyre pressure monitoring system (TPMS) on truck and trailer	TYRES4	-	-	-2,00	350,00	-	-	-2,10	420,00
Automated tyre inflation system (ATIS) on truck	TYRES5	-1,20	1.080,00	-1,90	1.080,00	-1,40	1.080,00	-2,00	1.080,00
Automated tyre inflation system (ATIS) on truck and trailer	TYRES6	-	-	-2,00	1.350,00	-	-	-2,10	1.350,00
Wide base single tyres	TYRES7	-1,20	-35,00	-1,9	-70,00	-1,40	-35,00	-2,00	-70,00

Table 11 Efficient vehicle solutions

CO2 reducing technologies	TNO-2018-R10214	Vehicle group 4		Vehicle group 5		Vehicle group 9		Vehicle group 10	
	TNO code	%	€	%	€	%	€	%	€
<u>Aerodynamics</u>									
Roof spoiler plus side flaps	AERO1	0,00	2.000,00	-2,20	2.000,00	0,00	2.000,00	-2,10	2.000,00
Side and underbody panel at truck chassis	AERO2	-1,40	750,00	-1,50	750,00	-1,10	750,00	-1,50	750,00
Aerodynamic mud flaps	AERO3	-3,00	1.000,00	-3,20	1.000,00	-2,40	1.000,00	-3,20	1.000,00
Rear/side view cameras instead of mirrors	AERO4	-0,80	3.078,00	-0,90	1.539,00	-0,70	3.078,00	-0,90	1.539,00
Redesign, longer and rounded vehicle front	AERO5	-0,80	40,00	-0,90	100,00	-0,70	60,00	-0,90	120,00
Side and underbody panels at trailer chassis	AERO6	-	-	-1,10	200,00	-	-	-1,10	200,00
Boat tail short, additional Aerodynamics	AERO7	-	-	-1,30	3.000,00	-	-	-1,30	3.000,00
<u>Mass</u>									
5% Mass reduction (truck/tractor)	MASS1	-2,20	794,00	-3,20	1.416,00	-2,90	1.402,00	-3,30	1.416,00
10% Mass reduction (truck/tractor)	MASS2	-3,30	1.588,00	-4,70	2.831,00	-4,50	2.805,00	-4,80	2.831,00
<u>Transmission</u>									
Reduced losses (lubricants, design)	TRANS1	-2,00	250,00	-2,60	250,00	-2,20	250,00	-2,80	250,00
Transition from manual to AMT	TRANS2	-2,90	2.661,00	-3,50	3.288,00	-3,10	2.661,00	-3,60	3.288,00
<u>Engine</u>									
Improved turbocharging and EGR	ENG1	-4,80	1.050,00	-4,80	1.050,00	-4,80	1.050,00	-4,80	1.050,00
Friction reduction + improved water and oil pumps	ENG2	-2,40	309,00	-2,40	309,00	-2,40	309,00	-2,40	309,00
Improved lubricants	ENG3	-1,20	23,00	-1,20	23,00	-1,20	23,00	-1,20	23,00
Waste heat recovery	ENG4	-2,40	5.000,00	-2,40	5.000,00	-2,40	5.000,00	-2,40	5.000,00
Downspeeding (combined with DCT optimization)	ENG5	-0,20	1.250,00	-0,20	1.250,00	-0,20	1.250,00	-0,20	1.250,00
10% Engine downsizing	ENG6	-1,00	-400,00	-1,20	-640,00	-1,10	-560,00	-1,30	-700,00
<u>Hybridisation</u>									
48V system with starter/generator	HYBRID1	-1,70	4.184,00	-2,60	6.694,00	-2,00	5.857,00	-2,80	7.321,00
Full electric hybrid	HYBRID2	-2,50	8.367,00	-3,70	13.387,00	-3,00	11.714,00	-4,00	14.642,00