Reducing the Carbon Footprint of Logistics Service Providers

A Case Study at DHL Parcel Benelux

D. van Hemert
Reducing the Carbon Footprint of Logistics Service Providers
A Case Study at DHL Parcel Benelux

by

Dick van Hemert

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Thesis committee: Dr. ir. D. Schot, TU Delft committee Chair, Faculty
                Dr. B. Atasoy, TU Delft committee member, Faculty
                E. Dijkstra, Company Supervisor, DHL Parcel
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Preface

Before you lays my masters thesis on the Greenhouse gas emissions reduction at Logistics Service Providers. I believe that the future shows an interesting time with respect to global warming. I really pleased that instead of talking for ever with policy makers on how to tackle the problem by the end of the year DHL Parcel gave me the opportunity to actually "take my hands out of my pockets" and tackle a part of the problem first hand.

This project would not have been possible with the help of multiple people. I would like to thank Erik for his supervision during the project, from a business pragmatic perspective, and Bilge for the support on how to translate it into a scientific research, as well as what steps to take next.

Hopefully you will enjoy reading my thesis and afterwards be convinced of the advantages of the use of vehicle to route allocation optimizations.

Dick van Hemert
Delft, January 2020
Parcel deliveries have seen a massive growth over the past several years, mainly in the B2C sector due to the rise of online shopping. Due to this growing market, more transport movements in the last mile are required. These extra driven kilometers add up to an increase in Greenhouse Gas (GHG) emissions. In a world where the ask for more sustainable operations is on the rise, this can be seen as a problem.

Logistics Service Providers (LSPs) are trying to come with solutions to tackle this problem, where most of them are of strategic kind, pushing the outcome to future instead of achieving results in the present. One of the solutions to realize emission reduction is the use of zero-emissions vehicles in the last mile delivery phase. However, current operations of these zero-emissions vehicles are not optimal. For that reason, a model is designed to optimize vehicle allocation to predetermined routes in order to keep the GHG emissions to a minimum.

This optimization model requires a method on how to determine the GHG emissions values per driven kilometer and energy source used by the vehicle. People tend to think solely about CO$_2$ when talking about environmental harming gases. However, the largest human influence of global warming is not caused by CO$_2$ alone, but through a combination of gases, summarized under the term greenhouse gases. The sum of emissions caused by these gases is standardized with the help of a Global Warming Potential (GWP), and is presented as CO$_2$ equivalents. Calculating and reporting on these GHG emissions can be done according to a variety of methodologies and standards. In order to achieve sector wide comparable results, the EN 16258 standard, issued by the European Committee for Standardization, is used as a guideline to specify emission values.

The optimization model is setup to cope with a heterogeneous vehicle fleet. A heterogeneous vehicle fleet is considered a fleet where multiple vehicle types exist with individual characteristics in terms of range and parcel capacity. It also considers the possibility that a vehicle is able to drive multiple routes on a single given day, taking a decreasing range in to account.

The effect of the optimization model is determined with the help of adequate Key Performance Indicators (KPIs). These KPIs are total GHG emissions, total energy consumption, capacity utilization, electric vehicle utilization ratio, fuel costs and network performance. The network performance calculates the emitted grams of GHG emissions per parcel. In order to create a more insightful result the result of the KPI is rearranged to represent the number of parcels delivered per kg emitted GHG emissions.

The impact of the optimization model on these KPIs was simulated and compared in a LSP’s last mile delivery network. Results from the case study showed that allocating vehicles to routes on a day to day basis, instead of a fixed schedule, improves the environmental impact as the total GHG emissions decreased and the network performance improved. Depots with higher average route distance had a negative impact when accounting for a decrease in battery capacity of electric vehicles, concluding that the model should account for cold winter days. By allowing vehicles to charge between routes during a single given day, depending on the charging power and time only showed a positive effect at depots with these longer average route distances. Finally, as the total fuel costs also decreased, it was concluded that no argument can be given that the model might impose extra costs, and thus a reason for not implementing it.

Although the case study showed promising results for the scenario where vehicles are to roam freely between depots of a LSP at the end of each day, emissions caused by the relocation of these vehicles cancels out the achieved savings. For future research it is therefore recommended to add these relocation emissions so that a truly dynamic vehicle fleet for depots in vicinity of each other can be established.
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Glossary

**Acronyms**

**B2B**  Business to Business

**B2C**  Business to Consumer

**BREEAM**  Building Research Establishment Environmental Assessment Method

**CEN**  European Committee for Standardisation

**EV**  Electric vehicle

**FTL**  Full Truckload

**GHG**  Greenhouse Gas

**GWP**  Global Warming Potential

**HDV**  Heavy Duty Vehicle

**ISO**  International Standardisation Organisation

**KPI**  Key Performance Indicator

**kW**  Kilowatt

**kWh**  Kilowatt hour

**LSP**  Logistics Service Provider

**LTL**  Less than Truckload

**NEDC**  New European Driving Cycle

**RDW**  Rijksdienst voor Wegverkeer

**TLN**  Transport en Logistiek Nederland

**TTW**  Tank-to-Wheels

**UN**  United Nations

**VOS**  Vehicle Operating System

**VRP**  Vehicle Routing Problem

**WBCSD**  World Business Council for Sustainable Development

**WLTP**  Worldwide Harmonised Light Vehicles Test Procedure

**WRI**  World Resources Institute

**WTT**  Well-to-Tank

**WTW**  Well-to-Wheels
**Nomenclature**

CH₄  Methane
CO₂ₑ  Carbon Dioxide equivalent
CO₂  Carbon Dioxide
HFC  Hydrofluorocarbon
N₂O  Nitrous Oxide
PFC  Perfluorocarbon
SF₆  Sulphur Hexafluoride
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Introduction

Sustainability issues have gained in popularity and interest over the past few years. Not only do ratifications made by policy makers, such as the Paris Agreement, require companies to drive their businesses to a more sustainable operation, but expectations and demands from the general public concerning their carbon footprint is also gaining attention rapidly (Oberhofer and Dieplinger, 2014). Companies, who will always try and strive towards a competitive advantage use these demands as one of the factors to steer their businesses towards a more sustainable operation. Due to this competition, companies typically make decisions mostly based on economic factors, including decisions concerning sustainability. Where the road freight transport sector, and in more detail the last mile delivery sector, are highly competitive markets (Joerss et al., 2016).

Within the European Union, the road transport sector still is a growing market, with an increase of 4.5% between 2016 and 2017 (Eurostat, 2019), accounting up to 24% of Greenhouse Gas (GHG) emissions within the European Union, and when looking at the global picture, around 20% of world wide CO$_2$ emissions is emitted due to road transportation (Ritchie and Roser, 2019). More locally, the market for parcel deliveries in the Netherlands is still growing rapidly, postal & parcel delivery companies showed a revenue growth of 9% in 2017, in a market where ordinary letterbox post is still declining by 6% (Autoriteit Consument & Markt, 2018). Which indicates a growing market with respect to parcel delivery services. Due to this market potential, proper measurements focused on performance is required to improve the overall service level (Choy et al., 2013). Where companies within the transport sector tend to improve on measuring and reporting their carbon footprint, prior research show over 140 developed calculation tools, including data bases, calculation methods, software tools and standards for the calculation of GHG emissions (Ehler et al., 2016). Commercially available tools might give inconsistencies in output values while input values are similar, which may be due to different calculations methodologies or conversion factors (Padgett et al., 2008). These inconsistencies in results make it difficult to compare results between companies, as they might be using completely different methods to calculate GHG emissions.

Countries ratifying the Paris Agreement agreed on keeping increase of the average global temperature below two degrees centigrade compared to pre-industrial levels, and to limit the maximum increase to 1.5°C (United Nations, 2015). To achieve this goal, the GHG emissions from the European Union should be reduced by 95% or more by 2050 compared to 1990. Instead of waiting for policy makers to set limits to companies concerning GHG emissions, several companies have implemented own goals to reduce their carbon footprint. Such as Mission 2050 by DHL, which sets the target to reduce all logistics related emissions to zero by 2050 (DHL, 2017). While mainly focusing on strategic decisions, literature research has shown that the impact of green actions on operational performance is still neglected (Evangelista et al., 2018). Without measuring the impact on operational performance it is difficult to see if the applied decisions improve on a day to day basis with respect to sustainability.

1.1. Research Objective

Policy makers and industries are still discussing how to offset emitted GHG emissions, where the main focus really should be in how to eliminate these emissions all together. Of course it is not a realistic assumption
that all environmentally pollution industries and services are a thing of the past in the coming years, as people tend to believe actions in order to reduce GHG emissions will hurt the economy (Nederlands Dagblad, 2011). It is however a good starting point to try and reduce the carbon footprint of companies by reducing emissions without making decisions which might alter the performance, and thus results of a company.

The objective of this research is therefore, the reduction of GHG emissions which focuses on the contributing factors with respect to GHG emissions within the network of an LSP, in correct chosen quantitative values while maintaining the same operational performance. With the goal to achieve these GHG emission savings with an immediate effect, thus focusing on day to day operational decisions.

1.2. Research Question

With the objective of this research in mind the following research question has been formulated:

*How can the Greenhouse gas emissions of an LSP be reduced and thus improving the environmental performance, without giving in on operational network performance?*

To give a proper answer to this research question six sub questions have been formulated:

1. What is the layout of an LSP, and which aspects are to be taken into account when calculating GHG emissions?
2. What are GHG emissions, and what are current methodologies used determining these emissions?
3. How to determine the GHG emissions specifically for an LSP?
4. How can the network performance of an LSP including GHG emissions be measured?
5. What decisions can be made with respect to the last mile delivery operation to reduce GHG emissions?
6. How will the environmental performance be impacted by applying these decisions?

1.3. Research Scope

As the research objective is set to achieve immediate savings, by only concentrating on operational decisions the scope of this research is set to boundaries. In order to achieve the highest possible savings in terms of GHG emissions the research solely focuses on the last mile part of transportation. The decision to do so is explained in more detail in chapter 2. Possible decisions to improve the carbon footprint of companies can be achieved in several ways according to Smokers et al., 2019. These include the following:

- ✔ Reduction of number of vehicle kilometers by improving logistics operations
- ✔ Development of value adding logistic solutions
- ✔ Efficient use of vehicles
- ✗ The use of more sustainable transport modes
- ✗ Change in spatial organization of production and product sourcing
- ✗ Adjustments in supply chain design and organization

Where is becomes clear only three of the improvements mentioned by Smokers et al., 2019 can be directly be applied to a last-mile delivery operation, without the help of other parties influencing the complete supply chain. These improvements are the reduction of vehicle kilometers by improving logistics operations, the development of value adding logistic solutions and the efficient use of vehicle.

**Reduction of number of vehicle kilometers by improving logistics operations**

The reduction of vehicle kilometers is mainly affected by routing algorithms used by the LSP, and how accurate the driver sticks to the planned route.
1.3. Research Scope

Development of value adding logistic solutions
Essentially the only value added for last mile deliveries is getting the shipment from A to B. For the development of new solutions it can be assumed that this is a process that would take up a longer period of time, with the ever so changing field of technology. Which means it is safe to say the development of value adding logistics solutions is a long term solution.

Efficient use of vehicles
The first step in increasing the efficiency of vehicles, is making sure where possible the full load capacity of the vehicle in question is used. A next step in achieving a higher efficiency is allocating vehicles to routes while looking at the load factor. For example, if a vehicle on a route is not using its full capacity and where on a other route two smaller vehicles are used due to higher capacity it might be useful to swap out these vehicles with each other.

The use of more sustainable transport modes
One viable option might be to shift parts of transportation to more sustainable transport modes, such as by rail or sea. However, shifting the last mile logistics to one of these transport modes is an unrealistic idea. One could say to shift more towards bicycles, as last-mile parcel deliveries by cargo bicycles have gained the interest of the logistics sector over the last years. However, delivering parcels with cargo bicycles do have limitations. Research has shown that the use of cargo bikes are only more cost effective than delivery trucks for deliveries in close proximity to the distribution centre. Thus, only effective for routes under 10 kilometers and with a demand lower than 40 parcels (Sheth et al., 2019). Concluded was that cargo bikes are best suited for time sensitive express deliveries.

Change in spatial organization of production and product sourcing
As an LSP has no influence where products are produced and to where these products need to be shipped, it can been seen as infeasible option for this particular research.

Adjustments in supply chain design and organization
Again, last-mile logistics operators have little to none influence in the total supply chain design and if so decisions made would be more strategic and thus long term, meaning it lays outside of the scope of this research.

1.3.1. Demand Growth
Parcel deliveries in the Netherlands is still a growing market, as can be seen in Table 1.1. For the last two year the market grew a 19% increase. It would be unrealistic to say that the market will keep on growing with 19% for the coming years, which would mean nearing one billion parcel deliveries in the next five years, it is safe to say the growth will continue. Post NL, the biggest player within the dutch parcel delivery market expects a slightly lower growth in volume of 14% (NRC, 2019). With these growth numbers and including the

<table>
<thead>
<tr>
<th>Year</th>
<th>Volume in millions</th>
<th>Growth</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>208</td>
<td>11%</td>
<td>(Autoriteit Consument &amp; Markt, 2016)</td>
</tr>
<tr>
<td>2016</td>
<td>234</td>
<td>12%</td>
<td>(Autoriteit Consument &amp; Markt, 2017a)</td>
</tr>
<tr>
<td>2017</td>
<td>295</td>
<td>19%</td>
<td>(Autoriteit Consument &amp; Markt, 2017b)</td>
</tr>
<tr>
<td>2018</td>
<td>351</td>
<td>19%</td>
<td>(Autoriteit Consument &amp; Markt, 2019)</td>
</tr>
</tbody>
</table>

expected the growth in online shopping of groceries would show an increase from 12 vans up to 60 vans per day moving through a street (Logistiek.nl, 2018b). This of course is an unpleasant perspective. Thus, parcel delivers, together with other stakeholders are required to innovate the last-mile delivery process in order to keep cities livable (Logistiek.nl, 2015).

With in mind that long term strategic decisions are required to cope with the ever growing demand of last-mile deliveries together with the fact that Transport en Logistiek Nederland (TLN) tries to realise zero-emission city distribution by 2025 (TLN, 2018; Logistiek.nl, 2017), and that the aim of this research model is improve the
performance concerning GHG emissions on an operational level day to day basis, in the present, the growth in demand over the coming years in not specifically included in the researched scenarios.

Summarizing all of the above viable options, the scope of this research is set to focus on the efficient use of vehicles in order to reduce GHG emissions of logistics service providers.

1.4. Report Structure
The structure of the research is graphically illustrated in Figure 1.1. The research starts of with an analysis of the network layout of an LSP in chapter 2, answering the first sub research question, in order to make substantiated decisions which aspects should be taken into account when trying to reduce GHG emissions without affecting the operational performance of an LSP.

The next step is to conduct a literature research what GHG emissions actually are, which gasses should be included when talking about these emissions and what is their contributing factor in global warming, answering the second sub-research question. The next step is to find out what kind of methodologies are currently used to account for these emissions and what their respective strengths and flaws are, in order to make decisions what kind of methodology should be used. This is all discussed in chapter 3. The chosen methodology is further addressed how it should be used in the case of an LSP in chapter 4.

Chapter 5 discusses the ways possible how to measure the network performance with respect to emitted GHG emissions. KPIs are introduced as green performance indicators, concluding to how LSPs should keep track of their carbon footprint, answering the fourth sub-research question. Continuing towards chapter 6, to answer the fifth research question, where possibilities are discussed how to emission reduction might be possible, and a model will be designed and described how to achieve these possible emissions savings.

The just described model will be put to test at a case study at DHL Parcel in chapter 7. Multiple scenarios will be analysed to which conclusions will be drawn up on what impact the model could achieve by integrating it in the network of an LSP.

Finally the conclusions from each sub-research question will be discussed in a successive way in order to answer the main research question in chapter 8 together with further research recommendations and recommendations towards DHL will be made.
• Chapter Two: The Layout of an LSP network

• Chapter Three: Green House Gas Emissions
• Chapter Four: Calculating Green House Gas emissions

• Chapter Five: Network Performance with respect to emissions
• Chapter Six: Reducing emissions while staying effective

• Chapter Seven: Case Study at DHL Parcel

• Chapter Eight: Conclusions & Recommendations

Figure 1.1: Report Structure
The Network Layout of an Logistics Service Provider

Delivering goods from A to B requires a more complex network than one might think. It requires a bit more than just being picked up and delivered straight away. In order to properly understand the layout of a logistics service providers network required, this chapter focuses on answering the first sub-question:

*What is the layout of an LSP, and which aspects are to be taken into account when calculating GHG emissions?*

To better understand the network layout of a LSP, it will be explained in more detail in accordance to the current layout of DHL Parcel. The layout consists of two separate networks, one network for Business to Business (B2B) shipments and another for e-commerce deliveries.

### 2.1. Business to Business Network

The B2B network focuses on larger shipments sizes and volumes to single receiving addresses. In essence, the B2B network contains a pick-up part, as a parcel with smaller vans or larger items with trucks. The next step in the process is outbound transshipment sorting in a distribution centre. Afterwards depending of the final destination of the goods, a line haul part fulfilled by trailer/truck combinations is required to ship the goods to a different distribution centre. When the goods are arrived at the new terminal, an inbound sort is conducted. From which goods are sorted to their specific route area within the distribution centre. The last part again is operated in the same way as the pick-up part but now for delivery, depending on the size and weight of the goods, transported by a van or a truck. However this is not always the case. Many different options are available for the complete network completion for a specific shipment. Just as Figure 2.1 points out, it is not always necessary for a line haul part. This would occur when a shipper and its customer are located within the same service area of the outbound distribution centre. It is also possible that a shipment is picked up by a truck and delivery the next day is done by a van or other type of vehicle. All this taken together creates a complex network with many parameters which might influence the carbon footprint of a shipment. As can be seen in Figure 2.1, the pick-up and delivery part are a mirrored process. One can say that picking up goods is the exact same process as delivering goods, as well as the outbound and inbound sort. Line haul transportation can also be seen as a fixed distance route with full truckload shipping.
2.2. E-commerce Network layout

E-commerce shipments are Business to Consumer (B2C) shipments, where businesses send shipments directly to consumers homes. These deliveries require a different approach as shippers send many shipment to many different receivers, as well as that receivers tend to receive less shipments a time compared to businesses. Shipments are delivered to a E-commerce distribution centre, either by a third party appointed by the shipper or via trucks from DHL itself. At the distribution centre all shipments are sorted to one of 137 depots in the Netherlands, based on their final delivery address, and placed into dedicated roll containers. To keep truck movements to a minimum, roll containers for depots in the vicinity of each other are bundled and brought to a transloading centre (OVC) where the roll containers are sorted to a depot level. When finally they are brought to their corresponding depot. Arrived at the depot, shipments are sorted on route level and loaded in to the vehicle operating said route. Where multiple types of vehicles, in terms of range and capacity may be available. A simplified graphic of this process is shown in Figure 2.2.
2.3. Types of Transportation options

Multiple options of transportation within the network of a LSP. The three most common types of transport, in terms of vehicle usage will be discussed, with each of these individual vehicles having their own specifications.

Vans
Within the specific case of the B2B network of DHL Parcel vans are used to ship packages which are still able to be handled by hand by one person, mainly constrained by weight and size. Mostly referred to as package or parcel delivery. These type of parcel deliveries are characterized by their high amount of stops per trip by aggregating parcels into larger units to keep costs to a minimum. More than one hundred stops are no exception for a regular delivery trip (Dennis, 2011). Where all vans at B2B distribution centre are of the same type and size.

In the case of E-commerce deliveries, all shipments are delivered by a van as most parcels tend to be of a handleable size for a single person. The difference compared to the B2B network is that at a single depot, multiple types of vans in terms of size, range and emissions values are present.

Trucks
For shipment heavier than a certain weight, in case for DHL at 50 kilograms, due to labour rights, it is required to ship this on a pallet, as it than can be handled by a fork lift truck or a pallet jack. However not only shipments weighing more than 50 kilograms are shipped on these pallets. A shipper may just as well choose to ship multiple pieces stacked on a pallet without even weighing close to those 50 kilograms, but it would still take up a pallet size of floorplace in the truck, which could be referred to as Less than Truckload (LTL) transportation. LTL transportation consists of the pick-up, consolidation, line haul and delivery of goods that will not fill up a complete truckload and weighing between 50 and 5000 kilograms (Veloso De Aguiar and Woolard, 2014).

Line Haul
Line haul transportation takes place mostly during the night to transport the shipped goods from a distribution centre near to the pick-up location toward a distribution centre in the region of its delivery address in the case of B2B shipments and to a transloading centre or depot when looking at E-commerce deliveries.
One might assume that the line haul part of the transport journey can be seen as Full Truckload (FTL) transportation. This may sometimes be the case for when a truck drives fully loaded from one distribution centre to another with only goods for this particular centre. However, it may occur that a truck carries a load for multiple distribution centres, where it may be offloaded at one of these centres where the goods not destined for this location are consolidated with another truck. It may also be possible that the truck goes onward after unloading only the goods destined for a particular distribution centre. Here the next complexity immediately arises. By consolidating the to be transported goods it is difficult to determine what effect each shipment has on the truck by means of volume and/or weight.

2.4. Types of to handle goods

From the different type of vehicles used in the process of transporting goods it became clear that multiple type of goods are being shipped. All these different types of goods require their own way of handling, specifically within the distribution centres during the transshipment process. The most obvious type is a parcel which is of a conveyable type. This type has a maximum weight and dimensions which makes it able to be transported and sorted by a conveyor sorting machine within the facility. It is possible that a parcel is not restricted by its weight but only by its dimensions to be transported over a conveyor belt system. This would mean an employee of the distribution centre is required to move this parcel by hand to the correct destination within the facility. This type of good is referred to as non-conveyable. The other already discussed type of good is the pallet. Goods transported on a pallet can be moved within the distribution centres facility by using a machine powered forklift truck or manual pallet jacks are used. At B2B distribution centres loose parcels may placed in open top cages to facilitate combined loads of loose parcels and pallets during the Line haul transportation, in order to speed up the loading and unloading process of the trailers. These cages themselves are moved, within the facility, from one location to another in the same way as pallets. The parcels placed in the cages are transported over the conveyor sorting system. E-commerce parcels are placed in roll containers similar to the ones used in supermarkets, with wheels underneath the containers which allows them to be moved by hand without the use of extra equipment. To summarize the types of goods transported can be split into following:

- Conveyable goods
- Non-conveyable goods
- Pallets
- Mixed type of Conveyable and pallet use

Each individual shipment might require different means of transport and handling which all have their own carbon footprint. An ideal situation would be to calculate the emissions of each shipments/piece in detail, but one should keep in mind not to create a too complex model to keep it feasible. Not forgetting that the facility itself where the sorting process is conducted creates emissions due to heating, lighting etc.

2.5. Transshipment

Not only the transportation of goods by vehicles require an amount of energy consumption within the logistics sector. Warehousing and the handling of goods also contribute to these emissions. According to Schmied et al., 2012, it is most often a result of the following aspects:

- Thermal energy consumption by the and buildings
- Power consumption by the handling equipment, and buildings
- Consumption of diesel, liquefied petroleum gas or electricity for additional equipment such as swap body vehicles or forklift trucks
- Refrigerant losses from freezers and cold storage

A more in depth review is conducted into what aspects play a role in energy consumption of distribution centres. Noting that an increasing request for more sustainable solutions of logistic issues able to minimize the external costs due to both inbound and outbound logistics has been observed (Boenzi et al., 2016), and that new buildings are designed with a carbon footprint which is as low as possible.
2.5.1. Buildings
Distribution centres may differ in building type and the range of use and operating conditions vary. This together with the inconsistency in building energy models makes it challenging to create a standardized carbon footprint calculation (Rüdiger et al., 2016). According to Marchant, 2010 there are multiple contributors to the carbon footprint of warehouses and distribution centres.

- Warehouse Heating
- Warehouse Lighting

These are direct energy consumption of the building alone. There are other factors that also influence the energy consumption. Gas is the primary source of energy for heating and electricity for cooling, and the amount of energy consumed for temperature control is mainly determined by the temperature required to maintain the quality of the to handle goods in a satisfactory condition, and the background temperature of the internal space required for employees to do their work in comfort (McKinnon et al., 2010). This research assumes that LSPs only transport goods at ambient temperature, so no goods which require any sort of temperature control, only the background temperature of the facility to maintain comfortable working conditions is influencing the energy consumption with respect to warehouse heating. The energy consumption for lighting is dependent on the type of lamp type in terms of Watts per m². Depending on the lamp type an amount of energy is required. By taking proper decisions and keeping up with maintenance energy savings up to 20% can be created (Marchant, 2010), thus energy consumption values may vary largely based on maintenance upkeep and chosen type of lighting.

During the design phase of building distribution centres designers focus more and more on building these centres independent of gas (Transport & Logistiek, 2018; DuurzaamGebouwd.nl, 2019; Logistiek.nl, 2018a). The focus is not only on being less independent on gas as a energy source, but building the distribution centers extremely sustainable (Logistiek.nl, 2019), thinking about placing solar panels on the immensely large rooftops (Logistiek.nl, 2018c), building according the Building Research Establishment Environmental Assessment Method (BREEAM) certified standard and the ability to automate the processes within the centers even further. With these aspects in mind one can assume that the source of the electricity is green as well.

2.5.2. Equipment
At a typical distribution centre of a LSP goods can be moved through the facility over a conveyor sorting system, by the use of a forklift or by hand. Direct contributions towards the carbon footprint of the facility are created when a forklift or conveyor belt is used. The carbon footprint of goods sorted by hand can be neglected. Conveyor belt systems most likely run on electricity where forklifts have different type engines, LPG, diesel or electric. Where diesel and LPG powered forklifts remain the most popular, however in Europe battery powered forklifts are predominant (Boenzi et al., 2016). Knowing that diesel powered forklifts tend not to be used indoors (Johnson, 2008), the assumption is made that all forklifts used for the transshipment of goods within a distribution centre of a LSP are battery powered.

2.6. Comparing Impact
To emphasize the impact of transshipment compared to transportation of goods, a simple calculation has been done into what the CO₂ emissions are one average for one pallet. A calculation has been done for multiple areas in the Netherlands, as in less urbanized areas the average driven kilometers might be higher due to longer distances between stops. For this calculation the assumption is made that the distribution centre uses BT levio s pallet trucks (Toyota, 2019), with a battery capacity of 625 Ah at 24 Volts, which result in 15 kW.h. Another assumptions is made that the trucks are charged every day and use 80% of their battery capacity. For the transportation of the pallets another set of assumptions is made. The trucks used for delivery are medium sized trucks and the driven kilometers and delivered pallets are evenly distributed. Four extra parameters for the calculation are needed:

- Medium sized truck emission: 0.758 kg CO₂/km (Milieubarometer.nl, 2019)
- Emission for electricity: 0.649 kg CO₂/kWh (Milieubarometer.nl, 2019)
- Handled pallets per forklift per working day: 240
2. The Network Layout of an Logistics Service Provider

- Daily energy consumption per forklift: 12 kWh

With data from DHL Parcel, presented in Table 2.1 the calculation is done. It turns out that for the region Amsterdam the CO₂ emissions created by the transport are 121 times as high as the forklifts, and in the region Hengelo the emissions created due to transport are 285 times as high. Which means for the Amsterdam area forklift trucks account for 0,82% the CO₂ emissions and for the Hengelo area this is only 0,32%. Due to the much higher impact on emissions caused by transportation another reason is to leave the transshipment of goods out of the scope of this research.

Table 2.1: The difference of CO₂ emissions between transport and transshipment

2.7. Conclusions

The goal of this chapter was to answering the following sub-research question: What is the layout of a LSP, and which values are to be taken into account when calculating GHG emissions? Which actually consists of two questions itself.

2.7.1. Network Layout

As stated at the beginning of the chapter, it is now clear that transporting goods from A to B can be rather complex for a LSP. Many factors play a role in how a shipment ends up at its final destination. There is no one fixed solution for transporting shipments through the network of a LSP. In the case of DHL Parcel the two main differences are between B2B and B2C shipments, as both are handled by two separate networks. Where the B2B network mainly focuses on larger shipments and higher volumes to single receivers. Whereas the B2C network is designed to transport large amount of shipments from relatively little shippers to many different consumers spread across the Netherlands. Transport is done by different type of vehicles, ranging from trailer/truck combinations to small vans.

In order to deliver shipments to the correct destination, distribution centres are required to sort these shipments accordingly. The way shipments are handled at these distribution centres depends of the size and weight of each shipment. Parcels are mainly sorted by a sorting machine, whereas odd sized shipments and pallet shipment need to be sorted by hand or with the help of forklift trucks.

2.7.2. GHG emissions within the network

The most obvious part of GHG emissions is produced through transportation by the different type of vehicles. However, transshipment of goods may also contribute to the total amount of emitted emissions. Heating and lighting are the main contributors of the energy consumption for the buildings itself. The other contribution comes from equipment used within the distribution centres. Depending on the energy source and power requirements the total energy consumption can be determined.

2.7.3. Final Words

Energy is consumed over the whole network of a LSP, and thus GHG emissions are emitted. During the transport phase these are created by the vans and trucks, and during transshipment energy consumption of buildings and used equipment results in GHG emissions. However, now knowing that new distribution centres are designed in accordance with the BREEAM standard, it can be assumed that the energy consumption
within distribution centres come from renewable sources. A simple calculation also showed that the impact in terms of energy consumption, of a forklift truck is negligible compared to actual transport.

Assumed that the first mile has the same layout of the last mile, it is chosen not to focus on the first mile. As stated line-haul transportation can be considered as Full truck-load transport driving fixed kilometers, together with the fact that in order to keep network performance the way it is, linehaul routes are driven no matter what. Therefore, linehaul driven kilometers are also placed out of the scope of this research. Lastly, looking at the transshipment phase, the energy consumption to take into consideration is created by the buildings itself and the used equipment at the facility. Analyzing current trends in the development of new distribution centres, and the assumption that all equipment within a distribution centre of a LSP is run on electricity instead of fossil fuel, and that this electricity is produced through a renewable energy source. Therefore the scope of this research will focus on the last-mile delivery.
Greenhouse Gas Emissions in the Logistics Service Providers Industry

To fully understand the impact of GHG emissions is is necessary to describe what is meant with the term greenhouse gas, where they consist of and how these emissions are to be determined. After this a literature review is conducted into the different methodologies focusing on GHG emissions in order to answer the following sub-research question:

*What are GHG emissions, and what are current methodologies used determining these emissions?*

### 3.1. Greenhouse Gas Emissions

Where most people talk about CO$_2$ when referring to emissions harming the environment, GHG emissions exist of multiple gasses and not solely CO$_2$ gasses. Though, CO$_2$ emissions have the largest contribution, CO$_2$ and green house gasses are therefore used synonymously to each other. Next to CO$_2$, there are five additional green house gasses contributing to global warming according to the Kyoto Protocol Annex A (United Nations, 1997). The six gasses are the following:

- Carbon Dioxide (CO$_2$)
- Methane (CH$_4$)
- Nitrous Oxide (N$_2$O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbon (PFCs)
- Sulphur Hexafluoride (SF$_6$)

In the past companies have only been calculating CO$_2$ emissions. However current standards demand the calculation of the other gasses as well. To avoid a overly complex calculation it is advised to calculate the total emissions in terms of CO$_2$ equivalents, CO$_2$e. This is done using a GWP. The greater this GWP the more the gas contributes to global warming. It is a relative term, which indicates the amount of heat trapped by a certain gas in comparison to the amount of heat trapped by CO$_2$. In other words, expressing the global warming potential of 1 kilogram of gas over 100 years as a factor of 1 kilogram of CO$_2$. Where the GWP of 1 kilogram of CO$_2$ is standardized to 1. The values of Carbon dioxide, Methane and Nitrous oxide are shown in Table 3.1. The other three gasses are not included as these gases are not the product of the combustion of oil, gas or fuels but results from industrial processes (Schmied et al., 2012).

From now when mentioning GHG emissions, it refers to the combination of the above mentioned gasses.
Table 3.1: GWP for certain greenhouse gases (IPCC, 2014)

<table>
<thead>
<tr>
<th>Green House Gas</th>
<th>Chemical Formula</th>
<th>GWP factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide</td>
<td>CO₂</td>
<td>1</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>28</td>
</tr>
<tr>
<td>Nitrous Oxide</td>
<td>N₂O</td>
<td>265</td>
</tr>
</tbody>
</table>

3.1.1. **Direct and Indirect Emissions**

To properly account for the source of the emissions, GHG emissions can be split into two types of emissions, direct emissions and indirect emissions. The direct emissions are the most obvious emissions. These are emissions from sources owned or controlled by the reporting entity. For the road transportation logistics sector these are dependent on the type of vehicle, the load, the traveled distance and the amount and type of fuel used (Schmied et al., 2012).

Indirect emissions are emissions that are a consequence of the activities of the reporting entity, but occur at sources owned or controlled by another entity. Such as the production of power and fuels, the manufacture of vehicles and the construction of streets and the maintenance of the transport network (Schmied et al., 2012).

Translating these two types of emissions to vehicle usage is done by the following definitions:

- **Well-to-Tank (WTT) emissions** (energy processes): WTT emissions are the recordings of energy consumption and all indirect emissions form fuel provision from the well to the vehicle tank. The energy consumption includes losses during the production of the energy sources.

- **TTW emissions** (vehicle processes): TTW emissions are the recordings of all direct emissions from the vehicle operation.

- **Well-to-Wheels (WTW) emissions** (vehicle and energy processes): WTW emissions are the sum of the WTT and TTW consumption.

3.1.2. **Methods and Approaches**

The energy consumption and created GHG emissions due to transport services can be determined in two different ways, the consumption-based method and the distance-based method.

- **Consumption based method**: GHG emissions are calculated using measured energy consumption and energy-specific emission factors. In the logistics transportation sector this method can also be referred to as the fuel based approach. In this particular case using fuel content and assumptions regarding its combustion to estimate emission values.

- **Distance based method**: GHG emissions are calculated with the help of traveled distance and emission or consumption factors per vehicle kilometer. This approach is less accurate but can be used when detailed consumption data is not available, such as when using subcontractors. This method can also be mentioned as the activity based approach. This can be used when direct fuel consumption data is not available, but a measure of activity is available, driven kilometers for vehicles, multiplied with an emission factor to estimate total emitted emissions.

The consumption based method is more accurate in calculating GHG emissions, and thus the favourable method to use in calculating emitted emissions. However, detailed data about fuel consumption in volume or weight is needed, which might be difficult to keep track of, or won’t be registered by companies. The distance based or activity based method is therefore preferred by shippers and LSPs, because actual fuel consumption does not need to be known but can be estimated by different type of parameters such as driven kilometers and average fuel consumption per vehicle type. Table 3.2 shows a detailed comparison between the Fuel-based method and the distance-based method.
### Table 3.2: Fuel-based vs. distance-based methods (Ubeda et al., 2011)

<table>
<thead>
<tr>
<th></th>
<th>Fuel-based method</th>
<th>Distance-based method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td>More reliable</td>
<td>Easy to obtain data</td>
</tr>
<tr>
<td><strong>Drawbacks</strong></td>
<td>Not easy to calculate if only data on fuel consumption are available</td>
<td>High levels of uncertainty</td>
</tr>
<tr>
<td><strong>Data by vehicle type</strong></td>
<td>- Distance travelled</td>
<td>- Distance Travelled</td>
</tr>
<tr>
<td></td>
<td>- Fuel consumption factor</td>
<td>- Fuel consumption</td>
</tr>
<tr>
<td></td>
<td>- Heating values</td>
<td></td>
</tr>
<tr>
<td><strong>Data collection Sources</strong></td>
<td>- Fuel receipts</td>
<td>- Odometer logs</td>
</tr>
<tr>
<td></td>
<td>- Fuel expenditure costs</td>
<td>- Company fleet records of fuel economy by vehicle type</td>
</tr>
<tr>
<td></td>
<td>- Direct measurement records</td>
<td>- Vehicle manufacturer documentation showing fuel economy by vehicle type</td>
</tr>
<tr>
<td><strong>Calculating emissions</strong></td>
<td>- Collect data on distance travelled by vehicle type and fuel type</td>
<td>- Collect data on distance travelled by vehicle type and fuel type</td>
</tr>
<tr>
<td></td>
<td>- Convert distance travelled data into fuel use values based on fuel economy factors</td>
<td>- Convert distance estimate to CO2 emissions by multiplying distance travelled by distance-based emission factor</td>
</tr>
<tr>
<td></td>
<td>- Convert fuel estimate to CO2 emissions by multiplying fuel use values by fuel-specific factors</td>
<td></td>
</tr>
</tbody>
</table>

### 3.2. Current Methodologies

It becomes of more and more importance to companies to comply to regulations concerning calculating and publishing carbon footprints of transport services. As many countries have their own regulations, there have been many initiatives to calculate GHG emissions within the logistics sector. However, the complete logistics sector contains many modes of transport with all different contributing aspects to their carbon footprint. Most of these methods have been developed on the basis on individual initiatives. With all of them having their own starting point, intentions and approaches, resulting in incomparable and incompatible methods and outcomes (Auvinen et al., 2014).

Initiatives have been taken on to address the arisen problems, like the ISO 14064 standard and the GHG Protocol by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). These two however do not focus on transport directly, but more towards corporate carbon footprinting. Another standard by the International Standardisation Organisation (ISO) is the ISO 14067, which focuses on the carbon footprint of products. Other tools such as the EcoTransIT, smart Way and Green Freight Europe, are specifically designed tools for transport, but are not issued by a norm giving organization (Ehrler et al., 2016). There is one standard issued by the European Committee for Standardisation (CEN), the EN 16258, which does solely focus on transport and logistics. Having multiple methodologies results in challenging conditions to calculate and compare emissions created due to transport accurately. Detailed differences of these methodologies are shown in Table 3.3.
### Table 3.3: Differences between the most known standards and norms (Schmied et al., 2012)

<table>
<thead>
<tr>
<th>Standards and Norms</th>
<th>Corporate Carbon Footprinting</th>
<th>Product Carbon Footprinting</th>
<th>Transport and services footprinting</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Boundaries</td>
<td>Activities by own company obligatory, inclusion of subcontractors optional</td>
<td>Total value-added chain, irrespective of whether own or third party processes</td>
<td>Total transport chain, irrespective of whether own vehicles or vehicles belonging to sub-contractors</td>
</tr>
<tr>
<td>Environmental Parameters</td>
<td>All greenhouse gases (as CO₂e)</td>
<td>All greenhouse gases (as CO₂e)</td>
<td>All greenhouse gases (as CO₂e) and Energy Consumption</td>
</tr>
<tr>
<td>Emissions from the manufacture of energy sources</td>
<td>Manufacture of electricity used by own company: yes Other energy sources: optional</td>
<td>must be included</td>
<td>must be included</td>
</tr>
<tr>
<td>Permitted methods for allocating emissions to individual consignments</td>
<td>no provisions</td>
<td>preferably physical variables (e.g., weight) but monetary values permitted</td>
<td>only physical variables (weight preferred, but also number of pallets, load metres, TEU etc.)</td>
</tr>
</tbody>
</table>

### 3.2.1. The Green House Gas Protocol

The GHG protocol, or the GHG Protocol Corporate Accounting and Reporting Standard in full, provides a step-by-step guide for companies how to quantify and report their GHG emissions. However, it does not focus on transport directly, but it is mentioned in the literature many times, and is focused on the corporate carbon footprint of a company. It is very similar to the ISO 14064-1. Where the ISO document is shorter and goes in to less detail, the GHG protocol is more descriptive, by giving motivational reasons for reporting. Therefore, only the GHG protocol will be elaborated briefly.

As the protocol is developed to calculate the total carbon footprint of a company, emissions from single transport services are not required to be known. The emissions can be calculated as a whole can be calculated not specifying in detail what part of transport contributed towards the emitted emissions. The standards require a clear definition of system boundaries, distinguished by direct emissions and indirect emissions. To help delineate these direct and indirect emission sources, to improve transparency and to provide utility for different types of organizations and climate policies and business goals, three scopes are defined by the GHG protocol for accounting and reporting purposes (WRI & WBCSD, 2013). The direct GHG emissions are defined under scope 1, where the indirect emissions fall under scope 2. Scope 3 reports a GHG emissions inventory that includes indirect emissions resulting from value chain activities. To ensure two or more companies will not account for emissions in the same scope, scope 1 and scope 2 are carefully defined in the standard. To which scope the emissions belong to are shown in Table 3.4. According to the Corporate Accounting and Reporting Standard of the GHG Protocol, scope 1 and scope 2 must always be calculated where as scope 3 is optional. Transport services carried out by subcontractors and not by the LSP itself fall under scope 3, which might be a significant part of operated transportation routes for many logistics companies.
Table 3.4: Allocation of individual areas of importance for the environment to Scope 1 to 3 of the GHG Protocol (Schmied et al., 2012)

<table>
<thead>
<tr>
<th>Area</th>
<th>Scope 1</th>
<th>Scope 2</th>
<th>Scope 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption from company’s own lorries, cars, locomotives, ships, aircraft</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Liquefied petroleum gas/ compressed natural gas and fuel oil consumption of company’s own offices/warehouses</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Refrigerant losses from company’s own offices, warehouses and lorries</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Power consumption by company’s own offices/warehouses/cargo handling equipment</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>District heating consumption of company’s own offices/warehouses</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Business trips, journeys to work by staff</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Transport services by sub-contractors (lorry, rail, ship, plane)</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Third party warehouses and cargo handling equipment</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Energy consumption and emissions for energy sources (e.g. diesel)</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Energy consumption and emissions for products (e.g. paper manufacture)</td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

**Corporate Carbon Footprints**

If GHG emissions are determined for the whole company as one absolute quantity this can be referred to as Corporate Carbon Footprinting. The complete carbon footprint of a logistics providing company is drawn up by the emissions from all transport services conducted. Thus, on a corporate level, it is not required to determine the emissions for each individual transport service. So if the total fuel consumption of the vehicle fleet is known, the total emissions of all transport services can be calculated directly. The distribution of the emissions from a vehicle to each individual shipment, is not necessary in for corporate carbon footprints in alignment with the GHG protocol.

![Figure 3.1: Corporate Carbon Footprints (WRI & WBCSD, 2013)](image)

**Product Carbon Footprints**

Product carbon footprints are a measure of GHG emissions related to specific products from the extraction of raw materials required, manufacturing through to distribution and use, and disposal or recycling along the life of said product. If two products or services are to be compared with one another, then it must be ensured that this is based on the same usage. Therefore, when comparing two different lamps, it is not the lights which are compared but the delivery of a specific light output over a specific time period. For this
reason the life-cycle of a product includes the total value added chain as shown in Figure 3.2 (Schmied et al., 2012). Emissions from transport are normally of lower importance in comparison to the total emissions.

![Product Carbon Footprints](Asia Carbon Footprint Network, 2014)

However, in contrast to corporate carbon footprints, the emissions produced during the transport phase must be calculated and allocated to individual consignments. The Product Life Cycle Accounting and Reporting Standard in the GHG protocol recommends physical units are used for allocation, but if such data is not available, allocation based on monetary values is possible. However, in the transport sector allocation using monetary values isn't usual (Schmied et al., 2012). Which is why the EN 16258 Standard would be a better methodology to use for determining GHG emissions within the transport sector.

### 3.2.2. The EN 16258 Standard

The EN 16258 standard is developed by the European Committee for Standardisation (CEN) which enables it to be used across the European Union. According to the CEN, the standard establishes a common methodology for calculation and declaration of energy consumption and GHG emissions related to any transport service, freight, passengers, or both. Definitions, system boundaries, calculation methods, data recommendations and allocation rules are all specified. In order to promote standardised standardised, accurate, credible and verifiable declarations, regarding energy consumption and GHG emissions concerning any transport service quantified.

The advantage is that the standard does focus on transport logistics, and is therefore a good starting point for calculating GHG emissions. However, literature does discuss gaps and ambiguities in the use of the standard (Auvinen et al., 2014; Davydenko et al., 2014; Ehrler et al., 2016).

Namely:

1. The choice of the Vehicle Operating System (VOS)
2. The lack of “fairness” in respect to emission allocation to individual cargo units
3. Lack of data accessibility and availability
4. Lack of the method to include emissions accountability within logistics nodes

**Ambiguity with respect to the VOS**

The ambiguity of the standard with respect to the VOS arises due to the fact that the standard leaves a large degree of freedom to define the boundaries of the VOS. The VOS is defined as a consistent set of vehicle operations relevant to the transport leg being calculated (Davydenko et al., 2014). It is up to the user of the standard to decide the factors which affect the scale and composition of the VOS. Examples given by
the standard are the number and type of vehicles to be used and the period of time of activity of the selected vehicles. It only states that for all cases the VOS shall include the empty trips into a VOS. This would result into different selected VOSs within a transport chain, which makes the calculation of consistent and comparable results between different LSPs almost impossible (Ehrler et al., 2016). To overcome this problem Davydenko et al., 2014 proposed three distinct levels of VOS definitions for future standardization efforts.

- **Micro level** - Limit the VOS to the level of vehicle trips.
  At this micro level, the most detailed and comparable emission computations are possible. It allows for accurate supply chain optimisation with respect to emissions and it would allow for ex-ante calculations of GHG emissions. With ex-ante in its most general form meaning before the event, thus in this case before trips are conducted. The disadvantage of this level of detail is that a lot of data is required, where this might not be available or not even being logged. It would also create a complex model which might result into different emission values for identical shipments transported on different days when looking at a shipment level.

- **Meso level** - Limit the VOS to all vehicle movements within a trade lane, a corridor or a network.
  The meso level would take specific trade lanes into account which allows for emission comparison mechanisms between multiple LSPs. It does offer flexibility in terms of the definition of units of comparison, the definition of trade lane or corridor is open to arbitrary decisions.

- **Macro level** - limit the VOS to include all vehicle movements within a region or for a company.
  The macro level is the easiest to implement. The emissions per unit of transport will be computed as total emissions divided by the share of that unit in total transport work. Due to this setup the macro level does not allow for comparison to other companies active on specific routes or trade lanes. Thus limiting the accuracy of emission computations to total company efficiency with respect to tonne-kilometer of goods transported.

A VOS at macro level is not wanted in this research as it does not give an accurate image on emissions with respect to operational decisions. The most favourable level is the micro level, however, enough data should be available, which might not be the case, certainly when a LSP is working with subcontractors, and one should be careful to not create a overly complex model.

**Fairness in emission allocation**

The second problem arises how emissions are allocated according to the standard. The standard prescribes the use of weight and tonne-kilometers in the allocation of GHG emissions. This, however can lead to false estimations, as a vehicle might be volume capacity constrained, more vehicle movements are required and thus more emissions are emitted (Auvinen et al., 2014). To solve this problem a broader vehicle capacity utilization definition can be used, as the goods to be shipped in relation with the vehicle’s capacity is a better indication to what transport is needed, which determines the amount of generated emissions. The capacity of a vehicle has several dimensions next to weight, such as but not limiting to, volume, floor space and number of pallet places. By combining these several capacity related dimensions into one a broader and more fair definition can be created (Davydenko et al., 2014). An introduction of allocation weight is recommended, a single value that combines these several capacity dimensions into one. The allocation weight is defined as follows:

$$\text{allocation weight}_i = \frac{\text{shipment size in a parameter}_i}{\text{vehicle capacity in a parameter}_i}$$  \hspace{1cm} (3.1)

$$\text{allocation weight} = \max(\text{allocation weight}_i), \forall i$$  \hspace{1cm} (3.2)

First, Equation 3.1 computes the allocation weight for each determined capacity related dimension $i$. Then with the use of Equation 3.2 the maximum of the calculated allocation weights is found and this value is then used to determine the percentage of emissions.

The standard also prescribes the use of traveled kilometers per shipment instead of direct kilometers for every case other than distribution trips. This would result into unfairness in trips with multiple stops, where part of the shipments enjoy the most direct routing, while the other shipments are penalized due to service providers’ network optimisations. This can be solved by using direct distances. Direct distances are measured as a great circle distance as if only one shipment from its origin to its destination is under consideration, instead of using actual traveled distances, as Figure 3.3 illustrates, where the black line refers to the actual traveled distance and the red lines indicate the direct distance.
Lack of data accessibility and availability
The third problem is created due to the fact that the standard is orientated at the transport service providers but not towards the users of these services, the shippers. This would create a problem for shippers using multiple carriers, as they all might calculate their emission using different criteria making it hard for these shippers calculating their carbon footprint.

Lack of the method to include emissions accountability within logistics nodes
The last problem mentioned in the literature is the fact that the standard does not take emissions into account at nodes. Nodes in this case, can be understand as distribution centres. However as discussed in chapter chapter 2, the impact of energy consumption in these distribution centers is negligible compared to the emissions emitted by actual transport of the shipments.

3.3. Conclusions
The question asked at the beginning of this chapter was stated as: What are GHG emissions, and what are current methodologies used concerning these emissions?

Greenhouse gas Emissions
In order to properly understand the subject the question was asked what actually is meant by the term greenhouse gas. When talking about emissions impacting the environment, most people immediately think of CO₂ emissions. However, next to CO₂, the United Nations (UN) also considered five other gasses which harm the environment. Where CH₄ and N₂O are important concerning transport, as the others are no product of the combustion of fuels. A Global Warming Potential (GWP) is introduced to combine the three individual gasses into one number as CO₂ equivalents. Concluding that when mentioning GHG emissions in the remainder of this research, it is referred to the combination of these gasses as CO₂ equivalents.

Energy consumption and GHG emissions can be differentiated as direct and indirect emissions, where direct emissions are caused by TTW emissions and indirect emissions are caused by WTT emissions. In order to calculate these emissions, a consumption based method or a distance based method can be used. Where the consumption based method is the favourable one, but relies on detailed available data. So it is recommended to use the consumption based method where possible, and otherwise using the distance based method.

Methodologies
Literature research showed that there are multiple methodologies available for calculating GHG emissions. However, most of these methods are not specifically designed for the use in the transport sector, such as the one of the most widely mentioned and known protocol, the GHG protocol.

Only the EN 16258 standard is designed for the transport and logistics sector. In order to get most accurate
results in terms of emitted GHG emissions, it is decided that this standard should be used for calculating GHG emissions. How to calculate these emissions will be discussed in more detail in chapter 4.
Calculating Greenhouse Gas emissions

Now that it is known what types of methodologies exist concerning the reporting of GHG emissions, the next step is to actually calculate these with the help of the following sub research question:

**How to determine the GHG emissions specifically for an LSP?**

In chapter 3 it was concluded that to calculate GHG emissions during transport, the EN 16258 should be used as starting point. Where this standard is applicable for all modes of transport, it does show ambiguities on determining fuel consumption. Thus, the methodology is tailored to fit a last mile logistics network appropriately. First it is discussed how to calculate overall emitted GHG emissions and to what level of detail this should be done. When the total emissions are calculated a allocation method is designed to allocate emissions to single shipments. In order to deliver on the question being asked more and more by customers what the carbon footprint of their shipment is. One could argue what the added value is to allocate emitted emissions in such a level of detail. However, without such level of detail, calculated emission values are just a number on their own. Comparison with companies within the same field of operation would be meaningless, as the size and thus operating performance of competing companies would never be exactly equal.

### 4.1. Total Emitted emissions

First the total emissions have to be calculated. This should be done in accordance with the EN 16258 standard. The most recent version of the standard has been used at the time of writing. Which is the NEN-EN 16258:2012 issued by the Dutch Normalisation-institute NEN (CEN, 2012). The first step described by the standard is defining system boundaries, this is split up in processes to be included and processes explicitly not included. Processes discussed in the standard which do not fit within the scope of this research will be neglected and not mentioned as they add no value to this particular research. Obvious processes to be included are the direct emissions, the TTE energy consumption and GHG emissions. According to the standard, indirect emissions from the production of fuels and electricity, the WTT energy consumption and GHG emissions, should also be included in the calculation. Processes which should not be included are:

- Direct emissions of GHG resulting from leakage at the vehicle level.
- Processes consisting of short-term assistance to the vehicle for security or movement reasons.
- Processes implemented by external handling or transshipment devices, for the movement or transshipment of freight. in express delivery services and other transport services organised in networks, handling operations that take place inside platforms, and consisting of loading and unloading of parcels or pallets, belong to his category of processes.
- Processes at the administrative lever of the organisations involved in the transport services. These processes can be operation of buildings, staff commuting and business trips, computer systems, etc.
- Processes for the construction, maintenance, and dismantling of transport infrastructure used by vehicles.
- Not operational energy processes.
In accordance with the Kyoto protocol, the standard states that only the gasses described in chapter 3 should be included, any other gas should be excluded. All vehicles used, including those from subcontractors, all loaded and empty trips and all fuel consumption should be taken into account.

4.1.1. Determining the VOS

To calculate total emitted GHG emissions, the VOS should be determined. The VOS is, in essence the measured energy consumption for a transport leg. The unit of measurement depends on the type of energy used. Using a liquid fuel, predominantly diesel within the transport sector, the VOS would be measured in Liters, where as using an electricity source as energy type this would be measured in Kilowatt hour (kWh).

One of the ambiguities of the standard, is as discussed, the large degree of freedom to define the boundaries of the VOS. as mentioned in chapter 3, the literature suggested three distinct level of VOS definitions. To calculate the GHG emissions as accurate as possible for the last mile delivery, the decision has been made to measure the VOS at Micro Level, where the energy consumption is determined at vehicle trip level. The decision to measure at micro level has been made as it is gives the highest level of detail, and thus there is always the possibility to scale up to look at total network emissions for example.

Demir et al., 2011 discussed six different models to determine fuel consumption. Each model taking different factors into account, shown in Table 4.1. The table shows that model 1-5 require many factors which should be taken into account when determining fuel consumption. Model 6 only requires the vehicle mass, fuel type and speed. However when the actual fuel consumption is not known, it is assumed that the speed of the vehicle in question is also unknown, let alone the factors required for the other models. Therefore, a different method for calculating fuel consumption should be considered. A method with as little as possible

<table>
<thead>
<tr>
<th>Factors</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
</tr>
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<tbody>
<tr>
<td><strong>Vehicle related</strong></td>
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<td>Total vehicle mass</td>
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<td>Engine size</td>
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<td>Engine temperature</td>
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<td>Oil viscosity</td>
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<td>Gasoline type</td>
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<tr>
<td>Vehicle shape</td>
<td>x</td>
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<tr>
<td>The degree of use of auxiliary electric devices</td>
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<tr>
<td><strong>Environment related</strong></td>
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<tr>
<td>Roadway gradient</td>
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<tr>
<td>Wind conditions</td>
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<td>Ambient temperature</td>
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<td>Altitude</td>
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<td>Pavement type</td>
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<tr>
<td>Surface conditions</td>
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<td><strong>Traffic related</strong></td>
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<td>Speed</td>
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<td>Acceleration</td>
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</tbody>
</table>

factors required is wanted to not overcomplicate the model, but still maintain accurate estimation is desired. Literature (Kellner and Otto, 2012; Kellner, 2016; Leenders et al., 2017) and organizations which participated in the preparation of the EN 16258 standard recommend to use Equation 4.1 to calculate the amount of GHG emissions. Which overlaps with the standard, where the part within brackets is the chosen VOS and where EF, a energy conversion factor directly relates to \( g_w \) and \( g_t \).

\[
g_{gh} = [f^e + (f^f - f^e) \frac{q}{C} \times distance] \times EF
\]  

(4.1)
where: \( f^e \) = Average fuel consumption with empty vehicle \([\text{L} \cdot \text{km}^{-1}]\)
\( f^f \) = Average fuel consumption with fully loaded vehicle \([\text{L} \cdot \text{km}^{-1}]\)
\( q \) = load factor \([\text{kg}]\)
\( C \) = Vehicle capacity \([\text{kg}]\)

This method however, would require to calculate the fuel consumption each time the load of the vehicle changes. Which might work for goods transported over longer distances between stops. But for parcel deliveries calculating fuel consumption between each stop in accordance with Equation 4.1 would become a rather complex computation quickly, let alone the fact that driven distances between each stop should be known, which can not be assumed it is always the case. The EN 16258 standard also describes multiple approaches for determining consumption data. Four approaches for determining consumption data are permitted by the EN 16258 standard.

1. Individual measured values
2. Transport operator specific values
3. Transport operator fleet values
4. Default values

![Diagram](image)

Figure 4.1: Energy consumption determination approaches in accordance with EN 16258 (Schmied et al., 2012)

These approaches are sorted on most accurate to less accurate, Where the standard does not provide a detailed guidance on what is meant by each approach, Schmied et al., 2012 elaborated each approach. The first case, is the most accurate, but it is rarely the case exact energy consumption data is available per individual transport service. It is more likely that reliable data is available for the second approach. Average values determined over a wider spread period of the vehicle or route are used. If data per route or vehicle is not available, the third approach can be used, where average data is used from the overall fleet of the transport operator. The last resort is using default values for when no data what so ever concerning energy consumption is available, however this should tried to be avoided as it is the least accurate of all (CEN, 2012).

In the case of a LSP it is assumed that exact values of fuel consumption per trip are not available, due to no recorded data, the first option would be unfeasible in most real life situations. As the aim is to design a method that will be used by companies, the use of the second or third option would be more realistic. However using one of these two approaches averages are taken over longer periods of time. By using fuel consumption
averages over longer periods of time and multiple vehicles, individual factors of certain vehicles contributing to fuel consumption would be divided over all trips made. Obvious factors having an impact on fuel consumption are of course the driving style of the driver, as Ericsson, 2001 pointed out that heavy acceleration and high engine speeds have great impact on fuel consumption, up to a 70% increase in fuel consumption on urban roads (Lenaers, 2009). Other factors influencing fuel consumption and thus CO₂ emissions are among others: congestion, the use of auxiliary systems and maintenance (Pountaras et al., 2017). Demir et al., 2014 summarized factors affecting fuel consumption into five categories: vehicle related, environment related, traffic related, driver related and operations related. With all of these categories measured by multiple individual factors as seen in Figure 4.2. Accounting for all of these factors while calculating fuel consumption would mean the use of a complicated calculation method, not even mentioning the amount of data required to calculate the fuel consumption.

To resolve this problem a compromise has to be made up. To determine fuel consumption per trip the average fuel consumption given by the vehicles inboard computer should be used. If this value is checked and updated regularly, an added advantage of using this value is that by comparing it to the value of each individual vehicle of the same type in the fleet of a LSP, aggressive driving styles or required maintenance can be spotted, which if used effectively, also contributes to reducing GHG emissions.

4.1.2. Actual calculations
The standard prescribes that the calculation shall consist of four results. The energy consumption and the GHG emissions for both WTW and TTW levels. The energy consumption and GHG emissions can be calculated using fixed conversion factors. The factors used are preferably values specified by the fuel supplier in
4.2. Emissions at Shipment Level


\[ E_w = F(VOS) \times e_w \quad [\text{MJ}] \quad (4.2) \]

\[ E_t = F(VOS) \times e_t \quad [\text{MJ}] \quad (4.3) \]

\[ G_w = F(VOS) \times g_w \quad [\text{kg CO}_2\text{e}] \quad (4.4) \]

\[ G_t = F(VOS) \times g_t \quad [\text{kg CO}_2\text{e}] \quad (4.5) \]

where:
- \( E_w \) = Well-to-Wheels energy consumption [MJ]
- \( E_t \) = Tank-to-Wheels energy consumption [MJ]
- \( G_w \) = Well-to-Wheels GHG emissions [kg CO\(_2\)e]
- \( G_t \) = Tank-to-Wheels GHG emissions [kg CO\(_2\)e]
- \( e_w \) = Well-to-Wheels energy factor [MJ/\text{L}]
- \( e_t \) = Tank-to-Wheels energy factor [MJ/\text{L}]
- \( g_w \) = Well-to-Wheels emission factor [kg CO\(_2\)e/L]
- \( g_t \) = Tank-to-Wheels emission factor [kg CO\(_2\)e/L]
- \( F(VOS) \) = Measured energy consumption [L]

The measured fuel consumption \( F(VOS) \) depends on the used energy type, and as mentioned in chapter 3 how the VOS is chosen. In this case the standard unit is described in liter as this is the most obvious unit for fuel consumption, however other standard units such as kilogram or kWh can be chosen depending on the used energy type. The calculation of the energy consumption in MJ is mentioned because this value can be used to compare when different types of energy sources are used.

4.2. Emissions at Shipment Level

Now it is determined how to calculate GHG emissions per trip, the next step is to allocate these calculated emissions to single pieces. As discussed in chapter 3 no calculation method specifically aimed at allocating emissions to shipments is mentioned. Estimating total emitted emissions for a single trip is certainly possible, the next step, allocating these emissions to the proper entity can be a challenge (Leenders et al., 2017; C.H. Robinson, 2015; Kellner, 2016).

Multiple options for allocation have been discussed in the literature, from simple straightforward methods to methods derived from game theory. The methods will be explained where both advantages and disadvantages will be mentioned to make a substantiated decision on which method to use in this research.

4.2.1. Game Theory Methods

Naber et al., 2015; Leenders et al., 2017 discuss the possibilities of using cooperative game theory for the emissions allocation problem. In order to do this the allocation problem is transformed into a cost game. The game consists of a pair \((N,c)\) where \(N = \{1, 2, ..., n\}\) denotes the set of participants. The elements of \(N\) are called players, customers or shipments in this case, and subsets of \(N\) are called coalitions \(S\), routes or trips in this case. The characteristic function \(c: 2^N \rightarrow \mathbb{R}\) maps each coalition \(S \subseteq N\) to real numbers.

For the following explanation the following parameters are defined.

where:
- \( i \) = A shipment within the network
- \( N_t \) = The set of stops on trip \( t \)
- \( y_i \) = The amount of CO\(_2\) allocated to shipment \( i \in N_t \)
- \( T \) = The set of trips conducted in a transport network
- \( E_t \) = The total amount of emitted CO\(_2\) for trip \( t \)

Both papers mention multiple allocation methods, Naber et al., 2015 discusses a proportional allocation based on common practice, the Shapley value, the Nucleolus, the Lorenz Allocation and the Equal Profit Method, whereas Leenders et al., 2017 also discuss a variation of common practice, as well as the \(\tau\)-value method, the IR1-Method and the IR2-Method.
4. Calculating Greenhouse Gas emissions

Allocation Criteria
Both require allocation criteria to assess the allocation methods. Leenders et al., 2017 split the criteria into fairness criteria, derived from Engevall, 1996 and Engevall et al., 1998. Namely the kickback, efficiency, individual rationality and marginality, and carrier criteria defined with the help of a LSP operating in the Netherlands. Where as Naber et al., 2015 evaluated the methods based on stability, consistency, robustness and computation time, and he assumes that the efficiency and individual rationality criteria will always hold.

The kickback criterion conditions that no shipment can obtain a negative value of CO₂, so:

\[(C1): y_i \geq 0, \text{ for all } i \in N_t, t \in T\]  \hspace{1cm} (4.6)

Efficiency states that the total amount of emissions emitted on a trip should be allocated to the shipments transported on that trip, which is defined as:

\[(C2): E_t = \sum_{j \in N_t} y_j, \text{ for all } t \in T\]  \hspace{1cm} (4.7)

The individual rationality criterion describes that for each shipment the allocated amount of CO₂ emissions does not exceed the amount of CO₂ that would be emitted if the customer would transport the shipment individually, defined as:

\[(C3): i\tau_t \geq y_i \text{ with } h\]  \hspace{1cm} (4.8)

\[ir_t = k[(d_{o,h} + d_{i,e})f_j + d_i(f_j - f_n)\frac{q_i}{G_i})]r, \text{ for all } i \in N_t, t \in T\]  \hspace{1cm} (4.9)

Marginality conditions that the amount of CO₂ allocated to a certain shipment \(i\) is to equal or greater than to the marginal amount of CO₂ emitted by including this shipment in trip \(t\). In simpler words, it states that no shipment should be charged less than the marginal costs of including this shipment (Engevall, 1996):

\[(C4): m_i \leq y_i, \text{ for all } i \in N_t, t \in T\]  \hspace{1cm} (4.10)

Where the marginality of shipment \(i\), \(m_i\) is the maximum value between the difference of CO₂ emitted on trip \(t\) and the CO₂ emitted on the same trip excluding shipment \(i\),

\[m_i = \max(\sum_j e_{t,j} - \sum_{j|i|} e_{t,j}, 0) \text{ for } i, j \in N_t, i \neq j, t \in T\]  \hspace{1cm} (4.11)

If this criterion does not hold, a incentive is created for other customers served on the trip to send their shipment separately.

The first carrier criterion states that the allocation method used should be straightforward, in a way that it is rational and understandable for both the LSP’s employees and its customers. Rationality is described as the parameters influencing the amount of CO₂ emitted on a trip should be used in the allocation method, and that the relative impact of the parameters on the allocation should resemble the relative impact of the parameters on the actual CO₂ emissions. An understandable method implies that the allocation should be "easy" to explain to stakeholders who are not familiar with CO₂ calculations an allocations. The second carrier criterion states that the allocation method should drive customers to carbon emissions reductions. If customers order larger lot sizes, efficiency increases in transportation and the transportation activity decreases compared to smaller, more often orders. This is then defined by \(\frac{q'_i}{q_i} < \frac{q'_i}{q_i}\), where \(q_i\) and \(q'_i\) are two orders placed by a customer \(i\) at two different occasions.

<table>
<thead>
<tr>
<th>Allocation criterion</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1: Kickback</td>
<td>(y_i \geq 0) No negative allocation</td>
</tr>
<tr>
<td>C2: Efficiency</td>
<td>(E_t = \sum_{j\in N_t} y_j) The total CO₂ should be allocated</td>
</tr>
<tr>
<td>C3: Individual rationality</td>
<td>(ir_t \geq y_i) Allocation per customer should be less than or equal to the emissions of delivering separately</td>
</tr>
<tr>
<td>C4: Marginality</td>
<td>(m_i \leq y_i) Allocation per customer should be greater than or equal to the emissions of including the shipment in the trip</td>
</tr>
<tr>
<td>C5: Carbon efficiency</td>
<td>(\frac{t}{q} &lt; \frac{t}{q'}) Drive customers to CO₂ emissions reductions</td>
</tr>
</tbody>
</table>
4.2. Emissions at Shipment Level

Allocation Methods

Different allocation methods are briefly described, the common practice method, the \( \tau \)-value method, IR1-Method and the IR2-Method, Shapley value, the Nucleolus, and an adapted form of the Lorenz Method and the Equal Profit Method.

Common Practice: The common practice allocation, not per se a concept for game theory, uses the distance from each individual shipment's origin to destination and its respective order size, such that the allocation per shipment is then defined as: \( y_i = \frac{d_i q_i}{\sum_{j \in N_i} d_i q_i} E_i \) for all \( i \in N_t, t \in T \). Only taking distance between the shipment's origin and destination \( d_i \) and the shipment quantity \( q_i \) into account.

\( \tau \)-value Method: This method does take the individual rationality and marginality criteria into account, resulting in an allocation definition per shipment \( i \) as: \( y_i = \min(i_r, m_i) + (\min(i_r, m_i) - \sum_{j \in N_i} \min(i_r, m_j)) \frac{\max(i_r - m_i, 0)}{\sum_{j \in N_i} \max(i_r - m_j, 0)} \), for all \( i \in N_t, t \in T \).

As this method uses the individual rationality and marginality criteria, it also takes the relative distance from the LSP's depot as well as from the other customers served into account. The main drawback of this method is the added complexity. Not only due to the fact that the marginality criterion must be determined for each shipment, but also that it might not be understandable for certain stakeholders.

IR1-Method The IR1-Method allocates CO\(_2\) emissions by weighting the shipment's individual rationality with the individual rationality of the complete trip: \( y_i = \frac{i_r}{\sum_{j \in N_i} i_r} E_i \) for all \( i \in N_t, t \in T \).

IR2-Method: The IR2-Methods uses the amount of CO\(_2\) emitted on a round trip to allocate it to each shipment. \( y_i = \frac{d_i (f_i + f_i^* - f_i^* - f_i^{*2})}{\sum_{j \in N_i} d_j (2f_j + f_j^{*2} - f_j^{*3})} \). This method however, does not take the relative distance between the customer and depot into account.

Shapley value: Within cooperative game theory the Shapley value is an average of the marginal contributions made by each player over all permutations of players, primarily used when contributions of each actor are different. In the case of emissions allocation this results into allocating emissions to each shipment equal to the average marginal emission over all coalitions. Resulting in the emission allocated to customer \( i \):

\[
x_i = \sum_{S \subseteq N \setminus \{i\}} \frac{|S|!(n-|S|-1)!}{n!} m_i(S)
\]

(4.12)

where the marginal emission of adding customer \( i \) to subset \( S \) is \( m_i(S) = v(S \cup \{i\}) - v(S) \).

Nucleolus: The nucleolus concept tries to find an imputation \( x = (x_1, \ldots, x_n) \) that minimizes the worst inequity. So asking coalition \( S \) how dissatisfied it is with the proposed imputation \( x \) and then trying to minimize the maximum dissatisfaction. The excess is defined as \( e(x, S) = v(s) - \sum_{j \in S} x_j \).

4.2.2. Pragmatic Approaches

As mentioned in chapter 3 the EN 16258 standard contains gaps and ambiguities and leaves room for interpretation concerning GHG emissions allocation to shipments. Multiple pragmatic approaches have already been discussed in the literature to allocate GHG emissions to single shipments. For instance, DSLV, 2013 mentions instead of only using weight, as described in the standard, the use of alternative allocation units such as, the number of shipments, the product of the number of shipments and distance, the number of stops, a combination of 50% weight and 50% stops.

Veloso De Aguiar and Woolard, 2014 first determine the miles driven per shipment \( i \) by simply dividing the total driven miles by the total number of shipments. Once these distances are determined the GHG emissions are estimated by multiplying this value with an emission conversion factor. Kellner and Otto, 2012 discuss
a Payload Weighted allocation $PA$. Allocation is done according to a weight vector $w_i = \{w_1, w_2, \ldots, w_n\}$ with $\sum_{i=1}^{N} w_i = 1$ and $w_i \geq 0$, and the joint cost $c(N)$. 

$$PA = c(N) \ast \frac{w_i}{\sum w_i} \quad (4.13)$$

Instead of using weight or volume to define the weight vector, a payload vector is suggested. With the vector being defined as: $w_i = \text{max} \{\text{mass}_i, \text{volume}_i \times mcw\}$, with $mcw$ being a constant to calculate the minimum cubic weight based on volume. Kellner and Otto, 2012 substantiate this decision because of their reasoning that weight increases fuel consumption and thus GHG emissions, and volume does not. Low density, high volume shipments however occupy a substantial part of a vehicles capacity and thus requiring an increase in engaged vehicles. Kellner and Otto, 2012 also mention a method where 85% is allocated based on direct distances between the depot and each stop, and the other 15% is allocated by the product of the direct distance and the mass of each shipment.

$$ghg = (0.85 \times \frac{D_{lt}}{\sum_{i=1}^{N} D_{lt}} + 0.15 \frac{D_{lt} \times \text{mass}_i}{\sum_{i=1}^{N} (D_{lt} \times \text{mass}_i)}) \times c(N) \quad (4.14)$$

Davydenko et al., 2014 suggests the use of an allocation weight. Using not only the vehicle weight capacity constraint but including other dimensions, such as but not limiting to, volume, floor space and number of pallet places. By combining these several capacity related dimensions into one a broader and more fair definition can be created (Davydenko et al., 2014). An introduction of allocation weight is recommended, a single value that combines these several capacity dimensions into one. The allocation weight is defined as follows:

$$\text{allocation weight}_i = \frac{\text{shipi size in a parameter}_i}{\text{vehicle capacity in a parameter}_i} \cdot \frac{\text{vehicle capacity in a parameter}_i}{\text{vehicle capacity in a parameter}_i} \quad (4.15)$$

$$\text{allocation weight} = \text{max} \{\text{allocation weight}_i\} , \forall i \quad (4.16)$$

First, Equation 4.15 computes the allocation weight for each determined capacity related dimension $i$. Then with the use of Equation 4.16 the maximum of the calculated allocation weights is found and this value is then used to determine the percentage of emissions.

### 4.2.3. Conclusions on Allocation

As stated before, the goal is to create an allocation method which will be accepted in practice. The method should therefore be understandable, fair and easy to implement. The other aim is to design a GHG emission and allocation method that is not just applicable to one single carrier, as the current situation, but one that is harmonized and can be used by all carriers within the same field of operation. Zhu et al., 2014, who researched emission allocations within the maritime logistics sector developed a number of principles to which, in their mind, an allocation scheme should adhere to to determine the appropriateness of a certain allocation scheme for a given scenario, not limited to the allocated schemes discussed by them, but also for other schemes within the logistics supply chain. The principles included are: completeness, no redundancy, simplicity, fairness, individual rationality, motivation, and consistency, as mentioned in Table 4.3

<table>
<thead>
<tr>
<th>Description of general principles</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Completeness</td>
<td>All emissions, including empty return trips, should be accounted for and allocated</td>
</tr>
<tr>
<td>No Redundancy</td>
<td>The same emissions should be allocated only once, thus avoiding double-counting</td>
</tr>
<tr>
<td>Simplicity</td>
<td>The required data for a scheme should be easily available, and the calculation method should be easily understandable, effectively implementable and as simple as possible</td>
</tr>
<tr>
<td>Fairness</td>
<td>The emissions should be allocated based on the characteristics of cargo, reflecting to the degree possible each cargo unit's contribution to the overall emissions</td>
</tr>
<tr>
<td>Individual Rationality</td>
<td>No cargo should be allocated more emissions than it would have if no other cargoes were involved in the chain</td>
</tr>
<tr>
<td>Motivation</td>
<td>The scheme should provide insights into opportunities and incentives for improving environmental efficiency</td>
</tr>
<tr>
<td>Consistency</td>
<td>The functional unit should be consistent across transport modes to be applicable for benchmarking multimodal logistics chains</td>
</tr>
</tbody>
</table>

The allocation methods based on game theory are evaluated on the criteria mentioned above. Naber et al., 2015 concludes that each discussed methods has its strong points and weaknesses and that the choice of allocation method should be based on the criterion deemed most important by the user. Together with Zhu et al., 2014 and Kellner and Otto, 2012, Naber et al., 2015 conclude that there is no scheme that will hold to all principles mentioned in Table 4.3, so that a trade-off should be made. One of the major drawbacks of using game theory methods is that the computations can get very complex.
Wick et al., 2011, who also use the Shapley value for allocating GHG emission savings due to logistics pooling, state that the application is very complex, increasing with a growing amount of players. A decision between the accuracy and fairness of the game theory methods and the simplicity and applicability of the pragmatic methods should be taken. As the acceptance of this model is desired, a decision in the direction of the pragmatic models is taken. A decision which is shared with Kellner, 2016, who states game theory methods wouldn’t be applicable for a wide group of users.

Kellner, 2016 uses the Shapley value as a benchmark to allocation methods based on more pragmatic factors. He runs multiple simulations, with up to 9 shipments per trip where the allocation vector produced by the Shapley vector is compared to the vectors produced by the other methods. Where the methods looking only at distance or number of stops made on the trip show the lowest deviation, and concluding that GHG emissions should be allocated on the basis of a single allocation factor. In his opinion, the distance between the origin and destination as only the particular shipment is transported. However, only looking at the distance between a distribution center and the destination of the shipment would create a big disadvantage to people and companies located far away from the distribution center. If only the volume of a shipment is considered, larger volume shipments would be penalized, thus removing the incentive for shippers and customers to consolidate shipments and orders.

4.3. Conclusions

Determining the GHG emissions for a single trip should be done according to the EN 16258 standard, as this gives the least chance of inconsistency. The main issue was the definition of the VOS. The decision has been made to define the VOS on a micro level, where the energy consumption is determined on trip level. The first step is to determine the fuel consumption of each trip. Prior research have come up with complicated models to determine the fuel consumption, however it is unlikely that logistics companies are willing to adapt to these calculations for fuel consumption. Therefore, the most straightforward way to go is to use average fuel consumption from the vehicle’s board computer where available. With these values the energy consumption can be calculated in accordance with the equations formulated by the EN 16258 standard.
Measuring Performance

In order to improve the performance of a company, managers must measure certain aspects of the company. Without taking measures, managers have no idea how they are performing, if decisions made improve or worsen the situation, whether they meet the predetermined set targets, and how they perform with respect to competitors. The sub-question to be answered is formulated as:

*How can the network performance of an LSP including GHG emissions be measured?*

### 5.1. How to Measure

In order to measure performance, companies use Key Performance Indicator (KPI) as explained by its name itself. It is a measure which evaluates performance of a company or a specific process. They show if the company is on track in fulfilling its pre-set goals. Which means KPIs are mainly used in a post-ante environment, meaning the indicators are used to evaluate past performance of a company by analysing data. Which means to measure something the correct type of data should be available. Companies should therefore try to optimize and steer decisions to improve the metrics where it is evaluated on.

There are countless possibilities for performance measurements within companies. To make sure only useful measures are done, and not to burden managers with a never-ending list, it is common to use Key Performance Indicators. KPIs are a set of measures that focus on the factors most critical to an organization's success; however, most companies still have too many, which results in overwhelming complexities (Parmenter, 2015). Companies often blindly copy industry recognized KPIs, which do not reflect their own organization and do not contribute to any positive impact. By using poorly chosen KPIs, different measures give different, and often conflicting results. It is important to take a balanced view of measures. Managers take decisions based on basic information given by the set measures, and show how well goals are being achieved. Depending on the goal, focus should be placed on certain measures while others should be neglected. Sadly, managers often ignore this advice, and use inappropriate measures, that are easiest to implement, support their view, or have always been used in the past (Waters, 2003).

#### 5.1.1. Decision Making

Decisions are made in one of three levels, at a strategic, tactical or operational level. These levels are categorized in time scale from strategic decisions with the longest time line to operational decisions focusing on day to day decisions, as well as sorted on the impact of decisions on the overall performance of a company. SteadieSeifi, 2011 explains the different levels of decision making for the logistics field.

**Operational Decisions**

Operational decisions are made in real time on a daily or weekly basis, so their scope is narrow. Decisions such as vehicle loading or dispatching, shipment, and warehouse routines are among the many types of operational decisions. These kinds of decisions are based on lots of detailed data and usually made by supervisors.
Tactical Decisions
Tactical decisions are made on a longer-term basis, whether monthly, quarterly, or even annually. Production planning, transportation planning, and resource planning are the best known types of logistics tactical decisions.

Strategic Decisions
Strategic decisions have long lasting effects, therefore, they are long-term kinds of decisions made over one or more years. Strategic decisions are business objectives and mission statements, as well as marketing and customer-service strategies. These decisions are made by executive administrators, top managers, and stockholders. Strategic decisions are steering towards optimization of three main objectives (Ghiani et al., 2004):

1. Capital reduction
2. Cost reduction
3. Service level improvement

5.1.2. Types of KPIs
It shows that strategic decisions are mostly made using financial performance measures, where as operational decisions are better handled using non financial measures (Gunasekaran and Kobu, 2007). The disadvantage of these measures relating to finance is that they are often indirect measures. They focus on past performance, are slow to respond to changes, rely on accounting conventions, and do not record important aspects of logistics. Customer satisfaction, belonging to service level improvement does not necessarily translate into financial measures, but into qualitative outcomes. Which has the disadvantage of values can be influenced by personal feelings or opinions. Due to the fact that these measures are indirect, financial and qualitative performance can show that something is wrong, but it does not show what is wrong or how it can be corrected.

Therefore, in practice, it is better to use direct measures with quantitative outcomes, like number of pieces delivered or distance traveled (Waters, 2003). By using direct measures, it is much easier to see what might cause a change in performance.

Another way to describe different type of KPIs are outcome and driver indicators. Outcome KPIs measure the output of past activity, often using financial values as representation, comparable with indirect indicators. Driver indicators, also known as leading indicators, measures activity in its current state and have a significant impact on outcome indicators. Driver indicators are more useful, since it gives individuals and their managers more time to adjust behavior to influence a desired outcome (Eckerson, 2009). Therefore, KPIs should be quantitative, relevant and comparable (DEFRA UK, 2006). Due to these quantitative values actions can be taken to achieve determined targets, and can be substantiated. A KPI should be relevant in such a way that is accompanied with a general explanation, explaining its purpose and impact. By creating Comparable KPIs, so that performance of a single entity can be compared relative to other entities.

5.2. Logistic Specific KPI's
The literature discusses many possible measures relevant for the logistics part of the supply chain. Most of these suggested measures have however, monetary outcomes, and thus not preferable at an operational level. Other measures mentioned multiple times have an intangible description, and thus are difficult to quantify. Such as among others, customer satisfaction or employee morale. To measure these factors numerical values are given to essentially non-quantifiable factors, and thus the results should be treated with caution (Waters, 2003). The KPIs mentioned in the found literature at operational decision level are mostly the same. By neglecting measures with a monetary outcome and intangible factors a selection of useful KPIs has been made and are visible in Table 5.1.
5.2. Logistic Specific KPI’s

<table>
<thead>
<tr>
<th>No.</th>
<th>Performance Indicator</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kilometers per day</td>
<td>(Krauth et al., 2005; Skowron-Grabowska, 2013)</td>
</tr>
<tr>
<td>2</td>
<td>Kilometers per trip</td>
<td>(Krauth et al., 2005)</td>
</tr>
<tr>
<td>3</td>
<td>Planned vs actual traveled distance</td>
<td>(Robinson, n.d.)</td>
</tr>
<tr>
<td>4</td>
<td>Number of deliveries</td>
<td>(Krauth et al., 2005)</td>
</tr>
<tr>
<td>5</td>
<td>Number of stops</td>
<td>(Robinson, n.d.)</td>
</tr>
<tr>
<td>6</td>
<td>Trips per period</td>
<td>(Krauth et al., 2005)</td>
</tr>
<tr>
<td>7</td>
<td>Number of trucks in use</td>
<td>(Krauth et al., 2005; Skowron-Grabowska, 2013)</td>
</tr>
<tr>
<td>8</td>
<td>Vehicle loading capacity utilization</td>
<td>(Krauth et al., 2005; Robinson, n.d.; Schönsleben, 2018)</td>
</tr>
<tr>
<td>9</td>
<td>average fuel consumption</td>
<td>(Krauth et al., 2005)</td>
</tr>
<tr>
<td>10</td>
<td>Level of CO₂ emissions</td>
<td>(Krauth et al., 2005)</td>
</tr>
<tr>
<td>11</td>
<td>Carrier Performance</td>
<td>(Smokers et al., 2019)</td>
</tr>
<tr>
<td>12</td>
<td>Network Performance</td>
<td>(Smokers et al., 2019)</td>
</tr>
</tbody>
</table>

5.2.1. Generic Performance Indicators

Most of the above-mentioned logistic specific KPIs are generic, and do not specifically address the carbon footprint. However, they might have a connection with GHG emissions, and thus the carbon footprint of a company. These measures can be categorized in the following categories:

Distance

Keeping track of traveled distance, the total driven kilometres per day and per trip can be measured. As well as the calculation of the ratio between planned and driven distance. By keeping track of the total driven kilometres per day, a company could try and keep traveled distance to a minimum. Measuring both total and per trip level traveled distance, insight can be created in effectiveness of the operation. Using these values together with the mentioned ratio could reveal route planning problems or unforeseen detours.

Deliveries

Using the total number of deliveries can be used to show the effectiveness of a LSP. Down drilling to the number of stops per vehicle, these numbers can be used to spot inefficient routes, which should be reevaluated.

Fleet Usage

Utilization of vehicles must also be considered as a performance measure. By keeping track of used vehicles, loading capacity can be calculated, by dividing the utilized capacity by its total capacity, all the way down to per vehicle utilization. This number can give insights in correctly allocating vehicles to routes.

Measuring average fuel consumption at a interval instead of total fuel consumption, could create insights in stopping and starting patterns that do not coincide with existing routes.

Fuel Costs

Having insight in fuel costs can have its advantages. It is performance measure of monetary value, but is can properly indicate if possible savings in operational costs are made by the decisions made.

5.2.2. Green Performance Indicators

Looking at indicators specifically measuring sustainable performance, Lean & Green, 2015 has identified that Lean & Green indicators should align with lean and green, meaning they should align business value indicators with emission profile. Improvement in the one should mean improvement in the other, fitting with common sense observations. They should be simple but useful for both internal analysis and for communication with external parties and should incorporate all the effects on the real utilization of resources. A single
KPI is inadequate for the purpose, requiring multiple KPIs, as no single indicator can do justice to the complexity of supply chains and the different roles and responsibilities. According to Smokers et al., 2019 there are two independent perspectives of the supply chain.

**Network Performance**
The first one is the perspective of a shipper. A shipper wants to deliver its products through a supply chain that might consist of multiple LSPs. This shippers perspective can be expressed in a KPI that indicates the translocation effectiveness.

\[
\text{Total Network Performance} = \frac{\text{total ghg emissions}}{\text{network performance}} = \frac{E_{CO_2}}{\sum_i U_i}
\] (5.1)

The network performance is the total amount of goods shipped, expressed in weight or volume. This indicator tells straightforward how much emissions are generated by the supply chain. It is the basis for carbon reporting and is affected by all efforts to reduce distances and increase effectiveness.

**Carrier Performance**
The other perspective is that a LSP wants to optimize its own business. The transport performance is the value added to the goods by transport, which is moving the goods from origin to destination, expressed as the amount of goods per shipment, in volume or weight times the shortest distance, the great circle distance. The actual taken path is not of interest, as it does not add value to the translocation of the shipment. Its goal is optimizing the combination of multiple products, delivery addresses, routes and transport modes and transport equipment. This perspective can be expressed in a KPI that indicates the effectiveness of the transport by the LSP in quantity of emissions per unit km. This perspective will be referred to as the carrier performance.

\[
\text{Total Carrier Performance} = \frac{\text{total ghg emissions}}{\text{transport performance}} = \frac{E_{CO_2}}{\sum_i U_i \times d_i}
\] (5.2)

In order to calculate the carrier performance it is thus necessary to know the great circle distance between the distribution centre and each delivery address.

**Total Emissions**
The numerator of Equation 5.1 and Equation 5.2 is stated as total GHG emissions, which can be seen as a KPI on its own. This should be calculated in accordance with the EN 16258 standard as discussed in chapter 4. With its corresponding WTW and TTW values, depending on the to calculate value. Preferably all emissions are taken into account, including those from empty return trips, relocating trips or maintenance trips in order to optimize these trips as well. However, detailed data of these trips should therefore be available. As the total energy demand in the world keeps rising, including energy from oil and gas (British Petroleum, 2019; IEA, 2019), it was decided that the emission factor should solely focus on the direct TTW emissions. As it assumed the WTT emissions will be created anyway due to this rise in world wide energy demand.

**Total Energy**
The EN 16258 standard also prescribes that the total energy consumption should be reported. This should therefore be done in order to make insight full comparisons between different modes of transport, where the type of fuel or emission values vary from each other.

### 5.3. Conclusions

The goal of this chapter was to answer the sub-research question: *How can the performance concerning GHG emissions of a LSP be measured?*

The performance should be measured using KPIs. From the literature useful general generic performance indicators where found, together with the green performance indicators. By using KPIs from both of these categories, better insights are created and better decisions can be made on improving the GHG emissions of a LSP.

Green performance indicators are not yet widely used in the industry. To start it is wise to start measuring the total emitted emissions. This should be possible for most LSPs, as in the most basic way of calculating only the total driven distance is required to be known. Standard conversion values in accordance with the EN
16258 can be used for further calculations.

From these total calculated emissions the network performance and carrier performance can be calculated. For the network performance the only required extra data is the amount of shipments, whereas for the carrier performance the great circle distance between origin and destination is also required. This might still be a value that is not kept by LSPs, and therefore is advised to start calculating this distance in order to use the carrier performance KPI in the future.
Improving Greenhouse Gas emissions efficiency while staying effective

The aim of this research is to reduce GHG emissions while maintaining operational performance. In other words one might say, improving GHG emission efficiency while staying effective, thus answering the following sub-research question:

*What decisions can be made with respect to the last mile delivery operation to reduce GHG emissions?*

Decisions at the operational level should be made to reduce the environmental impact of last mile delivery. The emission factors are determined by the type of fuel used and vehicle type. One way to decrease the amount of emitted GHG emissions is therefore trying to lower the emission factor. This can be done by changing to the use of an other type of fuel, such as sustainable biofuels, or by using vehicles with lower or none emissions, such as hybrid or fully electric vehicles. Changing to biofuels may not always be possible due to scarce availability within the vicinity of the LSP its network or incompatibility with the currently operating fleet. The use of more efficient vehicles require large investments and could take up to 20 years to turn the entire vehicle fleet into a zero emission fleet. Which is thus a more strategic decision than day to day operational decisions. These measures alone however, are not enough to achieve the required reduction in GHG emissions to be able to reach the 2050 targets set by the Paris Agreement. So it is evident that additional improvements are required (Smokers et al., 2019).

As mentioned in chapter 1, the reduction of driven vehicle kilometers mainly relies on routing optimization. However, in order to maintain the same level of effectiveness, and to create a as big as possible impact on the reduction on GHG emissions, a modification of the vehicle routing problem lies outside the scope of this research which lies outside the scope as well as the development of new value added logistic solutions. As by optimizing the vehicle routing problem even further it assumed that this would only result in a few kilometers gain, as opposed to allocating the right vehicle to the right route.

It was concluded that the focus should therefore be on the use and management of available vehicles. Multiple companies are shifting towards the use of zero emission vehicles, but this is a process that can take multiple years, mainly due to the fact that vehicles with a traditional combustion engine are still of economical value to these companies, and renewing a complete vehicle fleet at once would require a huge investment. The combined use of these zero emission vehicles and traditional emission generating vehicles should therefore be optimized.

### 6.1. Fleet Optimization

A model has to be designed that best fits the aim of this research and will help to answer the research questions. To try and reduce the GHG emissions during transport at an operational level, Fleet management can be optimized. Fleet management is a broad concept that incorporates decisions about but not limited to fleet sizing and configuration, fleet allocation and vehicle routing. Each subject has already many literature written about it. However most studied literature focuses on the long term strategic decisions.
Research conducted by Hoff et al., 2010 says it is necessary to consider routing and fleet composition decisions simultaneously, unless when routing and trip scheduling are already predetermined. On a strategic decision level it is possible to have an influence on the composition of fleet. However, at the operational level, trips can only be conducted with vehicles available at that time.

6.1.1. Literature on vehicle fleet

Literature discussing problems concerning vehicle fleet allocations mainly focus on optimization concerning cost reductions. Salhi et al., 2014 discuss a vehicle routing problem with multiple vehicle types, where each vehicle type only differs in capacity and fixed and running costs. Literature have discussed fleet to route assignments concerning heterogeneous vehicle fleets. Kopfer et al., 2014 did research into to which extend a fleet of mixed-sized vehicles enables the reduction of fuel consumption, and thus according to him also CO₂ emissions, compared to a case where only a homogeneous vehicle fleet with equally sized vehicles is used. The research relies on fuel consumption based on the weight of the transported goods, and only use Heavy Duty Vehicles (HDVs). Moutaoukil et al., 2014 compares the use of a homogeneous fleet to the use of a heterogeneous fleet for one depot visiting 10 addresses. Sawik et al., 2017 tries to optimize the fleet size based on multiple criteria, the maximization of capacity of trucks, minimization of fuel, carbon emissions and noise. Jiménez and Román, 2016 proposes a methodology to optimize the assignment of an urban bus fleet to a fixed set of routes for multiple types of buses. Li et al., 2015 also discusses the optimization of bus fleets based on the approach of remaining life additional benefit-cost, to maximize the net benefit of either early retirement or retrofitting the current bus fleet.

While all of these mentioned studies rely on vehicle fleet optimization for heterogeneous vehicle fleets, none mentions limited vehicle range, and thus assuming all vehicles are capable of executing a certain route when solely looking at distance traveled. The fleets in consideration also only contain vehicles powered by combustion engines. A fleet mix of polluting vehicles and zero emission vehicles is mentioned nowhere. Assuming zero emission vehicles are run on electricity provided by internal batteries, vehicle range might be a constraint for vehicle to route allocation. As Electric vehicles can help contribute to decarbonize the last-mile delivery distribution in a huge way, however, their range limitation upon this day is a disadvantage in using them (Juan et al., 2016).

Prior research in fleet optimization don’t take into account that one vehicle might be allocated to multiple routes during a single day. By assuming a certain vehicle only drives a single route on a given day, range constraints are limited by the single allocated route. However, when multiple routes per day are driven by a single vehicle the range constraint must take the distance of all driven routes between refueling or recharging of said vehicle into account.

The aim is thus to design a model which allocates a vehicle to a predefined route, with a given distance and parcel delivery demand. The vehicle can be allocated to multiple routes on a single given day, which means the range of the vehicles decreases over the day. All to try to reduce the total GHG emissions.

6.2. Required Factors

As can be seen in Figure 6.1, a emission factor together with the travel distance is required to calculate the total GHG emissions. Until recently CO₂ emission values of newly registered cars measured using standardized driving cycles such as the New European Driving Cycle (NEDC) (Helmers et al., 2019). The drawback of this particular test is that is conducted under idealized laboratory conditions, which deviates from real-world driving conditions. To overcome this problem a new procedure has been developed, namely the Worldwide Harmonised Light Vehicles Test Procedure (WLTP). Which, together with the Real Driving Emissions test is used by the Rijksdienst voor Wegverkeer (RDW) since September 2019 (RDW, 2018). As this new test has just become widely used in the recent past, no data was available for the used vehicles in the case studies. For this reason, the used emission values are calculated in accordance with the EN 16258 standard as mentioned earlier in this report. The fixed conversion factors are given by the standard and are in accordance with the European Commission Directive 2009/30/EC.

Assuming all vehicles use diesel as their fuel type, the TTW emission factor $g_d$ is given as $2.67 \text{ kg CO}_2/\text{L}$ and the WTW emission factor $g_d$ is given as $3.24 \text{ kg CO}_2/\text{L}$ for Diesel fuel. To account for the fact that emission factor is based on per liter fuel used, and the model uses driven kilometers, the emission factor is converted to emissions per kilometer using the average fuel consumption of selected vehicles in the fleet of DHL Parcel. Assuming electricity used for the charging of electrical vehicles come from renewable sources, and in
6.3. Model formulation

In accordance with the standard the TTW emission factor $g_t$ for electricity equals to zero. The TTW emission factor $g_w$ is preferably specified by the electricity supplier for the production-certified electricity bought. Otherwise, the value for the electricity bought is specified by the electricity supplier for its production in the relevant electricity grid within which the transport operation is performed. For the Netherlands the average TTW emission factor $g_w$ for electricity can be assumed as $547 \text{ g CO}_2\text{e/kWh}$ (Moro and Lonza, 2018). As this

![Diagram showing calculation of greenhouse gas emissions](image)

research focuses on the reduction of GHG emissions by improving the use of electric vehicles, it is expected that the amount of routes conducted by electric vehicles will increase and those by diesel powered vehicles will decrease and noting from Table 6.1 the TTW energy factor $e_t$ is ten times larger for diesel than for electricity, it is assumed that the total energy consumption will decrease massively as well. Therefore, no further research into the total energy consumption will be conducted.

As mentioned earlier, for the most accurate results, the exact amount of fuel used is used. However, this kind of detailed information is almost never available. Therefore, the decision has been made to use the average fuel consumption given by the vehicles on-board computer and multiplied with the distance required to complete the route. By choosing for the value calculated by the vehicle itself instead of default values, the driving style of the driver is also taken into account as well as averaging for the fact that the load of the vehicle is constantly changing, and thus the fuel consumption slightly alters as mentioned before. Where the state of the engine in terms of maintenance may also contribute to a deviation in fuel consumption, which now also be included in the fuel used. Only if absolutely no data about average fuel consumption is available, which might be the case when subcontractors are used, default values for fuel consumption may be used. When using these default fuel consumption values one should keep in mind that results may be less accurate.

Using actual driven distances in order to calculate GHG emissions would give the most accurate results. However, when using a model to allocate vehicles to certain routes in order to reduce these emissions, actual distances are of course not known yet. The value used should therefore be the distance given by the Vehicle Routing Problem (VRP) solution. This results in theoretical emissions, however assumptions are made that actual driven distances do not vary that much from distances calculated by vehicle routing software.

### 6.3. Model formulation

This section explains the model used and will be described mathematically. The parameters, decision variables, objective function and constraints will be mentioned.

#### 6.3.1. Parameters

The model relies on multiple parameters. These are placed in a corresponding index. Each index has one or multiple corresponding parameters shown in Table 6.3.

<table>
<thead>
<tr>
<th>Diesel</th>
<th>Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g_w$</td>
<td>3.24 kg CO$_2$e/l</td>
</tr>
<tr>
<td>$g_t$</td>
<td>2.67 kg CO$_2$e/l</td>
</tr>
<tr>
<td>$e_w$</td>
<td>42.7 MJ/l</td>
</tr>
<tr>
<td>$e_t$</td>
<td>35.9 MJ/l</td>
</tr>
</tbody>
</table>
6.3.2. Decision Variables
Let $X_{rk} = 1$ if a vehicle $k$ is traveling along route $r$, and $X_{rk} = 0$ otherwise.

6.3.3. Objective Function
The main objective is to reduce GHG emissions over all routes by allocating the best suitable vehicle, given by Equation 6.1.

\[
\text{Minimize } Z = \sum_{r=1}^{R} \sum_{k=1}^{K} d_r \cdot g_k \cdot X_{rk}
\]  

(6.1)

6.3.4. Constraints
To minimize GHG emissions, one would place all shipments in one vehicle. This is of course not possible due to several constraints. Thus making the objective function subject to several constraints.

each route serviced by only one vehicle

\[
\sum_{k=1}^{K} X_{rk} = 1, \quad r = 1..R
\]  

(6.2)

capacity

\[
\sum_{k=1}^{K} Q_k \cdot X_{rk} \geq q_r, \quad i = 1..R
\]  

(6.3)

Fleet size

\[
\sum_{r=1}^{R^m} X_{r^m k} \leq 1, \quad k = 1..K
\]  

(6.4)

\[
\sum_{r=1}^{R^a} X_{r^a k} \leq 1, \quad k = 1..K
\]  

(6.5)

Vehicle range constraint

\[
\sum_{r^m=1}^{R^m} d_{r^m} \cdot X_{r^m k} \leq D_k, \quad k = 1..K
\]  

(6.6)

\[
\sum_{r^a=1}^{R^a} d_{r} \cdot X_{r a k} \leq D_k, \quad k = 1..K
\]  

(6.7)

\[
da_r = \max(d_r - \text{extrarange}, 0)
\]  

(6.8)
binary non negativity

\[ X_{rk} \in \{0, 1\}, \quad r = 1...R, \quad k = 1...K \qquad (6.9) \]

Constraint 6.2 enforces that each route is serviced only once with one specific vehicle. Constraint 6.3 ensures that the capacity of the selected vehicle \( k \) is larger than the demand of corresponding route \( i \), constraint 6.5 ensures that a vehicle \( k \) is only selected once, and can not be allocated to multiple routes \( i \), constraints 6.6 and 6.7 make sure that a vehicle \( k \) has enough range to drive the complete distance of route \( i \). Finally the binary decision variables are defined in constraint 6.9.

6.4. Verification of the Model

To ensure accuracy of the model and to make sure the model is implemented in accordance with the specifications set by the conceptual model, verification is required. This is done by answering the following question: Is the model right?

To verify the model, continuity test runs are conducted, meaning multiple simulations with slightly different parameters are run. The simulations chosen, together with their expected results and real outcomes are shown in Table 6.4. Data from a random depot of DHL Parcel on single day has been used to verify.

<table>
<thead>
<tr>
<th>Description</th>
<th>Expected result</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. High amount of Electric vehicles (EVs) available</td>
<td>Only EVs selected</td>
<td>All EV are selected and emissions decrease vastly</td>
</tr>
<tr>
<td>2. High demand on routes</td>
<td>Mainly large vehicles selected</td>
<td>An increase in utilization of large vehicles</td>
</tr>
<tr>
<td>3. Long distance routes</td>
<td>EVs will not be allocated</td>
<td>No EV is allocated to routes with long distances</td>
</tr>
<tr>
<td>4. Less vehicles available than routes</td>
<td>Model won’t run</td>
<td>Model is infeasible</td>
</tr>
</tbody>
</table>

Table 6.4: Verification of the model

In some runs, the model stopped running, often because there were no enough vehicles available. The data showed that 168,1 kilograms of CO2 was emitted. After the model was run once a saving of 31,2 kilograms of CO2 would have been possible if vehicles were allocated differently. At this depot there are thirteen vehicles with an internal combustion engine and only two electric vehicles. For the first simulation the amount of electric vehicles has been modified to five.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Base Run</th>
<th>Simulation 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Van</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Small Van</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Electric Van</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 6.5: Parameters for simulation

6.5. Conclusions

The question asked at the beginning of this chapter was: What decisions can be made with respect to the last mile delivery operation to reduce GHG emissions?

In order to reduce the emissions during the last mile delivery phase, an optimization model has been designed which accounts for an heterogeneous vehicle fleet and allocates each the available vehicles to a suitable predetermined route in order to achieve the lowest possible GHG emissions.
Case Study

This chapter deals with the last research question: *How will the environmental performance be impacted by applying these decisions?*

The goal of this question is to demonstrate to what extent GHG emissions can be reduced by allocating vehicles of different types to routes on a day to day operational basis, with the help of the model described in chapter 6.

Experiments on four scenarios have been modelled and analysed in order to help answer the research question. The experiments show different options and scenarios how the vehicle fleet can be allocated at five depot of DHL Parcel in the Netherlands. Analysis will be conducted on their performance according to the following KPIs:

- Capacity Utilization
- Electric Vehicle Utilization Ratio
- Total GHG Emissions
- Total Network Performance
- Total Energy Consumption
- Fuel Costs

All of these KPIs are described in more detail in chapter 5. The Carrier Performance, also mentioned in chapter 5 will not be analysed as data required, the great circle distance between origin and destination of shipments, is currently not available.

7.1. **Experimental Setup**

In order to achieve the highest possible savings in terms of GHG emissions it was chosen to apply the model on a case study within the E-commerce network of DHL, as explained in chapter 2. The B2B network was also considered but as mentioned in chapter 2 routes are executed by only two types of vehicles, namely trucks or vans, not varying in type or size. Where as the E-commerce network shows a much more varied vehicle fleet in terms of size, capacity and emission values.

Data of one month period were used for this case study, selected from five depots varying in size, location and vehicle fleet layout.

7.1.1. **Depot Locations**

The experiments will be run at five individual depots located across the Netherlands, visible in Figure 7.1, selected based on the population density, total number of vehicles, number of electric vehicles, average distance per route, and average parcels per route, values of which are summarized in Table 7.1.
Amsterdam:
Amsterdam has one of the highest population densities in the Netherlands. The vehicle fleet consists of four electric vans, 67% of the total fleet. The routes out of the Amsterdam depot have an low average distance of kilometers, but do show an high average utilization of parcels per route.

Delft:
The Delft depot is also located in a high populated area, right in between The Hague and Rotterdam, two of the largest cities in the Netherlands. It has therefore a large vehicle fleet of vehicles in total, of which two are electric vehicles. The route distance is the lowest overall of only kilometers with an average utilization of parcels per route.

Lichtenvoorde:
Lichtenvoorde is located in the east of Netherlands, near the border with Germany. A more agricultural dominated area, and thus a low population density. It serves an large area and has eleven vehicles at its disposal, of which only one is an electric vehicle. The average route distance is much higher, kilometers with an average utilization of parcels per route.

Middelharnis:
Middelharnis is a small village located in Zeeland, the southwest of the Netherlands. It has a very low population density, and thus the highest average route distance of kilometers, with an average utilization of parcels. The routes are served with one out of five vehicles, of which none is electric.

Woerden
Woerden is village located right in the middle of the Groene Hart, a rural area surrounded by the four biggest cities of the Netherlands. It has a lower population density than Amsterdam and Delft, but higher than Lichtenvoorde and Middelharnis. The depot serves the surrounding villages as well with seven vehicles, of which one is electric. The average route distance is kilometers with an average utilization of parcels.

(a) Depot locations of DHL Parcel in the Netherlands  (b) Selected depots for the case study

Figure 7.1: Depot locations
7.1. Experimental Setup

<table>
<thead>
<tr>
<th></th>
<th>Amsterdam</th>
<th>Delft</th>
<th>Lichtenvoorde</th>
<th>Middelharnis</th>
<th>Woerden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Density</td>
<td>very high</td>
<td>high</td>
<td>low</td>
<td>very low</td>
<td>medium</td>
</tr>
<tr>
<td>Total Vehicles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric Vehicles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Distance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parcels per Route</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7.1.2. Vehicle Characteristics

As mentioned in chapter 2, parcels can be delivered by multiple types of vehicles. In total there are seven different types of vehicles, spread across the five respective depots, which can be grouped in large (MCV), small (SCV) and electric vans (SCV-e).

**Large Vans (MCV):**

Large vans have an capacity of 160 parcels. The fuel type is diesel and has an emission value of 0.202 kg CO₂e/km. The large van has an range of 1250 km, far outreaching the average route distance. The Renault Trafic, with its capacity of 160 is considered a large van.

**Small Vans (SCV):**

Small vans have a capacity ranging from 98 to 123 parcels per van, due to multiple type of vehicle brands and types available. The emission value therefore ranges from 0.144 to 0.167 kg CO₂e/km. All of the small vans also have a range exceeding 1000 km, thus again outreaching the average route distances.

**Electric Vans (SCV-e):**

The electric vans have a relatively large capacity of 132 parcels. The range of these vehicles is only limited to 100 km in the most positive situation. This range limitation can be a major disadvantage, but on the other hand due to the electric drive system the emission value of electric vans is zero.

All vehicle types vary in maximum range, parcel capacity and GHG emissions per driven kilometer. Looking at maximum range, the Streetscooter has a maximum range of only 100 kilometers, where as the vehicles with an internal combustion engine all have a range exceeding 1000 kilometers. In terms of TTW emissions, one could say, the larger the van the higher amount of emissions per kilometer. All detailed numbers are shown in Table 7.2.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Type</th>
<th>Range [km]</th>
<th>Capacity [parcels]²</th>
<th>GHG emissions [kg CO₂e/km]</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renault Trafic</td>
<td>MCV</td>
<td>1270</td>
<td>160</td>
<td>0.202</td>
<td>(Renault, 2019b)</td>
</tr>
<tr>
<td>Renault Kangoo</td>
<td>SCV</td>
<td>1275</td>
<td>123</td>
<td>0.151</td>
<td>(Renault, 2019a)</td>
</tr>
<tr>
<td>Mercedes Citan</td>
<td>SCV</td>
<td>1275</td>
<td>116</td>
<td>0.151</td>
<td>(Mercedes-Benz, 2019)</td>
</tr>
<tr>
<td>Volkswagen Caddy</td>
<td>SCV</td>
<td>1000</td>
<td>96</td>
<td>0.157</td>
<td>(Volkswagen, 2019)</td>
</tr>
<tr>
<td>Opel Combo Van</td>
<td>SCV</td>
<td>1000</td>
<td>100</td>
<td>0.167</td>
<td>(Opel, 2018)</td>
</tr>
<tr>
<td>Citroen Berlingo</td>
<td>SCV</td>
<td>1000</td>
<td>101</td>
<td>0.144</td>
<td>(Citroën, 2018)</td>
</tr>
<tr>
<td>Streetscooter B16</td>
<td>SCV-e</td>
<td>1000</td>
<td>132</td>
<td>0</td>
<td>(Streetscooter, 2019)</td>
</tr>
</tbody>
</table>

² According to DHL theoretical average volume per parcel (0.0325 m³ per parcel)

Each of the selected depots has their own heterogeneous fleet layout, ranging from 4 electric vans in Amsterdam to none at the Middelharnis depot, and Delft and Lichtenvoorde respectively having six and four large Renault Trafic vans, were as the other three depots only having one each. Keeping in mind that the total number of vehicles at Delft and Lichtenvoorde is also significantly higher than compared to the other depots. Full details of the number of vehicles per depot are shown in Table 7.3, and a spread per category is shown in Figure 7.2.
Table 7.3: Number of vehicles per depot

<table>
<thead>
<tr>
<th></th>
<th>Amsterdam</th>
<th>Delft</th>
<th>Lichtenvoorde</th>
<th>Middelharnis</th>
<th>Woerden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renault Trafic</td>
<td>1</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Renault Kangoo</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mercedes Citan</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Volkswagen Caddy</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Opel Combo Van</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Citroen Berlingo</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Streetcruiter B16</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>14</td>
<td>11</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

![Vehicle spread per category]

Figure 7.2: Vehicle spread per category

7.2. Scenarios

The case study is conducted over five different scenarios. Where the first scenario is the current situation set as the base case, as no optimization has been carried out for this particular case. Data has been collected from these depots over the month June in 2019. The collected data consists of date, time frame, driven route & tour, number of delivered parcels, distance of the route according to routing software and type of vehicle operated.

7.2.1. Base case Zero: Current Situation

A scenario in the current set up is conducted to find out how the network performs with respect to GHG emissions in the current situation. No optimization will be undertaken, in order to compare future results with the current situation.

7.2.2. Scenario One: Depot Optimization

The first optimization scenario will optimize the vehicle allocation to routes at each individual depot in order to try and reduce GHG emissions immediately without further investments, using the optimization model mentioned in chapter 6.

7.2.3. Scenario Two: Range reduction on Electric Vehicles

One of the main drawbacks of electric vehicles is limited range. Not only is the range constrained by the size of the battery, the state of the battery pack can also induce a negative effect on the range of electric vehicles. Due to aging of the battery the maximum capacity decreases over time. Marques et al., 2019 conducted a comparative life cycle assessment of two typical lithium-ion battery types for electric vehicles, which showed a significant decrease in battery capacity over their respective life cycle as shown in Figure 7.3. Another factor impacting the capacity of electric vehicles is changing ambient temperatures due to seasonal effects, as battery performance strongly relies on temperature. With colder temperatures, battery efficiency, discharge capability, and available energy all decrease, whereas the internal resistance increases, decreasing power that
can be drawn from the battery. With higher temperatures, battery performance increases, but they do degrade faster at higher temperatures (Yuksel and Michalek, 2015). Weather impacts have a direct impact on battery efficiency and thus range of the vehicle. Hot or cold days also encourage the use of the air conditioner to cool or heat the drivers cabin. Users of electric vehicles have reported a decrease in range up to 40% due to temperature effects. Where the colder temperatures tend to have a larger effect, as batteries have poorer performance at low temperatures and electric heating consumes more power than cooling (Yuksel and Michalek, 2015; Barnitt et al., 2010).

Dong et al., 2018 discusses the technical and operational suitability of electric freight vehicles used for urban logistics, looking into energy efficiency, range and most importantly its seasonal variation of said range. Data was collected from multiple electric freight vehicles driving in multiple cities across north western Europe, and split into groups based on their gross weight. The fleet of vehicles consisted of seven small vehicles (<3.5 tonnes), 54 medium sized vehicles (3.5 - 7 tonnes) and 16 large trucks (>7 tonnes). Table 7.4 shows figures found for each group, showing that small sized vehicles correspond to the vehicles used by DHL, as average distance and range are similar numbers. Focusing on the small sized vehicles, results from (Dong et al., 2018)

<table>
<thead>
<tr>
<th>Weight Group</th>
<th>Distance (km) per day</th>
<th>Energy spent per day</th>
<th>Energy spent per km</th>
<th>Km per KwH</th>
<th>Average range (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3.5 t</td>
<td>77</td>
<td>16.2</td>
<td>0.23</td>
<td>4.8</td>
<td>106</td>
</tr>
<tr>
<td>3.5 - 7.5 t</td>
<td>43</td>
<td>23</td>
<td>0.65</td>
<td>1.9</td>
<td>115</td>
</tr>
<tr>
<td>&gt;12 t</td>
<td>64</td>
<td>60.6</td>
<td>1.01</td>
<td>1.1</td>
<td>170</td>
</tr>
<tr>
<td>Average</td>
<td>52</td>
<td>29</td>
<td>0.65</td>
<td>2.2</td>
<td>110</td>
</tr>
</tbody>
</table>

show that the average efficiency is 27% higher during summer when compared to winter months, visible in Figure 7.4a. The range of these small sized vehicles is on average 29% higher during summertime compared to the winter, as seen in Figure 7.4b. Concluding from these results, an experiment is run where first the range of electric vehicles is decreased by 20%, and then another experiment where the range is decreased by 30% to account for the maximum seasonal effects during winter.
7.2.4. **Scenario Three: Mixed Vehicle Fleet**
The third scenario will conduct where vehicles are roam freely between the depots at the end of the day. With the aim to see if large improvement are achieved by swapping vehicles between depots on a daily basis.

7.2.5. **Scenario Four: During the Day Recharging capabilities**
The last scenario is conducted in order to find out what the impact is when charging between tours on a single day is possible. Multiple experiments have been run, charging for 1 hour, 45 minutes and 30 minutes, with both a 3,6 kWh fast charger and a 22 kWh super charger. Assuming the electric vehicles can be charged with these types technologies. The gained range for each experiment is visible in Table 7.5.

<table>
<thead>
<tr>
<th></th>
<th>3,6 kW</th>
<th>22 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Hour</td>
<td>18 km</td>
<td>100 km</td>
</tr>
<tr>
<td>45 Minutes</td>
<td>13,5 km</td>
<td>82,5 km</td>
</tr>
<tr>
<td>30 Minutes</td>
<td>9 km</td>
<td>55 km</td>
</tr>
</tbody>
</table>

Table 7.5: Range extension due to during day charging

7.3. **Sensitivity Analysis**
The scenarios mentioned in section 7.2 are conducted together with the vehicle specific values mentioned in subsection 7.1.2. The GHG emissions of each of the small and large vans may vary from the set values. In order to compensate for this, the first scenario has been optimized once with 20% lower emission values per kilometer than set in Table 7.2.

Analysis of the results showed that the overall emissions reduced by 20%, which can be justified by the reduction of the emissions values. The allocation of each vehicle to routes remains the same between scenario one and the sensitivity analysis. It is therefore assumed that reducing the GHG emissions of vehicles has an linear impact on the total emitted emissions and that it has no effect on the vehicle allocation to routes. Thus, no further is deemed necessary with changing vehicle emission values. Results of this sensitivity analysis are printed in Appendix B.
7.4. **Results**

All the results of the scenarios will be discussed. At first the general results of each individual scenario will be discussed. Afterwards the results of each of the mentioned KPIs will be discussed separately.

### 7.4.1. **General**

**Base case Zero - Current Situation**

In order to have a benchmark for the optimization results, the calculated factors for the current situation are discussed briefly. The total emissions of the six selected depots sum up to a total of [___] kg of CO₂ emissions. Ranging from [___] kg of CO₂ emissions emitted by the Amsterdam depot, up to [___] kg of CO₂ emissions contributed by the depot in Lichtenvoorde, as can been seen in Table 7.7.

**Scenario One - Depot optimization**

The first optimization scenario showed how allocating different types of vehicles to routes every single day could decrease the GHG emissions. It shows that savings are possible at each depot, even at Middelharnis, which has no electric van in its current fleet of vehicles. Amsterdam and Delft, both depots with lower average distance per route show savings of 47% and 31% respectively in terms of GHG emissions. The other three depots, with longer average route distance, show savings of 13% for the Lichtenvoorde depot, and a reduction of 7% at the Middelharnis and Woerden depot. Showing that the depots with higher average route distances and less electric vehicles show less flexibility in optimizing vehicle allocation.

**Scenario Two - Seasonal effects**

The second experiment showed insights what seasonal effect could have on CO₂ emissions due to range decrease of electric vehicles. As Middelharnis has no electric vehicles to its disposal its excluded from these results. Due to the decrease in range the model became unfeasible for four days in Woerden and five days in Lichtenvoorde. These days of the corresponding depots have therefore been excluded for comparison for this scenario.

At the Amsterdam depot there was no change in results compared to the first scenario, where as Delft showed a slight increase of emissions and carbon footprint.

**Scenario Three - End of the Day free Roaming**

Allowing vehicles to be relocated at the end of each day showed the most promising results in terms of GHG emission reductions, [___] kg compared to the current situation. However this number does not take the emissions created by the relocation of the vehicles into account. These relocation emissions would total up to [___] kg of GHG emissions, annulling the created savings. Looking only at Amsterdam, Delft and Woerden, cities relatively nearby to each other, the relocation emissions drop down to a total of [___] kg. This would still add up to higher emissions when compared to the base case, the current situation. But it does show opportunities for further research and optimization.

As the overall savings of end of the day free roaming do not improve the total emitted emissions, Comparison of this scenario to the other scenarios has been neglected when discussing each KPI individually.

**Scenario Four - During Day Recharging Capabilities**

The last scenario was conducted to indicate further emission reductions by charging electric vehicles between routes. From the results it immediately became clear that during the day charging only has an effect at depots where the average distance per tour is higher than 50 kilometers, half the distance of the electric vans range. For both charging techniques there was no impact at Amsterdam and Delft compared to the current situation. The average route distance for both depots is way lower than the mentioned 50 kilometers, as can be seen in Table 7.6. At Woerden, where the average distance per route is much higher, savings in terms of emissions reach 1.8% when a electric van is charged for one hour at 3,6 Kilowatt (kW), and up to 6.3% when charged for 45 minutes with a 22 kW fast charger.
7.4.2. Total Emitted Emissions
All optimization scenarios showed a reduction in CO₂e emissions compared to the current situation. Accounting for seasonal effects in scenario three, results showed significant less optimal results for Lichtenvoorde and Woerden with both a maximum increase of 5.1% compared to scenario one, where as Delft only showed a maximum increase of 1.8%. Amsterdam showed no impact at all. Reducing emissions by recharging vehicles during the day would only begin to have an impact when charging for one hour or more is possible with a 3.6 kW charger, or if charging through a 22 kW charger would be possible. And only when average distances per route are longer than half of the electric vehicles range.
The results indicate that Amsterdam and Delft, depots with lower average route distance, are capable of the highest initial emission reductions. The other two depots with electric vehicles available, Lichtenvoorde and Woerden, shows less initial emission reductions. They do however show a gain in possible saving when charging electric vehicles between the morning and afternoon routes.
As the depot in Middelharnis has no electric vehicle in its current vehicle fleet, scenario one, three and four have been run once more for Middelharnis with the assumption there was one electric Streetscooter available, together with the already other vehicles there. Results showed that direct savings of [insert kg of CO₂e] can be achieved for scenario one, a reduction in emissions of 22%. Results of scenario four showed no further improvements by the ability for during the day charging at Middelharnis, where as the range reduction due to seasonal effects would decrease the savings by 4.5% to a total reduction of [insert kg of CO₂e].

<table>
<thead>
<tr>
<th></th>
<th>Amsterdam</th>
<th>Delft</th>
<th>Lichtenvoorde</th>
<th>Middelharnis</th>
<th>Woerden</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case Zero</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario One</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80% Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70% Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario Three</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Hour 3.6 kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45 Min 3.6 kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 Min 3.6 kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Hour 22 kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45 Min 22 kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 Min 22 kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7.4.3. Utilization of Vehicle Capacity
The utilization in terms of vehicle loading capacity remains quite similar overall, visible in Figure 7.5. Amsterdam shows a decrease of 1.4% to a utilization rate of 74%, noting that in the data it is visible that many routes were executed with a higher demand than the theoretical vehicle capacity.
For the other depots, the utilization rate changed from the current situation compared to scenario one, with an small increase at Delft and Lichtenvoorde and a decrease at Middelharnis and Woerden. Further changes between the first optimization scenario and the other optimization scenarios were zero or negligible, which becomes evident with the help of Figure 7.5.
Comparing the individual vehicle usage shows more promising results. Definitely when looking at utilization of the electric vehicles. Driven routes can be sub categorized in tours, which are coupled to a certain postal code area. Analysis of the current situation show that electric vehicles are currently allocated to fixed postal code areas each day. Where as the results from the optimization scenarios clearly indicate that a more even spread of electric vehicle allocation over different postal code areas is favourable, as visible in Figure 7.6, as well as using the electric vehicles more often as shown in Figure 7.7. Making it obvious that Amsterdam and Delft have the biggest impact in electric vehicle allocation, which have respectively four and two electric vehicles at their disposal. When no electric vehicle is available, such as in the case of the Middelharnis depot, improvements are made possible by making less use of the more polluting larger vans.

Amsterdam
The Amsterdam depot only showed a change in vehicle utilization between the current situation, and depot optimization. The use of electric vehicles became more wide spread over the different tours. The tour currently executed by electric vans is also the most favourite tour according to the optimization model. However the other tour currently executed is less favourable and it shows that it is more optimal to allocate electric vehicles to other tours. as shown in Figure 7.6a. It is also clear that the use of the electric vans can be intensified, comparing the current situation to the optimized solutions shows an increase of 19 routes executed by electric vans, almost 25%, and that routes currently executed by small vans are no longer required, visible in Figure 7.7a.

Delft
at Delft there was also a big change in vehicle utilization looking at depot optimization with respect to the current situation. Scenario three, the seasonal effect did however have a small impact on tour allocation, as can be seen in Figure 7.6b. It also showed that two tours were dominantly executed by electric vans, stroking with the fact that the Delft depot has two electric vans available. The vehicle fleet in Delft consists of six large vans, 43% in total. However, as Figure 7.7b demonstrates the usage of these large vans can be halved by using the optimization allocation model. It also shows that even thought seasonal effects have an effect on the range of the electric vans, they are allocated to different tours, as the total amount of electric van usage does not drop.

Lichtenvoorde
Lichtenvoorde, a depot with longer average route distances, showed results that in the current situation the electric van at its disposal was used only once in the month of June. In order to reduce emissions the electric van can be used 26 times more often. Due to these longer average distances per route it is visible what the impact is of scenario three, the seasonal effects are. The use of electric vans drops back to 21 times accounting for a 70% range. But on the other hand clearly showing the positive impact of electric vehicle allocation due to during the day charging capabilities, showing in Figure 7.7c
Middelharnis
The Middelharnis depot has no electric vehicle at its disposal so the only possible optimization would be between the current situation, scenario one, and the second scenario, depot optimization. Figure 7.7d shows that even when no electric vehicles are available, the model still optimizes the allocation of the vehicle fleet. Reducing the the use of the large van by 4% from 41 tours down to 32 tours, over a total of 200.

Woerden
Just as at the Delft and Amsterdam depots, the electric van at Woerden was mostly allocated to a single tour. By optimizing the vehicle allocation, the electric vehicle is allocated to 15 other tours as can be seen in Figure 7.6d. Showing that routes driven by vehicles should be assessed on a day to day basis instead of a fixed plan. Accounting for seasonal effects also take their toll at Woerden, showing a decrease in electric vehicle usage at scenario three. Enabling the option to charge electric vehicles between routes during the day shows that the allocation of electric vehicles can be doubled compared to the current situation, as visible in Figure 7.7e.

Overall
Looking at vehicle utilization, and than mainly the utilization of electric vehicles, the results indicate that currently they are allocated to the same areas each day. However the results from the optimization model strongly suggest that the route allocation of these electric vehicles should be done on a day to day basis in order to maximize emission reductions.
Figure 7.6: Electric vehicle allocation to tours
Figure 7.7: Vehicle Usage, Current Situation vs Depot Optimization
7.4.4. Network Performance

The network performance shows the amount of emitted grams CO$_2$e per parcel, thus the lower the value the better, visible in Table 7.8. This might cause confusions when talking about performance. To solve this issue the results of the network performance have been inverted and recalculated to create a value which displays the number of parcels delivered per kg CO$_2$e emitted. The network performance, and its improvements varies vastly between the depots, as each depot has an unique layout and different parameters. The results will therefore be discussed per depot.

Table 7.8: Network Performance values in gram CO$_2$e per parcel

Table 7.8 show that for scenario two and four the network performance does not change at the Amsterdam, Delft and Middelharnis depots. Results for these depots will only be analysed over the scenarios which do show a change in network performance. For the depots in Lichtenvoorde and Woerden all scenarios will be discussed, noting that the impact of different charging times at scenario four is minimal within each individual charging power category.

As the the number of parcels play a major role in calculating this KPI, important key values concerning these parcels are illustrated in Table 7.9.

Table 7.9: Parcel values per depot

Amsterdam

Amsterdam, a depot where the majority of the vehicle fleet is electric, shows that almost twice as much parcels can be delivered per kg CO$_2$e, rising from __ parcels per kg CO$_2$e up to ___ parcels per kg CO$_2$e. Remembering that the electric vehicle usage only rose with around 25%, the network performance makes clear that it is not just the vehicle usage that reduces the impact but also the optimized allocation in general.

Delft

At the Delft depot there are two electric vans available, but here they only account for 14% of the vehicle fleet. The original network performance is already much lower, at ___ parcels per kg CO$_2$e, changing to ___ parcels per kg, an improvement of 32.5%.
Lichtenvoorde
Lichtenvoorde has similar numbers compared to Delft in terms of total number of parcels and average parcels per route, but the average traveled distances are much higher. These longer distances translate into a much lower network performance of parcels per kg in the current situation, only improving to parcels for scenario two, an increase of 13.5%, and only showing a noticeable further improvement of 6% when during the day charging at 22 kW is possible.

Middelharnis
The depot in Middelharnis shows the lowest number of improvements by only improving from parcels to parcels per kg CO\textsubscript{2}e. As no electric vans is available at the Middelharnis depot, the optimization model has been run once more for scenario two with the addition of one electric vehicle at this particular depot. The results showed an improvement of 19.5% to parcels per kg CO\textsubscript{2}e, concluding that even though the depot is serves an area with a low population density, when an electric vehicle is available permanently allocating it to Middelharnis would contribute to the reduction of GHG emissions.

Woerden
Woerden, has a lower demand in parcel deliveries than Delft and Lichtenvoorde and shows more similarities with the Middelharnis depot. This results in comparable results concerning the network performance, with parcels per kg CO\textsubscript{2}e for the current situation, only improving by 7% to parcels per kg CO\textsubscript{2}e.

Conclusions
The network performance is mainly affected by the number of delivered parcels. Having a depot with lower average route distances and more parcels per route on average results in a better network performance, where seasonal effects and during the day charging have negligible impact on the network performance. For depots with longer distances per route initial improvements can be achieved by the addition of an electric van if none was currently allocated, but further improvements trough during the day charging show less improvements concerning network performance.

7.4.5. Energy Consumption
According the the EN 16258 standard the total energy consumption must also be taken into account. The TTW total Energy consumption have been calculated with the values in Table 6.1. The current situation shows the highest energy consumption as can be seen in Table 7.10. Through optimization of vehicle allocation the energy consumption reduces by 10% for scenario one, up to 12% for when during the day charging of vehicles is possible. Comparing the current situation with scenario one, Amsterdam and Delft show percentile reductions of 20%, Lichtenvoorde shows a reduction of 10% and Middelharnis and Woerden show a reduction of 7% in terms of energy consumption. Stroking with the fact that diesel fuel requires more energy than electricity and thus concluding that the depots with more flexibility in terms of vehicle allocation achieve higher energy reductions as well.

<table>
<thead>
<tr>
<th>Scenario Four</th>
<th>Amsterdam</th>
<th>Delft</th>
<th>Lichtenvoorde</th>
<th>Middelharnis</th>
<th>Woerden</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Hour 3.6 kW</td>
<td>3299</td>
<td>16032</td>
<td>55329</td>
<td>38565</td>
<td>33202</td>
<td>146427</td>
</tr>
<tr>
<td>45 Min 3.6 kW</td>
<td>3299</td>
<td>16032</td>
<td>55476</td>
<td>38565</td>
<td>33537</td>
<td>146909</td>
</tr>
<tr>
<td>30 Min 3.6 kW</td>
<td>3299</td>
<td>16032</td>
<td>55570</td>
<td>38565</td>
<td>33862</td>
<td>147328</td>
</tr>
<tr>
<td>1 Hour 22 kW</td>
<td>3299</td>
<td>16032</td>
<td>53416</td>
<td>38565</td>
<td>32971</td>
<td>144283</td>
</tr>
<tr>
<td>45 Min 22 kW</td>
<td>3299</td>
<td>16032</td>
<td>53491</td>
<td>38565</td>
<td>32973</td>
<td>144360</td>
</tr>
<tr>
<td>30 Min 22 kW</td>
<td>3299</td>
<td>16032</td>
<td>54826</td>
<td>38565</td>
<td>32789</td>
<td>145511</td>
</tr>
</tbody>
</table>
7.4.6. Fuel Costs

As mentioned in chapter 1, companies tend to make decisions based on economic factors before steering towards more sustainable goals. In order to make the results insightful in terms of monetary values, an analysis into fuel costs has been conducted.

For this analysis the price per liter Diesel was assumed at €1,333, in accordance with the average fuel price in June 2019 (CBS, 2019). Prizes for electricity are harder to determine, as the price varies vastly where the electric vehicle is charged. Electricity at home costs around €0.23 per kWh, where as charging through commercially available charging stations would cost around €0.45 per kWh and up to €0.65 per kWh alongside motorways at designated fast chargers. An average over these three values has been taken so that the cost per kWh is assumed at €0.45. Resulting in an average cost of €0,101 per km for large vans, €0,076 per km for small vans, and €0,09 per km for electric vans.

The total fuel costs per depot were calculated as follows:

\[
\text{Total Fuel Cost} = \sum \text{distance} \cdot \text{fuel consumption} \cdot \text{fuel cost}
\]

Where the fuel consumption is dependent on the vehicle type, and the fuel costs dependent on the energy source used. The numbers in Table 7.11 demonstrate that the current situation is the most expensive scenario in terms of fuel costs. The depot shows a slight increase in costs, this is due to the fact that with these cost values it is the cheapest to drive with small vans. During the optimization the routes driven by small vans have all been taken over by electric vehicles. This can also be concluded from the fact that the scenarios with range reductions show the lowest overall fuel costs, as routes previously driven by electric vehicles are now again driven by small vans.

By optimizing within these five individual depots, cost savings were achieved of . This might seem like a negligible number, but one must remember that DHL has 136 depots spread across the Netherlands and data of just one month was used. With this in mind together with the fact that the price per kWh is on the high side due to the averaging, not only savings in emissions are obtained, but significant fuel cost savings over a year can be achieved. Concluding that improving the carbon footprint does not have to affect the economic status of a company. However, fuel costs are ever so flexible. In order to account for changing fuel prices a sensitivity analysis has been conducted for the case where the price of diesel is assumed at €1,386, the average price of December 2019 and once where the price of electricity is set at €0,25 per kWh.

Higher costs of diesel result in an overall increase of fuel costs up to for the current situation, and for depot optimization. Which both is an increase, but due to the fact that electric vehicles are used more often in the optimization scenarios the overall saving still increase to for these five depots.

Assuming a lower price of electricity of €0,25 per kWh, allowing for cheaper costs at €0,05 per kilometer for electric vans, the overall fuel cost reductions rise towards . Almost doubling the savings compared to the original fuel prices.

Concluding that varying fuel prices for both diesel as electricity can influence total fuel costs, showing that when diesel prices rise, the fuel costs savings would still increase due to use of more electric vehicles, showing that the optimization model also shows an positive impact on overall fuel costs.

<table>
<thead>
<tr>
<th></th>
<th>Amsterdam</th>
<th>Delft</th>
<th>Lichtenvoorde</th>
<th>Middelharnis</th>
<th>Woerden</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td><strong>Table 7.11: Fuel costs per depot for each scenario</strong></td>
<td></td>
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<td></td>
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</table>
7.5. Conclusions

The goal of chapter 7 was to answer the sub research question: *How will the environmental performance be impacted by applying these decisions?*

A case study at five DHL operated depots spread across the country showed that by optimizing vehicle allocation to route parameters immediate saving in terms of GHG emissions can be achieved. The amount of savings differs per depot, based on the number of zero emission vehicles available, in this case electric vans, and location of the depots. Having more electric vehicles at a depot show higher percentile improvements. Depots serving routes to less dense populated areas show longer average route distances, and thus lower percentile improvements. For these depots with higher average distances, seasonal effects must be taken into account when allocating vehicles to routes, as cold temperatures can cause range reductions of electric vehicles up to 30%. If during the day charging of vehicles would become an option, depots with average route distances of over 50 kilometers should be the first to be fitted out with charging stations, as depots with average distances below 50 kilometer would benefit less from charging capabilities.

The most promising results were achieved with scenario three, which allowed vehicles to roam freely between each depot at the end of the day. However extra emissions created due to the relocation of vehicles have not been taken into account during this research. It merely demonstrates the possibilities for a group of nearby depots to improve further on GHG emissions reductions. As the cities of Amsterdam, Rotterdam and the Hague all have more than four depots in close vicinity to each other, future research should be done at depots in close vicinity to each other, to try and achieve further GHG emission reductions by free roaming vehicles.

Finally, the results showed that due to the optimization of vehicle allocations the costs of fuel also decreased. Concluding that reducing the carbon footprint of an LSP does not show an intrinsically linked impact to the economic status of said LSP.
Conclusion and Recommendations

This chapter concludes the research into GHG emissions in the logistics sector and the case study at DHL Parcel. The answers given on the sub-research questions will be addressed in order to help answer the main research question. Subsequently, recommendations for further research and for DHL will be discussed as well.

8.1. Conclusions

The main research question is answered better when answers to the sub-research questions are known. Therefor these will be discussed before answering the research question.

1. What is the network layout of a LSP, and which aspects are to be taken into account when calculating GHG emissions?

The generic network layout of a LSP consists of more than just transport of shipments. In order to get the shipments to their final destination not only actual transport is conducted but also the transshipment of goods within distribution centres, also consuming energy and thus GHG emissions. However, most new distribution centres are designed and build in in accordance with the BREEAM standard, it can be assumed that the energy consumption within distribution centres comes from renewable sources. Together with a simple calculation also showed that the impact in terms of energy consumption, of a forklift truck is negligible compared to actual transport. It is therefore concluded that the only aspect should the transport phase.

The transport phase also consists of multiple aspects, first mile, linehaul and last mile. Assuming the first mile is in essence the same as the last mile, these are assumed to be the same. Line haul operations are assumed as FTL transport with fixed kilometers. These line haul routes are driven no matter what in order to achieve the desired network performance. From these found revelations, it has been concluded to only focus on the last mile aspect of transport in order to improve the environmental impact.

2. What are GHG emissions, and what are current methodologies used determining these emissions?

In order to properly understand the subject the question was asked what actually is meant by the term greenhouse gas. When talking about emissions impacting the environment, most people immediately think of CO₂ emissions. However, next to CO₂, the UN also considered five other gasses which harm the environment. Where CH₄ and N₂O are important concerning transport, as the others are no product of the combustion of fuels. A Global Warming Potential (GWP) is introduced to combine the three individual gasses into one number as CO₂ equivalents when talking about GHG emissions. Energy consumption and GHG emissions can be differentiated as direct and indirect emissions, where direct emissions are caused by WTT emissions and indirect emissions are caused by WTT emissions. In order to calculate these emissions, a consumption based method or a distance based method can be used. Where the consumption based method is the favourable one, but relies on detailed available data. So it is recommended to use the consumption based method where possible, and otherwise using the distance based method.

Literature research showed that there are multiple methodologies available for calculating GHG emissions. However, most of these methods are not specifically designed for the use in the transport sector, such
as the one of the most widely mentioned and known protocol, the GHG protocol. Only the EN 16258 standard is designed for the transport and logistics sector. To get accurate results concerning emitted GHG emissions it has been decided to go further with the help of the EN 16258 standard to calculate the emissions created in the last mile transportation.

3. How to determine the GHG emissions specifically for a LSP?

Determining the GHG emissions for a single trip should be done according to the EN 16258 standard, as this gives the least chance of inconsistency. The main issue was the definition of the VOS. The decision has been made to define the VOS on a micro level, where the energy consumption is determined on trip level. The first step is to determine the fuel consumption of each trip. Prior research have come up with complicated models to determine the fuel consumption, however it is unlikely that logistics companies are willing to adapt to these calculations for fuel consumption. Therefore, the most straightforward way to go is to use average fuel consumption from the vehicles board computer where available. With these values the energy consumption can be calculated in accordance with the equations formulated by the EN 16258 standard.

4. How can the network performance of an LSP including GHG emissions be measured?

The performance should be measured using KPIs. From the literature useful general generic performance indicators were found, together with the green performance indicators. By using KPIs from both of these categories, better insights are created and better decisions can be made on improving the GHG emissions of a LSP.

Green performance indicators are not yet widely used in the industry. To start of it is wise to start measuring the total emitted emissions. This should be possible for most LSPs, as in the most basic way of calculating only the total driven distance is required to be known. Standard conversion values in accordance with the EN 16258 can be used for further calculations.

From these total calculated emissions the network performance and carrier performance can be calculated. For the network performance the only required extra data is the amount of shipments, where as for the carrier performance the great circle distance between origin and destination is also required. This might still be a value that is not kept by LSPs, and therefore is advised to start calculating this distance in order to use the carrier performance KPI in the future.

5. What decisions can be made with respect to the last mile delivery operation to reduce GHG emissions?

It was concluded that best suitable option was to improve the efficiency in using the available vehicles in the fleet. Thus, a vehicle allocation model has been designed that is able to cope with the relatively small range of electric vehicles and the fact that these vehicles should be able to drive multiple routes on a single day while taking their decreasing range into account.

6. How will the environmental performance be impacted by applying these decisions?

A case study at five DHL owned depots spread across the country showed that by optimizing vehicle allocation to route parameters immediate saving in terms of GHG emissions can be achieved. The amount of savings differs per depot, based on the amount of zero emission vehicles available, in this case electric vans, and location of the depots. Having more electric vehicles at a depot show higher percentile improvements. Depots serving routes to less dense populated areas show longer average route distances, and thus lower percentile improvements. For these depots with higher average distances, which are less flexible in allocating vehicles to routes, seasonal effects must be taken into account when allocating vehicles to routes, as cold temperatures can cause range reductions of electric vehicles up to 30%. It was also concluded that these same depots are the first to benefit from during the day charging facilities, as the afternoon routes with longer distances are then also accessible to drive with an electric vehicle.

"How can the greenhouse gas emissions of a LSP be reduced and thus improving the environmental performance, without giving in on operational performance?"
The overall greenhouse gas emissions within the network of a LSP could be reduced in a couple of ways. In order to achieve the highest amount of reductions the fastest it is best to allocate vehicles of a heterogeneous fleet to routes on a daily basis by looking at route demand and distance, while making sure that the vehicle capacity and range is not exceeded. By allocating vehicles to predetermined routes, the operational performance would remain the same while at the same time reducing emissions by making the most of zero emission vehicles and where possible excluding large polluting vans from the operation.

8.2. Recommendations
Recommendations into further research as well as recommendations towards DHL Parcel will be elaborated on.

8.2.1. Future Research
As this research only focused on the last mile delivery part of the supply chain is it recommended that the transshipment of goods within distribution centres will be taken into account when more standardized methodologies about this aspect come available.

Another recommendation would be to combine this model with the Vehicle Routing Problem (VRP), which was neglected during this research in order to keep the operational performance the same. By combining the two route distances could be minimized further, while routes could also be optimized for certain types of vehicles to try and create an as high as possible capacity utilization rate for each type of vehicle.

Finally, as mentioned in chapter 7, the end of the day free roaming scenario does not take the emissions created due to relocation into account. The model could be extended to incorporate these relocation emissions, so that a truly dynamic vehicle fleet for depots in vicinity of each other can be established.

8.2.2. DHL Parcel
In order for DHL to further improve on GHG emissions it is recommended to improve the data availability and accuracy of actual traveled distances of vehicles in order to accurately calculate the total emissions. As the Carrier Performance could not be calculated due to missing data in terms of the great circle distance between origin and destination of shipments, it is advised to start keeping track of these values so that the carrier performance can be measures as well.

Regarding the optimization of vehicle allocation, recommendations are made based on short term, medium term, and long term decisions.

In the short term DHL Parcel can start using the vehicle allocation model at each individual depot located in the Netherlands in order to reduce GHG emissions on a daily basis at an operational level.

For the medium term, data from the vehicle allocation model can be gathered over each of the depots in order to decide to invest in Fast Charging stations at the depots which might reduces emissions even further.

And in the long run, research can be conducted into which depots might be suitable for vehicle roaming at the end of each delivery day, so that an even more optimized use of the vehicle fleet can be achieved.
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Scientific Paper
Reducing the Carbon Footprint of Logistics Service Providers, while Maintaining the Same Operational Performance Levels

Dick van Hemert  Bilge Atasoy  Dingena Schot

Abstract—There are growing concerns on operating the transport sector in a more sustainable way. Logistics Service Providers (LSPs) undertake strategies on how to improve their carbon footprint, but operational actions are mostly neglected. In this paper, we present a methodology on how to account for Greenhouse Gas (GHG) emissions in the case for LSPs. Afterwards, we design an vehicle allocation optimization model to try and reduce these emissions. The model has been applied to a case study with five depots with different parameters spread across the Netherlands. The results show that through optimizing vehicle allocation to routes on a daily basis significant savings in GHG emissions can be achieved without impacting the operational performance and costs.

Keywords—Logistics Service Provider, GHG emissions, Vehicle Allocation, Optimization Model

I. INTRODUCTION

Sustainability issues have gained in popularity and interest over the past few years. Not only do policy makers, such as the Paris Agreement require companies to drive their businesses to a a more sustainable operation, but expectations and demands from the general public concerning their carbon footprint is also gaining attention rapidly [1]. Companies, who will always try and strive towards a competitive advantage, use these demands as one of the factors to steer their businesses towards a more sustainable operation. Due to this competition, companies typically make decisions mostly based on economic factors, including decisions concerning sustainability. These decisions are required in order to keep the increase in average temperature below 1.5°C Centigrade. To achieve this goal, the Greenhouse Gas (GHG) emissions from the European Union should be reduced by 95% or more by 2050 compared to 1990. Instead of waiting for policy makers to set limits to companies concerning GHG emissions, several companies have implemented own goals to reduce their carbon footprint. Such as Mission 2050 by DHL, which sets the target to reduce all logistics related emissions to zero by 2050 [2]. While mainly focusing on strategic decisions, literature research has shown that the impact of green actions on operational performance is still neglected [3]. Without measuring the impact on operational performance it is difficult to see if the applied decisions improve on a day to day basis with respect to sustainability.

A. Approach

The objective of this study was the reduction of GHG emissions which focuses on the contributing factors with respect to GHG emissions within the network of an Logistics Service Provider (LSP), in correct chosen quantitative values while maintaining the same operational performance. With a main research question formulated as follows:

How can the the Greenhouse gas emission of an LSP be reduced and thus improving the environmental performance, without giving in on operational network performance?

The research scope has been limited to the last-mile delivery phase, as emissions due to the transshipment of goods is assumed negligible in comparison to the transport phase. A quick calculation showed transporting one pallet by truck emits between 120 and 280 times as much CO2 compared to the transshipment of one pallet by a fork lift truck in a distribution centre. Further assumptions have been made that newer built distribution centres run on renewable energy and have a Building Research Establishment Environmental Assessment Method (BREEAM) certificate [4]-[6]

II. GREENHOUSE GAS EMISSIONS

Where most people talk about CO2 when referring to emissions harming the environment, GHG emissions exist of multiple gasses and not solely CO2 gasses. Though, CO2 emissions have the largest contribution, CO2 and green house gasses are therefore used synonymously to each other. Next to CO2, there are three additional green house gasses, produced by the combustion of oil, gas or fuel contributing to global warming according to the Kyoto Protocol Annex A [7]. The gasses are the following:

- Carbon Dioxide (CO2)
- Methane (CH4)
- Nitrous Oxide (N2O)

Current standards demand the calculation and reporting of all of the above mentioned gasses, because similar quantities of some gasses have a much larger impact in heating the atmosphere than CO2. In order to not overcomplicate the calculations, the total emissions are reported as a standardized value as CO2e, CO2 equivalents. This is done using a Global Warming Potential (GWP). The greater this GWP the more the gas contributes to global warming. It is a relative term, which indicates the amount of heat trapped by a certain gas in comparison to the amount of heat trapped by CO2.

In other words, expressing the global warming potential of 1 kilogram of gas over 100 years as a factor of 1 kilogram of
CO₂. Where the GWP of 1 kilogram of CO₂ is standardized to 1 [8]. Table I shows the GWP values for Carbon Dioxide, Methane and Nitrous Oxide.

<table>
<thead>
<tr>
<th>Green House Gas</th>
<th>Chemical Formula</th>
<th>GWP factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide</td>
<td>CO₂</td>
<td>1</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>28</td>
</tr>
<tr>
<td>Nitrous Oxide</td>
<td>N₂O</td>
<td>265</td>
</tr>
</tbody>
</table>

### A. Methodologies

A literature study showed that there are multiple methodologies available describing how to calculate GHG emissions. There is the GHG Protocol [10], the ISO 14064-1 and 14067 standards [11], [12], and the PAS 2050 [13]. The problem with these standards and methodologies is that none of them focuses on transport directly. There are several tools available, such as the the Eco TransIT, smart Way and Green Freight Europe, which are specifically designed tools for transport, but are not issued by a norm giving organization. For that reason the calculation of GHG emissions should be done in accordance with the EN 16258 standard [14]. A standard issued by the European Committee for Standardisation (CEN), specifically designed for the calculation of energy and emissions created by transport.

### B. Direct and Indirect Emissions

To properly account for the source of the emissions, GHG emissions can be split in two type of emissions, direct emissions and indirect emissions. The direct emissions are the most obvious emissions. These are emissions from sources owned or controlled by the reporting entity. For the road transportation logistics sector these are dependent on the type of vehicle, the load, the traveled distance and the amount and type of fuel used [8].

Indirect emissions are emissions that are a consequence of the activities of the reporting entity, but occur at sources owned or controlled by another entity. Such as the production of power and fuels, the manufacture of vehicles and the construction of streets and the maintenance of the transport network [8].

Translating these two types of emissions to vehicle usage is done by the following definitions:

- **Well-to-Tank (WTW) emissions** (energy processes): WTW emissions are the recordings of energy consumption and all indirect emissions form fuel provision from the well to the vehicle tank. The energy consumption includes losses during the production of the energy sources.
- **Tank-to-Wheels (TTW) emissions** (vehicle processes): TTW emissions are the recordings of all direct emissions form the vehicle operation.
- **Well-to-Wheels (WTW) emissions** (vehicle and energy processes): WTW emissions are the sum of the WTT and TTW consumption.

### C. Calculating Greenhouse Gas Emissions

The standard prescribes that the calculation shall consist of four results. The energy consumption and the GHG emissions for both WTW and TTW levels. The energy consumption and GHG emissions can be calculated using fixed conversion factors. The factors used are preferably values specified by the fuel supplier in accordance with the European Commission Directive 2009/30/EC [15].

\[
\begin{align*}
E_w &= F(VOS) \times e_w \\
E_t &= F(VOS) \times e_t \\
G_w &= F(VOS) \times g_w \\
G_t &= F(VOS) \times g_t
\end{align*}
\]

Where F(VOS) is the vehicle operating system, and depends on the used energy type, and level of detail chosen to select this VOS. The values of \(e_w, e_t, g_w\) and \(g_t\) are the conversion factors respectively for energy and emissions.

### III. Optimization Model

In order to reduce emissions of an LSP, on an operational level a model has been designed which allocates vehicles to certain routes, based on their capacity and range. The model is set up in a way that vehicles are able to drive multiple routes on a single day, in this case a morning route and another one in the afternoon. The models data and decision variable are as follows:

\[
\begin{align*}
&\text{r} = 1 ... R \text{ (number of routes)} \\
&r_m = 1 ... r_m \text{ (number of morning routes)} \\
&r_a = 1 ... r_a \text{ (number of afternoon routes)} \\
&k = 1 ... K \text{ (number of vehicles)} \\
&d_r = \text{distance of route } r \\
&q_k = \text{emission factor of vehicle } k \\
&D_k = \text{Max range of vehicle } k \\
&Q_k = \text{Max Capacity of vehicle } k \\
&q_r = \text{Demand for route } r
\end{align*}
\]

Decision variable:

\[
X_{rk} = \begin{cases} 
1, & \text{if vehicle k is assigned to route r} \\
0, & \text{otherwise}
\end{cases}
\]

### A. Constraints

To minimize GHG emissions, one would place all shipments in one vehicle. This is of course not possible due to several constraints. Thus making the objective function subject to several constraints.

1) **each route serviced by only one vehicle:**

\[
\sum_{k=1}^{K} X_{rk} = 1, \quad r = 1 ... R
\]
2) capacity:
\[ \sum_{k=1}^{k} Q_k \cdot X_{rk} \geq q_r, \quad i = 1\ldots R \]  
\[ (6) \]

3) Fleet size:
\[ \sum_{r=1}^{R_m} X_{r=1k} \leq 1, \quad k = 1\ldots K \]  
\[ (7) \]
\[ \sum_{r=1}^{R_m} X_{r=1k} \leq 1, \quad k = 1\ldots K \]  
\[ (8) \]

4) Vehicle range constraint:
\[ \sum_{r=1}^{R_m} d_r \cdot X_{r=1k} \leq D_k, \quad k = 1\ldots K \]  
\[ (9) \]
\[ \sum_{r=1}^{R_m} d_r \cdot X_{r=1k} \leq D_k, \quad k = 1\ldots K \]  
\[ (10) \]
\[ d_r^e = \max(d_r^e - extra range, 0) \]  
\[ (11) \]

5) binary non negativity:
\[ X_{rk} \in \{0, 1\}, \quad r = 1\ldots R, \quad k = 1\ldots K \]  
\[ (12) \]

Constraint 5 enforces that each route is serviced only once with one specific vehicle. Constraint 6 ensures that the capacity of the selected vehicle \( k \) is larger than the demand of corresponding route \( i \). Constraint 8 ensures that a vehicle \( k \) is only selected once, and can not be allocated to multiple routes \( i \). Constraints 9 and 10 make sure that a vehicle \( k \) has enough range to drive the complete distance of route \( i \). Finally the binary decision variables are defined in constraint 12.

B. Objective Function

The main objective is to reduce GHG emissions over all routes by allocating the best suitable vehicle, given by Equation 13.

\[ \text{Minimize } Z = \sum_{r=1}^{R} \sum_{k=1}^{K} d_r \cdot g_k \cdot X_{rk} \]  
\[ (13) \]

IV. CASE STUDY - DHL PARCEL

In this section the mathematical optimization model developed is applied to a case study at DHL Parcel the Netherlands. Data of an one month period were used for this case study. With varying routes and parcel demands over several depots selected in the Netherlands. The location of these depots is visible in Figure 1.

A. Depot Locations

The experiments will be run at five individual depots located across the Netherlands, chosen on multiple parameters, summarized in Table II

1) Amsterdam: Amsterdam has one of the highest population densities in the Netherlands. The vehicle fleet consists of four electric vans, 67% of the total fleet. The routes out of the Amsterdam depot have an low average distance of 35 kilometres, but do show an high average utilization of 104 parcels per route.

2) Delft: The Delft depot is also located in a high populated area, right in between The Hague and Rotterdam, two of the largest cities in the Netherlands. It has therefor a large vehicle fleet of 14 vehicles in total, of which two are electric vehicles. The route distance is the lowest overall of only 27 kilometres with an average utilization of 74 parcels per route.

3) Lichtenvoorde: Lichtenvoorde is located in the east of Netherlands, near the border with Germany. A more agricultural dominated area, and thus a low population density. It serves an large area and has 11 vehicles at its disposal, of which only one is an electric vehicle. The average route distance is much higher, 73 kilometres with an average utilization of 78 parcels per route.

4) Middelharnis: Middelharnis is a small village located in Zeeland, the southwest of the Netherlands. It has a very low population density, and thus the highest average route distance of 91 kilometres, with an average utilization of 66 parcels. The routes are served with one out of five vehicles, of which none is electric.
5) Woerden: Woerden is village located right in the middle of the Groene Hart, a rural area surrounded by the four biggest cities of the Netherlands. It has a lower population density than Amsterdam and Delft, but higher than Lichtenvoorde and Middelharnis. The depot serves the surrounding villages as well with 7 vehicles, of which one is electric. The average route distance is 67 kilometres with an average utilization of 67 parcels.

<table>
<thead>
<tr>
<th>TABLE II</th>
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<tbody>
<tr>
<td>DEPOT PARAMETERS</td>
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<tr>
<td>Amsterdam</td>
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<tr>
<td>Population Density</td>
</tr>
</tbody>
</table>

B. Vehicle Types

The Vehicles used to deliver parcels at all five depots can be categorized in three types. Average values are displayed in Table III

1) Large Vans (MCV): Large vans have an capacity of 160 parcels. The fuel type is diesel and has an emission value of 202 g CO₂e/km. The large van has an range of 1250 km, far outreaching the average route distance.

2) Small Vans (SCV): Small vans have a capacity ranging from 98 to 123 parcels per van, due to multiple type of vehicle brands and types available. The emission value therefore ranges from 144 to 167 g CO₂e/km. All of the small vans also have a range exceeding 1000 km, thus again outreaching the average route distances.

3) Electric Vans (SCV-e): The electric vans have a relatively large capacity of 132 parcels. The range of these vehicles is only limited to 100 km in the most positive situation. This range limitation can be a major disadvantage, but on the other hand due to the electric drive system the emission value of electric vans is zero.

<table>
<thead>
<tr>
<th>TABLE III</th>
</tr>
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<tbody>
<tr>
<td>AVERAGE VALUES OF VEHICLE TYPES</td>
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<tr>
<td>MCV</td>
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<tr>
<td>Capacity [parcels]</td>
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<tr>
<td>Range [km]</td>
</tr>
<tr>
<td>Emissions [g CO₂e/km]</td>
</tr>
</tbody>
</table>

C. Scenarios

Five scenarios have been analyzed with data from the month June of 2019 of the before mentioned five depots.

1) Current Situation: In order to set a base case to compare the results to, the first scenario analyzed is the current situation. No optimization at all has been undertaken at all.

2) Depot Optimization: The second scenario will optimize the vehicle allocation to routes at each individual depot in order to try and reduce GHG emissions immediately without any further investments.

3) Seasonal Effects: One of the main drawbacks of electric vehicles is its limited range. Not only is the range constrained by the size of the battery, the state of the battery pack can also induce a negative effect on the range of electric vehicles. Due to aging of the battery the maximum capacity decreases over time [16]. Another factor impacting the capacity of electric vehicles changing ambient temperatures due to seasonal effects yuksel2015. Because of these issues two experiments are run, with the first one reducing the range of Electric vehicles (EVs) to 80% and a second experiment with a further reduced range of 70%.

4) End of the Day Free Roaming: The fourth scenario will conducted where vehicles are roam freely between the depots at the end of the day. With the aim to see if large improvement are achieved by swapping vehicles between depots on a daily basis.

5) During the Day Charging Capabilities: The last scenario is conducted in order to find out what the impact is when charging between tours on a single day is possible. Multiple experiments have been run, charging for 1 hour, 45 minutes and 30 minutes, with both a 3,6 kWh fast charger and a 22 kWh super charger. Assuming the electric vehicles can be charged with these technologies.

D. Key Performance Indicators

Many factors may influence the performance of an LSPs network. In order to make the right decisions Key Performance Indicators (KPIs) are used to measure the performance of the network. The KPIs used in this study are shown in Table IV.

<table>
<thead>
<tr>
<th>TABLE IV</th>
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<tbody>
<tr>
<td>KPIs</td>
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<tr>
<td>Performance Category</td>
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<tr>
<td>Generic Indicators</td>
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<td>Green Indicators</td>
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<tr>
<td>Costs</td>
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</tbody>
</table>

V. RESULTS

This section will discuss the results of the scenarios by evaluating the before mentioned KPIs.
**A. Capacity Utilization**

The utilization in terms of vehicle loading capacity remains quite similar overall. Amsterdam shows a decrease of 1.4% to a utilization rate of 74%, noting that in the data it is visible that many routes were executed with a higher demand than the theoretical vehicle capacity.

For the other depots, the utilization rate changed from the current situation compared to scenario two, with an small increase at Delft and Lichtenvoorde and a decrease at Middelharnis and Woerden. Further changes between the second scenario and the other optimization scenarios were zero or negligible.

**B. Electric Vehicle Utilization Ratio**

Looking at the electric vehicle utilization the most significant changes occurred between scenario one, the current situation and scenario two, depot optimization. The effects of the other scenarios were of less interest. The Amsterdam depot with a high percentage of EVs showed that small vans are not necessary anymore, and that the utilization of large vans would remain the same. For the other depots the results showed that the use of large vans can be decreased and that the use of EVs can be improved significantly, as the results show in Figure 2.

The results also showed that currently EVs are allocated to the same postal code areas for each single day. It is however more optimal to spread the allocation of these vehicles over multiple postal code areas, endorsing the fact that the model should be used on a daily basis.

**C. Total Emitted Emissions**

All optimization scenarios showed a reduction in CO₂e emissions compared to the current situation, visible in Table V. Accounting for seasonal effects in scenario four showed significant less optimal results for Lichtenvoorde and Woerden with both an maximum increase of 5.1% compared to scenario two, where as Delft only showed a maximum increase of 1.8%. Amsterdam showed no impact at all. Reducing emissions by recharging vehicles during the day would only begin to have an impact when charging for one hour or more is possible with a 3,6 Kilowatt (kW) charger, or if charging through a 22 kW charger would be possible. And only when average distances per route are longer than half of the electric vehicles range.

**TABLE V**

| Total Emission Values in kg CO₂e |

As the depot in Middelharnis has no electric vehicle in its current vehicle fleet, scenario one, four and five have been run once more for Middelharnis with the assumption there was one electric Scooter available, together with the already other vehicles there. Results showed that direct savings of 67 kg of CO₂e can be achieved for scenario two, a reduction in emissions of 22%. Results of scenario five showed no further improvements by the ability for during the day charging at Middelharnis, where as the range deduction due to seasonal effects would decrease the savings by 4.5% to a total reduction of 53 kg of CO₂e.

**D. Network Performance**

The network performance was calculated according to equation 14 given by [17].

$$\text{total ghg emissions} = \frac{E_{CO_2}}{\sum r \cdot q_r}$$

The network performance is mainly affected by the amount of delivered parcels. Having a depot with lower average route distances and more parcels per route on average results in a better network performance, where seasonal effects and during the day charging have negligible impact on the network
performance. For depots with longer distances per route initial improvements can be achieved by the addition of an electric van if none was currently allocated, but further improvements through during the day charging show less improvements concerning network performance.

| TABLE VI |
| NETWORK PERFORMANCE IN G/PARCEL |

E. Energy Consumption

According the EN 16258 standard the total energy consumption must also be taken into account. The TTW total Energy consumption have been calculated with the values in Table 6.1. The current situation shows the highest energy consumption as can be seen in Table 7.10. Through optimization of vehicle allocation the energy consumption reduces by 10% for scenario two, up to 12% for when during the day charging of vehicles is possible.

F. Fuel Costs

For this analysis the price per liter Diesel was assumed at €1.33, in accordance with the average fuel price in June 2019 cbfsfuel. Prizes for electricity are harder to determine, as the price varies vastly where the electric vehicle is charged. Electricity at home costs around €0.23 per Kilowatt hour (kWh), where as charging through commercially available charging stations would cost around €0.45 per kWh and up to €0.65 per kWh alongside motorways at designated fast chargers. An average over these three values has been taken so that the cost per kWh is assumed at €0.45. Resulting in an average cost of €0.101 per km for large vans, €0.076 per km for small vans, and €0.09 per km for electric vans. The eventual fuel costs were calculated as follows:

\[ \text{FuelCost} = \sum \text{distance} \cdot \text{fuelcost} \cdot \text{fuel consumption} \]

The numbers in Table VII clearly demonstrate that the current situation is the most expensive scenario in terms of fuel costs. The depot shows a slight increase in costs, this is due to the fact that with these cost values it is the cheapest to drive with small vans. During the optimization the routes driven by small vans have all been taken over by electric vehicles. This can also be concluded from the fact that the scenarios with range reductions show the lowest overall fuel costs, as routes previously driven by electric vehicles are now again driven by small vans.

By optimizing within these five individual depots, cost savings were achieved of €. This might seem like a negligible number, but one must remember that DHL has 136 depots spread across the Netherlands and data of just one month was used. With this in mind together with the fact that the price per kWh is on the high side due to the averaging, not only savings in emissions are obtained, but significant fuel cost savings over a year can be achieved. Concluding that improving the carbon footprint does not have to affect the economic status of a company.

| TABLE VII |
| FUEL COSTS |

VI. CONCLUSIONS

A case study at five DHL owned depots spread across the country showed that by optimizing vehicle allocation to route parameters immediate saving in terms of GHG emissions can be achieved. The amount of savings differs per depot, based on the amount of zero emission vehicles available, in this case electric vans, and location of the depots. Having more electric vehicles at a depot show higher percentile improvements. Depots serving routes to less dense populated areas show longer average route distances, and thus lower percentile improvements. For these depots with higher average distances, seasonal effects must be taken into account when allocating vehicles to routes, as cold temperatures can cause range reductions of electric vehicles up to 30%.

The most promising results were achieved when vehicles are able to roam freely between each depot at the end of the day. However extra emissions created due to these relocation have not been taken into account during this research. It merely demonstrates the possibilities for a group of nearby depots to improve further on GHG emissions reductions. Finally it was concluded that due to the optimization of vehicle allocations, the costs of fuel also decreased. Meaning that making decisions in order to improve the carbon footprint of an LSP does not perse impact the economic status of said LSP.
A. Further Research

As this research only focused on the last mile delivery part of the supply chain is it recommended that the transshipment of goods within distribution centres will be taken into account when more standardized methodologies about this aspect come available.

Another recommendation would be to combine this model with the Vehicle Routing Problem (VRP), which was neglected during this research in order to keep the operational performance the same. By combining the two route distances could be minimized further, while routes could also be optimized for certain types of vehicles to try and create an as high as possible capacity utilization rate for each type of vehicle.

ACKNOWLEDGMENTS

This work has been made possible with the help of DHL Parcel Netherlands, and Delft University of Technology. This paper was based on work by [18].

REFERENCES


Results of the Sensitivity Analysis
Population Density in The Netherlands
Figure C.1: Population density of the Netherlands in 2017 CBS, 2017