Sustainable measures for the large goods fleet of DHL Express the Netherlands

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Sustainable measures for the fleet of DHL Express

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Editorial Note

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Executive Summary

Introduction

Driving forces for transport companies to implement sustainable fleet measures are the rising demand for green transportation and consciousness for the importance of a sustainable responsible business. Furthermore, transport companies face difficulties with upcoming stringent legislation on environmental zone access. Challenges rise when sustainable measures need to be implemented, since most measures are still in their infancy or no elaborate experience is available and since environmental benefits have to be balanced with investments. The aim of this research is to assist DHL the Netherlands with the sustainability strategy decision-making process. The research focused primarily on opportunities for reducing CO2-emissions, by presenting measures which can be applied on the large goods fleet of the Express division of DHL the Netherlands.

The main research question was formulated as follows:

"To what extent can the transport of large goods of DHL the Netherlands be optimized from the perspective of CO2-reduction and under which conditions will a reduction in CO2-emission in practice actually occur?"

Analysis

Calculations with data from DHL have been performed to set up the delineations of the research. It turned out that the large goods vehicles are responsible for the largest share of CO2-emissions amongst the fleet.

A set of sustainable fleet measures was created, using feedback sessions with DHL and literature. The repetitive improvements and elaboration on the measures resulted in a comprehensive set of measures with state-of-the-art characteristics. Promising measures that appeared in literature or in conversations with experts were included in the research. The measures in the set differed considerably from each other: some measures were technological solutions, others focused more on organizational aspects. However, the set is not only applicable on DHL. The measures can be relevant for any organization that wishes to improve the environmental performance of their truck fleet. All measures, except a modal shift and consolidation of goods, are even applicable on smaller goods vehicles and cars.

Most measures comprised several sub-measures with different characteristics. Because the set of measures was so comprehensive, no elaborate research could be performed on certain measures (e.g. a modal shift or consolidation of goods).

Results

A two-stage multi-criteria analysis (MCA) was conducted on the set of measures: social welfare criteria were used in the first stage and operational criteria in the second stage. The criteria for the analysis were set up amongst others by consulting DHL managers, to obtain criteria that comply with the key performance indicators of the company. The MCA was evaluated with the Pareto efficiency concept in order to emphasize the greenhouse gas criterion, since the research mainly focuses on CO2-emissions. A pair wise comparison with a preferential ranking of two components has been used to obtain weights for
the operational management criteria. DHL managers were asked to provide their view on the relative importance of the criteria. Difficulties arose when the MCA was applied on measures that comprise several sub-measures. This resulted in split up measures in order to achieve a fair comparison. Another issue was that potential barriers came up during the assessment. These barriers have been elaborated on so they can be taken into account in the decision-making process.

Case results

A case study at DHL terminal Amsterdam has been conducted on three measures that remained from the MCA, i.e. improved driving behaviour, hybrid drivetrains and improved aerodynamics and rolling resistance. GPS output from DHL vehicles and other parameters have been used in this case study. First, a transformation has been performed wherein the GPS-coordinates were converted to RD-coordinates, in order to make the coordinates suitable for calculations. The RD-coordinates and other parameters were used in a data analysis, wherein the measures were applied on the operation of DHL in the Amsterdam region, with a methodology to calculate the effects, e.g. consumed fuel and CO₂-emissions. The distances provided by the methodology in this calculation tool appeared to approach actual values with small errors. The current amount of CO₂-emissions amongst the large goods fleet of DHL Express turned out to be 912 tons for terminal Amsterdam. The potential savings that can be achieved with the three sustainable measures compared to the current vehicles range from 44,36 to 65,64 ton CO₂ per year, while the payback period ranges from 1 to 1 months. The results showed that a hybrid drivetrain provides the most promising results in daytime operation with more start-stop traffic, but the high savings for hybrid drivetrains and improved driving behaviour decrease when the consumed fuel at night is included in the results, due to the long distances traveled at constant speed at night. The results also showed that that the low scores of improved aerodynamics and rolling resistance in daytime improve once the results from the nocturnal line-haul transport are analyzed. The long stretches of freeway traveled at night form opportunities for aerodynamic and rolling resistance improvements.

Conclusions

A considerable amount of measures is available for making the fleet of DHL the Netherlands more sustainable. Measures that seem promising for DHL are improved driving behaviour, hybrid drivetrains and improved aerodynamics and rolling resistance. The issues with these measures have been addressed and determine to which extent the measures can be implemented. The main challenges are financial feasibility and technological developments. The implementation of the measure improved driving behaviour or improved aerodynamics and rolling resistance will lead to satisfying results. These measures combine a considerable decrease in CO₂-emissions and an attractive financial performance: a win-win situation for DHL and the environment and an example for other transport companies.
Preface

This master thesis research was performed for the MSc. Transport, Infrastructure and Logistics at Delft University of Technology. Attending seminars forms one of the courses of this MSc. programme and it was at a seminar at DHL terminal the Hague when I got into contact with DHL. I talked with a DHL manager after the seminar and showed him my interest in the field of goods logistics and parcel delivery. I also mentioned that I was interested in a graduation project at DHL and the manager responded positively, where after we exchanged our contact details. The idea stayed in my mind the following months and I called the manager when I was ready for the start of my thesis project, resulting in a visit to DHL terminal Roosendaal where we discussed the subject and other matters involved with the start of my project.

Full of positive energy I started my thesis project. It was very nice to have a work place at the terminal close to the actual operations, not only to get inspired by the daily processes, but also because it was easy to approach DHL employees and ask my questions and their opinion on subjects from my project. However, personal circumstances absorbed a considerable amount of my energy and time for a period during the project. The influence on the project was visible. I got stuck with analyses, went into too much detail and there was not enough progression. The drive to finish the project got stronger after a difficult time and I was back on track. I finished the matters that I had been stuck with and the last phase of the research elapsed without delay.

I would like to thank DHL for offering me the opportunity to graduate at their company. I especially want to thank Marcel, Henrik, Wilfried and the people at terminal the Hague for supporting me, giving me feedback and helping me which way to go with the project.

I also would like to thank my graduation committee. Hans, thank you for all the meetings and feedback opportunities with critical remarks and support, which steered me in a good direction and kept me on track. Ramon, thank you for your constructive and concise feedback sessions and your availability on the short term in the end of the project. Lori, thank you for your support and constructive feedback during the meetings with the thesis committee.

Finally, I would like to thank my family and friends for being there for me. I would not have made it without your support. Especially Gaye, who was always there for me to show me the positive sides and Sanna, for always making me feel better and supporting me.

Dad, you will always be here with me.

Jonas Hogenelst
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<tr>
<td>3F</td>
<td>Forest, Food and Fuel</td>
</tr>
<tr>
<td>ACTS</td>
<td>Afzet Container Transport Systeem</td>
</tr>
<tr>
<td>BEV</td>
<td>Battery Electric Vehicle</td>
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<tr>
<td>BL</td>
<td>Black Liquor</td>
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<tr>
<td>BTL</td>
<td>Biomass to Liquid</td>
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<tr>
<td>CBG</td>
<td>Compressed Biogas</td>
</tr>
<tr>
<td>CNG</td>
<td>Compressed Natural Gas</td>
</tr>
<tr>
<td>CSR</td>
<td>Corporate Social Responsibility</td>
</tr>
<tr>
<td>CTL</td>
<td>Coal to Liquid</td>
</tr>
<tr>
<td>DHL</td>
<td>Dalsey, Hillblom and Lynn</td>
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<tr>
<td>DPDHL</td>
<td>Deutsche Post DHL</td>
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<tr>
<td>DME</td>
<td>Dimethyl Ether</td>
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<tr>
<td>DSI</td>
<td>DHL Solutions and Innovations</td>
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<tr>
<td>EEV</td>
<td>Enhanced Environmentally friendly Vehicle</td>
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<td>EGR</td>
<td>Exhaust Gas Recirculation</td>
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<td>EIS</td>
<td>Enterprise Innovation System</td>
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<td>FAME</td>
<td>Fatty Acid Methyl Ester</td>
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<tr>
<td>FC</td>
<td>Fuel Cell</td>
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<td>FT</td>
<td>Fischer-Tropsch</td>
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<tr>
<td>GHEV</td>
<td>Gasoline Hybrid Electric Vehicle</td>
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<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
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<tr>
<td>GIS</td>
<td>Geographical Information System</td>
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<tr>
<td>GRG</td>
<td>Grootgoed</td>
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<tr>
<td>GTL</td>
<td>Gas to Liquid</td>
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<tr>
<td>GVW</td>
<td>Gross Vehicle Weight</td>
</tr>
<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
</tr>
<tr>
<td>HEV</td>
<td>Hybrid Electric Vehicle</td>
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<tr>
<td>HGV</td>
<td>Heavy Goods Vehicle</td>
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<tr>
<td>HHV</td>
<td>Higher Heating Value</td>
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<tr>
<td>HVO</td>
<td>Hydro-treated Vegetable Oil</td>
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<tr>
<td>ICE</td>
<td>Internal Combustion Engine</td>
</tr>
<tr>
<td>KLG</td>
<td>Kleingoed</td>
</tr>
<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
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<tr>
<td>LBG</td>
<td>Liquefied Biogas</td>
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<tr>
<td>LCA</td>
<td>Life Cycle Analysis</td>
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<tr>
<td>LHDC</td>
<td>Long Haul Driving Cycle</td>
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<tr>
<td>LHV</td>
<td>Long Heavy Vehicle, Lower Heating Value</td>
</tr>
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<td>LNG</td>
<td>Liquefied Natural Gas</td>
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<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
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<tr>
<td>MCA</td>
<td>Multi-criteria Analysis</td>
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<tr>
<td>NEDC</td>
<td>New European Driving Cycle</td>
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<tr>
<td>NGV</td>
<td>Natural Gas Vehicle</td>
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<tr>
<td>OBMS</td>
<td>On-Board Monitoring and Reporting System</td>
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<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
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<table>
<thead>
<tr>
<th>Abbr.</th>
<th>Term</th>
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<tbody>
<tr>
<td>PHEV</td>
<td>Plug-in Hybrid Electric Vehicle</td>
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<tr>
<td>PM</td>
<td>Particulate Matter</td>
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<tr>
<td>PPO</td>
<td>Pure Plant Oil</td>
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<tr>
<td>TBL</td>
<td>Triple Bottom Line</td>
</tr>
<tr>
<td>TCO</td>
<td>Total Cost of Ownership</td>
</tr>
<tr>
<td>TEU</td>
<td>Twenty foot Equivalent Unit</td>
</tr>
<tr>
<td>TPMS</td>
<td>Tire Pressure Monitoring System</td>
</tr>
<tr>
<td>RD</td>
<td>Rijksdriehoek</td>
</tr>
<tr>
<td>RDW</td>
<td>Rijksdienst voor het Wegverkeer</td>
</tr>
<tr>
<td>RME</td>
<td>Rapeseed Methyl Ester</td>
</tr>
<tr>
<td>SCR</td>
<td>Selective Catalytic Reduction</td>
</tr>
<tr>
<td>SNG</td>
<td>Synthetic Natural Gas</td>
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<tr>
<td>SVO</td>
<td>Straight Vegetable Oil</td>
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<tr>
<td>V12</td>
<td>GVW of 12</td>
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<tr>
<td>V18</td>
<td>GVW of 18</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile Organic Compound</td>
</tr>
<tr>
<td>VTG</td>
<td>Vehicle to Grid</td>
</tr>
<tr>
<td>WHDC</td>
<td>World Harmonized Duty Cycle</td>
</tr>
<tr>
<td>WTT</td>
<td>Well-to-tank</td>
</tr>
<tr>
<td>WTW</td>
<td>Well-to-wheel</td>
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<tr>
<td>WVO</td>
<td>Waste Vegetable Oil</td>
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1 Introduction

‘Everything stands still without transport’. This well known phrase from the Dutch transport sector concisely captures the essential role in our economy that the transportation of goods plays, but also shows that transport companies face difficulties with upcoming stringent legislation on environmental zone access. Other drives for transport companies to implement sustainable fleet measures are the rising demand for green transportation and consciousness for the importance of a sustainable responsible business. Challenges rise when sustainable measures need to be implemented, since most measures are still in their infancy or no elaborate experience is available and since environmental benefits have to be balanced with investments.

More insight in sustainable measures thus has to be gained in order to offer transport companies such as DHL assistance in the decision-making process on which strategy to choose, so that the desired emission reductions can be achieved against feasible investments. This research focuses on sustainable opportunities for large trucks. A comprehensive set of measures is created and investigated, resulting in a support methodology for decisions on new truck purchase. The measures are assessed in a framework and the three most promising measures are selected, on which data analysis is conducted in order to estimate effects of these measures. The set of measures is created using surveys with DHL and literature, including state-of-the-art technologies. A multi-criteria analysis (MCA) is used to select the most promising measures from the set. The effects of these measures are investigated by means of a case study, using GPS tracker output from the DHL fleet in the Amsterdam region including emission and fuel consumption parameters from literature.

1.1 Problem description

Road transportation is an important branch within the transportation of goods, since a considerable share of the total transportation of goods in the Netherlands is performed by road transport, as shown in Figure 1-1 (Francke et al, 2007). These circle graphs show the modal split in percentages of the total cargo ton-kilometers on Dutch territory.

Figure 1-1: Modal split on Dutch territory in ton-kilometers (Francke et al., 2007)
More than 80% of the total energy use in the European Union is consumed by road transport. Furthermore, the demand for road transport is growing much faster than for other transport modes (European Commission, 2009). This continuously growing transport market entails negative consequence. Examples of these consequences are more greenhouse gas (GHG) emissions, depletion of fossil fuel sources and poor air quality, particularly in (large) cities. It is widely accepted that the emission of greenhouse gases is the main cause of global warming (Baumert et al., 2005) (Gilbert and Pearl, 2008) (Metz et al., 2007). The greenhouse gas CO₂ is seen as one of the most influential greenhouse gases. The CO₂-footprint accounts for 50% of the Ecological Footprint which is a metric for the human pressure on the planet (Global Footprint Network, 2011). The road transport sector emits around 5000 tons of CO₂ per year, contributing 12% of global emissions of GHG’s in 2005 (Nautilus and Enkvist, 2009). Fossil fuel sources will become depleted within a few generations. Peak oil, the point in time when the maximum rate of global petroleum extraction is reached, after which the rate of production enters terminal decline, will occur in the near future (International Energy Agency, 2007) (Hirsch et al., 2005) (Hanlon and McCartney, 2008). The air quality in a considerable part of the Netherlands is below accepted levels. Particulate matter (PM) accepted levels for instance are exceeded frequently (Landelijk Meetnet Luchtkwaliteit, 2011).

It is evident that road transport needs to be organized more sustainable and this is acknowledged by large companies such as DHL. Operating in a sustainable way is a very actual topic within DHL the Netherlands. Several measures have been implemented in order to reduce CO₂-emissions in 2009, e.g. replacement of part of the fleet, testing of alternative techniques and optimizing routes and capacity. Furthermore, the environmental protection program GoGreen is implemented. Through this program the company aims to minimize environmental impact based on a precautionary approach and to improve resource efficiency worldwide. It is a challenge to make the processes within DHL more sustainable while allowing for an optimal course of business. A more sustainable operation may lead to cost savings in different ways: not only directly by reducing energy and fuel consumption, but also indirectly. For instance, the company can be positioned in the market with a green image, by bringing forth company sustainability in a smart way which may lead to an increase of customers.

The aim of this research is to assist DHL the Netherlands with the sustainability strategy decision-making process. The research focuses primarily on opportunities for reducing CO₂-emissions, by presenting measures which can be applied on the large goods fleet of the Express division of DHL the Netherlands. However, the set is not only applicable on DHL. The measures can be relevant for any organization that wishes to improve the environmental performance of their truck fleet. All measures, except a modal shift and consolidation of goods, are even applicable on smaller goods vehicles and cars.

The problem definition is explained in section 1.2, where after the research objectives and research questions are presented in section 1.3. Next, the research scope and research methodologies are described in section 1.4 and the report structure is presented in section 1.5.

1.2 Problem definition

Operating in a sustainable way is a very actual topic within DHL as mentioned before. Steps have to be taken to make the operations of the company more sustainable and to reach the targets. DHL the Netherlands is the problem owner. Calculations show that the CO₂-emissions of the fleet were around 71.4% of the total CO₂-emissions of DHL NL in 2009, which is shown in Figure 1-1. This number includes emissions from lease cars, but this will be a minor part. It seems effective to implement sustainable
measures for the fleet with this insight. Small gains in emission reductions for one vehicle result in large absolute emission reductions considering the size of the Dutch vehicle fleet of around 1500 vehicles. The research therefore focuses on sustainable measures for the fleet, primarily to reduce CO₂-emissions.

Figure 1-1: CO₂ emission categorization

1.3 Research objectives and research questions

The main research objective is to determine what the possibilities are for sustainable measures for the fleet and to assist the problem owner with the decision making process on sustainable strategies in order to reduce CO₂-emissions. Furthermore, it should be determined whether sustainable measures are cost-effective and therefore insight in the current CO₂-emissions from the fleet needs to be gained. The research objectives can be translated into the following main research question:

'To what extent can the transport of large goods of DHL the Netherlands be optimized from the perspective of CO₂-reduction and under which conditions will a reduction in CO₂-emission in practice actually occur?'

The research question concerns large goods, which is explained in section 1.4.1. Six sub research questions have been set up in order to answer the main research question:

1. Which measures are available for reducing CO₂-emissions?
2. Which framework can be used to investigate these measures?
3. Which assessment criteria can be used to investigate these measures?
4. How can these measures be modeled on the processes of DHL?
5. What is the current amount of CO₂-emissions amongst the large goods fleet DHL Express?
6. What are the feasible CO₂-emission reduction levels in practice?

A support methodology for decisions on new truck purchase is developed with the assessment from chapter 4. The assessment in that chapter is used to set up a decision tree for DHL. This decision tree forms an aid for the decision-process of purchasing new large goods vehicles. The information from section 4.2 is used as a basis for the decision tree. The tree itself is not part of research and thus not included in this report.

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1.4 Research approach

1.4.1 Research scope

The research is geographically delineated on the Netherlands. This delineation has been made since DHL NL is the problem owner. Visions and developments from DHL divisions in other countries are not left out of consideration, but the main research question focuses on the Netherlands. DHL NL is divided into five divisions as will be explained in chapter 2. Almost the entire fleet, comprising around 1500 vehicles, belongs to the division Express. The divisions Express and Freight accounted for 80% of the total CO₂-emissions of DHL NL in 2009. The scope of the research comprises the division Express and the branch Euronet Domestic of division Freight, since this branch organizes the nocturnal long distance Express transport from terminal to terminal. Other Freight business activities concern e.g. transport performed by subcontractors but these activities fall outside the scope of the research, since it takes considerably more effort to induce subcontractors to implement sustainable measures than the effort it takes within DHL to implement measures.

The use of fossil fuels and the emission of harmful matters do not only occur amongst the fleet in the logistical chain of DHL NL. Lights are on, heating installations run and waste is generated in the premises. Insight needs to be gained in the environmental impact of all areas of the company when a sustainable business strategy is pursued. Calculations with data from DHL and parameters from Agentschap NL (2010) show that CO₂-emissions from the fleet accounted for 71.4% of the total CO₂-emissions in 2009, compared to 16.6% for property CO₂-emissions and 12.0% for waste, as can be seen in Figure 1-1. This research therefore focuses on sustainable measures for the fleet. Primarily technical measures are investigated, but attention is also paid to driving behaviour, intermodal transport, a modal shift and consolidation of goods. Other organizational improvements such as route planning optimization or load factor optimization are outside the scope of this research. It must be noted that DHL NL includes sustainability management on the whole logistics chain in the company’s vision. All premises for instance run on electricity generated from renewable energy sources and incentives are ongoing for providing DHL employees with this electricity at their private homes. Waste is separated in a considerable amount of terminals and tests have been conducted with LED lighting systems. Furthermore, lighting in the goods halls is controlled with timers and printers are not located on unattended positions, in order to avoid uncontrolled inordinate printing behaviour.

Global warming is not the only issue that logistics service providers like DHL have to be concerned with; environmental issues also play an important role locally. Primarily PM and NOx emissions are of major influence on local air quality, especially in (large) cities. The emission of NOx is still a problem in the Netherlands even though NOx emissions have been decreasing from 570 kiloton in 1990 to 400 kiloton in 2002 (Janssen et al., 2006). The NOx problem is bigger than was assumed because truck performance results from practice are not satisfying compared to results from approval tests (Gense, 2011, personal interview). However, Beijk et al. (2007) state that the decrease of NOx and PM levels can not be determined for the last seven years. Wesseling and Beijk (2008) also mention inconclusive measurement results for PM and NOx emission trends on street level in the period 2000 to 2007, but another source claims that PM accepted levels are exceeded frequently in the Netherlands (Landelijk Meetnet Luchtkwaliteit, 2011). The primary focus of the efforts of DHL is the emissions of carbon dioxide and climate protection. Nonetheless the environmental protection program GoGreen also covers local
pollution and a broad range of other aspects such as biodiversity, water and waste. This research thus focuses primarily on reducing CO₂-emissions (see the introduction of chapter 0 for more information on the global CO₂-problem), but other emissions are not excluded.

CO₂-emissions from the fleet can be further divided into CO₂-emissions per vehicle type. Figure 1-2 has been set up with calculations and shows that the heaviest and largest vehicles accounted for 66.2% of the fuel consumption of the total fleet in the period January to September 2010. These vehicles have the DHL designation V18, V12 or longer heavier vehicle (LHV). V18 means a gross vehicle weight (GVW) of 18 tons, an LHV has a maximum length of 25.25 meters and a GVW of 50 tons for the total combination of tractor and trailer. V18 vehicles, which form the largest part of the fleet, can be divided in two types: articulated lorry tractor-trailer combinations, where a tractor unit tows a semi-trailer through a fifth wheel coupling and rigid lorries with cargo carrying capacity. The few LHV’s of DHL consist of a rigid lorry with cargo carrying capacity which also pulls a second cargo trailer, using a drawbar link. Other versions of LHV’s are discussed in section 4.2.5. The V18, V12 and LHV vehicles are mainly deployed for transport of ‘grootgoed’ or large goods and this research is therefore delineated to the transport of these goods.

![Figure 1-2: Fuel consumption per vehicle type](image)

The set of measures that is presented in chapter 3 is not only applicable on DHL vehicles. The measures can be relevant for any organization that wishes to improve the environmental performance of their truck fleet. All measures, except a modal shift and consolidation of goods, are even applicable on smaller goods vehicles and cars.

The influences of a sustainable measure on the logistical processes within DHL are not part of this research, but these influences are apparently taken into account during the process of selecting sustainable measures. Possible consequences on logistical processes are described in section 7.2, together with other recommendations for further research.

### 1.4.2 Research methodologies

The sub research questions have been answered by using various research methodologies. An appropriate approach for every sub research question is presented in this section.

A comprehensive inventory of sustainable measures is set up by performing a literature study to answer the first sub research question, in order to give the problem owner an elaborate insight in current and
future sustainable measures. Decisions on which measure should be part of the inventory are described with substantiated steps. State-of-the-art knowledge on sustainable logistical operations is used for this inventory. The consequences of omitting or inclusion of a measure is investigated. The results are discussed with involved employees of DHL, after which a set of measures is composed. The communication with DHL led to adaptations to the set of measures resulting in a cyclic process. This process is elaborated on in the introduction of chapter 3.

The literature which is used for creating the set of measures, founded theories and tools from the Til master education were used to answer sub research question two. The assessment framework was applied on the set of measures (chapter 4 and chapter 5) and consists of a two-stage multi criteria analysis (MCA). A first MCA with social welfare criteria is used to make a rough selection of measures. Operational criteria are used in the second MCA, wherein a more in-depth assessment with criteria weights is performed on the set of measures. Finally a reduced set of measures remained, which is investigated further using the other sub research questions. The third research question is answered using literature and expert analysis. The criteria are set up amongst others by consulting DHL employees and other experts, to obtain criteria that comply with the key performance indicators (KPI) of the company. A case study is conducted for terminal Amsterdam to answer the fourth research question. The software tool Microsoft Office Excel is used to process route data from the terminal in order to model fuel consumption and CO₂-emissions. The fifth and sixth sub research questions are answered with emission results from the case study.

1.5 Report structure

The structure of the report is shown in Figure 1-4. First, more background information will be presented in chapter 2. Next, a comprehensive set of measures is created and investigated in chapter 3 and 4. This assessment is evaluated in chapter 5 with a MCA framework and the three most promising measures are selected. Subsequently, a data analysis case study for the Amsterdam region is conducted in chapter 6 in order to estimate effects of these measures. Lastly, the conclusions and recommendations are presented in chapter 7.

![Figure 1-4: Report structure](image-url)
2 Company profile

The company of DHL is elaborated on in this chapter. First, an introduction is presented in section 2.1, wherein a basic profile of the company is outlined. Next, the international and national sustainability strategies are presented in section 2.2 and 2.3, respectively. In the last section, guidelines for implementation of innovations at DHL are presented.

2.1 Introduction

This section provides a brief overview of DHL the Netherlands and its activities, in order to clarify on which parts of the company this research focuses and why this focus is followed. The actual delineations of the research were explained in section 1.4.1.

The parent company of DHL is Deutsche Post DHL (DPDHL). The other subsidiary of DPDHL is Deutsche Post. Deutsche Post is the successor company of the German state company Deutsche Bundespost. Deutsche Post primarily delivers mail and parcels in Germany, but also offers other services. The business units of Deutsche Post are Mail Communication, Press Services, Retail Outlets, Dialog Marketing en Parcel Germany. DHL is the logistics branch of DPDHL. All possible forms of logistic service are offered within DHL. From now on the term DHL will be used in the report to denote DHL the Netherlands. The five divisions of DHL the Netherlands are:

1. DHL Global Mail
2. DHL Global Forwarding
3. DHL Freight
4. DHL Supply Chain
5. DHL Express

DHL Global Mail offers global cross border and domestic mail service in countries outside the Netherlands, having direct lines to over 200 countries. DHL Global Forwarding (DGF) offers global 'end-to-end' transport solutions in the airline- and seaborne freight sector. Furthermore, DGF offers 'control tower' services, customs facilities and industrial projects amongst others. DHL Freight offers European transport solutions. These services comprise European groupage, part- and full loads and European customs services amongst others. DHL Freight also offers several client-specific transport services. DHL Supply Chain (DSC) focuses on operation and control of (a part of) the logistic chain of a client, from production to delivery. Areas wherein DSC operates are warehousing and transport management, amongst others. The offered solutions are client- and situation specific. DHL Express transports shipments globally by road and air transport. The core business of DHL Express is transportation of time-critical documents and goods from door to door. This research focuses on the domestic part of DHL Express and this delineation is explained in section 1.4.1.

The entire fleet of DHL the Netherlands comprises around 1500 vehicles. All these vehicles belong to the division Express, except for 31 Freight vehicles, which are deployed for dedicated tin ware transport. All the other transport activities organized by Freight are performed by subcontractors. Shipments can be sent via three services within Express: Same Day (SD), Time Definite (TD) or Day Definite (DD). SD shipments will be delivered within 24 hours. DD shipments are delivered within a few days. TD shipments can be delivered on the first possible day before 09:00, before 12:00 or before the end of the
Sustainable measures for the fleet of DHL Express
day. The establishments of, amongst others, DHL the Netherlands and the services that are offered at these terminals are shown in Figure 2-1.
Figure 2-1: DHL terminals in the Benelux and their activities
Express shipments are picked up and delivered with practically every type of vehicle in daytime. A distinction is drawn between ‘kleingoed’ shipments (small goods shipments or KLG) and ‘grootgoed’ shipments (large goods shipments or GRG). GRG shipments consist chiefly of pallets and are transported with various types of trucks and tractor-trailer combinations. This research focuses on these large goods vehicles and this delineation is explained in section 1.4.1. KLG shipments consist mainly of parcels and are transported with different types of vans. DD shipments are transported between DHL terminals at night. This nocturnal transport is organized by DHL Freight, by order of DHL Express and with trucks of DHL Express. The DHL Freight branch that organizes these nocturnal ‘linehauls’ is called Euronet Domestic, or ‘Landelijk net’ which is domestic network in Dutch, or Beneluxnet. Various terms are used for this branch amongst different divisions of DHL, since the name changed multiple times and some divisions stick with old names. The term Beneluxnet is used since there are cross-border routes to terminals in Belgium and Luxembourg. The 31 vehicles owned by Freight are not deployed in these nocturnal linehauls, but in client specific services.

2.2 International sustainability strategy

The sustainability approach of DHL outside the Netherlands is elaborated on in this section. This approach does not only focus on concrete fuel consumption reduction measures, but also on the inclusion of these measures in the general sustainability policy of the company. Divisions of DPDHL outside the Netherlands may pursue other visions on sustainability. The elaboration on the international and national sustainability strategy of DPDHL, respectively in this section and in section 2.3, show that the sustainable measures investigated in this research fit in these strategies. The sustainable measures are listed in the introduction of chapter 3.

Responsible operations and management are a key component of the business strategy of DPDHL. The approach of DPDHL to sustainability is based on the triple-bottom-line concept (TBL) derived from the United Nation’s 1987 report on strategies for sustainable development, ‘Our Common Future’, also known as The Brundtland Report (Corporate Responsibility Report, 2010). The TBL concept is shown in Figure 2-2, with the social, environmental and economic bottom lines and their relations explained. The bottom lines are sometimes referred to as people, planet and profit and the TBL theory is then referred to as the 3P theory. The corporate responsibility strategy (CSR) of DPDHL is built around these three categories. Sustainability was first defined by the Brundtland Commission of the United Nations in 1987: they defined sustainable development in simple terms as paths of progress which meet the needs and aspirations of the present generation without compromising the ability of future generations to meet their needs (Brundtland, 1987). People, planet and profit succinctly describe the triple bottom lines and the goal of sustainability.
Sustainable measures for the fleet of DHL Express

Figure 2-2: The triple bottom line concept (Adams, 2006)

The social bottom line pertains to fair and beneficial business practices toward labour and the community and region in which a corporation conducts its business. A TBL company conceives a reciprocal social structure in which the well-being of corporate, labour and other stakeholder interests are interdependent. In concrete terms, a TBL business would pay fair salaries to its workers, would maintain a safe work environment and tolerable working hours, and would not otherwise exploit a community or its labour force. Regarding the social dimensions, DPDHL adopts a strict policy to avoid food competition when biofuels are used or examined. Food competition is also known as the 3F problem (Veringa Niemela et al., 2010): fuel with food or forest, where forest is sometimes referred to as fiber. Directly related to the 3F problem is the land-use problem. A more in-depth analysis of these problems is presented in the section 3.2. The safety aspect for society is an important aspect for DHL, considering the amount of kilometers driven by DHL vehicles. Several projects are conducted, for example the support of DHL for an asthma volunteering foundation for young people, which forms another example of the social dimension.

The environmental bottom line refers to sustainable environmental practices. A TBL company endeavors to benefit the natural order as much as possible or at least do no harm and curtail environmental impact. A TBL company reduces its ecological footprint by, among other things, carefully managing its consumption of energy and non-renewables and reducing manufacturing waste as well as rendering waste less toxic before disposing of it in a safe and legal manner. "Cradle to grave" is uppermost in the thoughts of TBL manufacturing businesses which typically conduct a life cycle assessment of products, to determine what the true environmental cost is from the growth and harvesting of raw materials to manufacture to distribution to eventual disposal by the end user. Life cycle analysis is very applicable on sustainable measures for the DHL vehicles and is further discussed in section 4.1.1. The environmental focus of DHL mainly concerns global warming via the CO₂ targets which are imposed by DPDHL headquarters, but apparently DHL also takes other emissions than CO₂ into account. These are more directly harmful to people than to the earth (e.g. nitrogen oxides (NOₓ) and PM).

The economic bottom line, also referred to as the profit dimension, is the economic value created by the organization after deducting the cost of all inputs, including the cost of the capital tied up (i.e. any capital that is not immediately accessible as money). It therefore differs from traditional accounting definitions of profit. In the original concept, within a sustainability framework, the economic aspect needs to be
seen as the real economic benefit enjoyed by the host society. It is the real economic impact the organization has on its economic environment. However, the economic dimensions within this study mainly consist of all the costs involved with the implementation of a sustainable measure. For technical measures, the profit dimension comprises the total cost of ownership (TCO) of a DHL Express vehicle. Elements comprised by the TCO which are relevant for this research are purchase costs, maintenance costs, (environmental) taxes or subsidies, fuel costs and insurances amongst others.

The program GoGreen has commenced within the parent company DPDHL in order to pursue the TBL concept. The goal of this program is to reduce CO₂-emissions, which are brought about by the operational management within DHL, with specific actions. GoGreen forms an integral part of the sustainability approach of DPDHL. The company has set the target to improving their carbon efficiency by 30% by 2020 compared to 2007. This includes emissions from subcontracted transportation. CO₂-emissions should have been decreased with 10% by 2012 (Corporate Responsibility Report, 2010). Although CO₂-emissions are mentioned specifically in the GoGreen target, other environmental effects (PM, NOₓ, SOₓ, raw material usage, waste, water usage, noise nuisance etc) are included in the GoGreen program too since 2010. Furthermore the company wants to comply with applicable international, regional and national environmental regulations and wants to develop and maintain an environmental management system which is ISO 14001 compliant. DPDHL wants to foster innovation and use advanced technologies to minimize atmospheric emissions and noise, particularly from their aircraft and vehicle fleets, thus this research may form a contribution for the company’s strategy.

The business unit DHL Solutions & Innovations (DSI) is established in 2009. DSI brings together existing fields of innovations within DPDHL, including the activities of the DHL Innovation Center in Troisdorf, Germany. The task of DSI is to develop innovative solutions and stimulate cooperation between divisions globally. This includes combining existing approaches and solutions, besides developing new technologies. The DHL Innovation Center is keeping up an overview with all the global DHL sustainability projects. Experiences of DHL divisions in several countries with sustainable measures are presented in this overview. Examples of these measures are biofuels, compressed natural gas (CNG), liquefied petroleum gas (LPG), ecotuning, electric and hybrid drivetrains, longer trucks and speed limiters. The purpose of this project is to stimulate divisions from different countries to share experiences, which may lead to divisions finding sustainable measures that fit in with their specific operations.

DPDHL supports the use of alternative fuels under the condition that they are produced sustainably. At this stage, DPDHL states that several factors hinder a sustainable production of liquid biofuels and these and the related risks need to be addressed: the support and usage of biofuels is only realistic if international regulations are set in place that ensure transparency throughout the entire production chain including a consistent life-cycle analysis. DPDHL calls for these international regulations and legislation to ensure such a sustainable and transparent production of biofuels. Until these requirements have been met, DPDHL will not use liquid biofuels other than in tests for research and development programs that protect the environment and further develop their sustainable logistics services. Therefore the company only conducts pilot projects to test the operational usability of future first generation plus, second and third generation liquid biofuels. These biofuel generation categories are explained in Figure 2-3 and in section 3.2. In particular, DPDHL does not support first generation liquid biofuels, as no advances are expected in the future.
2.3 Sustainability strategy in the Netherlands

The TBL concept can apparently also be found back in the sustainability strategy of DHL the Netherlands. DHL departments in every country have received targets from the mother company DPDHL. The five divisions together in the Netherlands received the following targets: 10% CO₂-efficiency in 2012 and 30% CO₂-efficiency in 2020 compared to 2007. However, DHL the Netherlands switched to electricity produced from renewable sources of energy in January 2010, resulting in a considerable reduction of CO₂-emissions. Therefore, the targets were nearly reached and thus not very challenging. The five divisions in the Netherlands acting as a collective decided to take an extra step in reducing CO₂-emissions and set a target of 20% CO₂-emissions in 2012 with a base line year of 2009. This means that the five divisions together need to reach the target. DHL the Netherlands thus has another vision than DPDHL’s headquarters. Another difference in the sustainability approach is that DHL NL sometimes clusters other environmental effects (particulate matter (PM), NOₓ and SO₂ emissions, raw material use, waste, water consumption, noise nuisance etc.) under an environmental management system according to the ISO 14001 standard, instead of under the GoGreen program.

DHL the Netherlands is trying to reduce CO₂-emissions from the fleet in various ways already. Newly purchased vehicles use state-of-the art technologies. Already 72 light-duty vehicles in the Dutch fleet are powered by natural gas. Natural gas thus fits in the sustainability strategy of DHL and is investigated as a sustainable measure in this research for the large goods fleet. Furthermore, tests are running within DHL with bi-fuel vehicles, where compressed natural gas (CNG) is injected together with the conventional...
Sustainable measures for the fleet of DHL Express

fuel, but technical issues still have to be solved. A considerable CO₂-emission reduction is still to be gained, for instance by reducing fuel consumption. A project has been conducted on economic driving, called Diamond Driver. Within this project insight was gained in the role and vision of drivers and the drivers were stimulated to drive more fuel-efficient. Furthermore, DHL has started to cooperate with the program ‘Duurzame Logistiek’ (sustainable logistics in Dutch) of Connekt, which is an independent network of companies and authorities aiming for more sustainable mobility in the Netherlands. DHL, amongst other companies, has received the ‘Lean and Green’ award. Companies which earn this award can count on privileges, e.g. access to environmental zones in large cities and longer allowed time-spans for deliveries.

2.4 Innovation implementation at DHL

The implementation process of sustainable fleet measures at DHL is discussed in this section. Innovation is critical for an organization. Organizations must grow and change, amongst others by adopting and implementing innovations, if they are to survive and prosper in a changing environment. Innovations typically impose changes in the way people work, what they need to do and how and that can be a real problem. Every innovation will have some kind of an effect on people. If changes affecting staff are significant or important, then the innovation has a potential to fail, not because the technology could not have worked, but because it did not work in practice.

The research paper ‘Toward a Framework of Innovation Management in Logistics Firms: A Systems Perspective’ presents a guideline for implementing innovations at logistics firms such as DHL (Shen et al., 2009). DHL is explicitly mentioned in the introduction of the article. Logistics firms and opportunities to adapt to a competitive marketplace are discussed. A framework is presented, the Enterprise Innovation System (EIS), wherein innovations are seen as a system which is composed of six elements. This framework is shown in Figure 2-4. Attention is also paid to the relations amongst these elements in the context of the systems theory. Furthermore, suggestions are mentioned how to manage an EIS to achieve systematic innovation and sustained innovation, in order to attain competitive advantages with strategic perspectives for logistics firms. Three innovation elements are discussed in the context of DHL: strategic innovation, organizational innovation and cultural innovation.

![Figure 2-4: Model of Enterprise Innovation System (Shen et al., 2009)](image-url)
Strategic innovation

The first element that is discussed is strategic innovation. Strategic innovation is defined as ‘the fundamental reconceptualization of the business model and the reshaping of existing markets (by breaking the rules and changing the nature of competition) to achieve value improvements for customers and high growth for companies’ by Schlegelmilch et al. (2003). The strategy of DPDHL has been changed in accordance with developments in the transport sector to a low-carbon future. An endeavour is made to meet demands for sustainable transport with the environmental protection program GoGreen. According to Li et al. (2005), logistics firms have to make strategic adaptations (or changes) to meet customers’ needs and adjust to the environmental changes, in order to be successful in the market competition. It is clear that logistics firms should respond to the growing need for environmental friendly transport, but regarding this research, environmental changes also include requirements from authorities. Examples of such requirements are limited time-frames wherein polluting vehicles may enter certain city areas or general prohibitions of access to certain city areas.

DPDHL does considerable investments in R&D. The business unit DHL Solutions & Innovations (DSI), described in section 2.2 is an example of this. The environment changes rapidly: the transport market demands more sustainable transport and the government sets up stricter emission regulations and other legislation on, for instance, city access and delivery time-frames. The sustainable fleet measures that are investigated in this research offer opportunities for DHL to deal with these environmental changes.

Organizational innovation

Organizational innovation is the second element of the EIS and is defined as the change and development of organizational forms of logistics firms, namely, the change of organizational structure and the transformation of relevant managerial modes in general’ (Woodman et al., 1993). Moreover, Shen et al. (2009) state that organizational innovation means the reconfiguration of enterprise resources and that the goals of organizational innovation are to create a flexible management structure and to break communication barriers amongst organizational departments and employees. This research mainly focuses on the reconfiguration of the fleet resources. However, implementation of the sustainable fleet measures covers the scope of various departments of DHL and therefore communication between these departments is necessary. The implementation of the sustainable measures may, for instance, deal with procurement, operations, R&D and corporate communications, thus communication barriers should be avoided.

Organizational inertia is one of the most important holdbacks in the transformation of strategy for continuous innovation (Shen et al., 2009). This inertia is mainly reflected by 2 levels: organizational structure and organizational culture (Nelson and Winter, 1982). Coordination and communication between departments is necessary to implement sustainable fleet measures. Figure 2-5 shows the departments of the Express division of DHL the Netherlands. The departments within the red circles are departments that are involved in the implementation process of sustainable fleet measures.
Sustainable measures for the fleet of DHL Express

Not only departments within DHL Express in the Netherlands need to mutually cooperate. The purchase of new vehicles is a process where the procurement department of parent company DPDHL is involved, thus a department at a higher organizational level. Therefore, coordination is also necessary between departments at cross-hierarchical levels within DPDHL.

Cultural innovation

The third element is cultural innovation. Culture generally focuses on common values and behavioural criteria within enterprises, where cultural changes amongst employees may be achieved through appropriate rational control and guide of emotion, in order to influence individual behaviour associated with the firm’s strategic intention (Hoffman, 1999). It is important to create understanding and awareness amongst DHL employees, in order to gain as much benefit as possible from the sustainable fleet measures. The right mindset and cooperation of a driver is essential regarding economic driving behaviour, but it is also important for e.g. driving a hybrid truck. A positive mindset of the driver towards fuel consumption reduction will result in appropriate driving characteristics, using the hybrid drivetrain optimally and this will lead to better CO$_2$-efficiency results. Furthermore, drivers should be explained why certain procedures may have changed in order to create understanding. Refuelling a natural gas vehicle, for instance, takes considerably longer, which may raise annoyance amongst drivers. An example of creating understanding is to show performance charts of fuel consumption reduction or CO$_2$-emission reduction over a certain period to drivers. This way, drivers see concrete results of their efforts.
Organizational culture is another aspect where organizational inertia can occur. 'New organizational forms or managerial attitudes initiate some reforms on task allocation, reporting lines and formal coordination mechanisms and interaction patterns. These reforms reshape some norms, rules and behavioural values, namely which characterize new culture. On the other hand, logistics firms have to create new synergic cultural ambience that will replace employee's old behavioural routines and institutional beliefs (Robbins, 1990).’ The task allocation for DHL drivers probably remains unchanged to a large extent for the measures that are investigated in this research. Changes that may occur are, for instance, a new sustainable vehicle that needs more or different inspections before starting the route, or refuelling the vehicle has to take place at another location and is more labour-intensive, which takes more time of the driver. Furthermore, especially behavioural routines regarding driving behaviour will have to change.

2.5 Summary

A summary of the company profile is presented in this section. Responsible operations and management are included in the business strategy of DPDHL. The approach of the company to sustainability is based on the triple-bottom-line concept (TBL). The program GoGreen has commenced within the parent company DPDHL in order to pursue the TBL concept. The goal of this program is to reduce CO₂-emissions, which are brought about by the operational management within DHL. The business unit DHL Solutions and Innovations (DSI) keeps up with sustainable developments outside and within DHL operations around the world. DHL the Netherlands is trying to reduce CO₂-emissions from the fleet in various ways, so this research may form an aid to achieve these reductions. The company has started to cooperate with the program 'Duurzame Logistiek' (sustainable logistics in Dutch) of Connekt, which is an independent network of companies and authorities aiming for more sustainable mobility in the Netherlands.

Several departments of DHL the Netherlands and DPDHL are involved in the implementation process of sustainable fleet measures. Coordination and communication between these departments is necessary to implement sustainable fleet measures, and the cultural aspect of implementing innovations is of major importance. Mindsets and behavioural values should be paid attention to in order to gain as much benefit as possible from sustainable fleet measures.
Sustainable measures for the fleet of DHL Express
3 Sustainability and the transport sector: the state of practice

The sustainable measures for the DHL heavy goods fleet that are investigated in this research are presented in this chapter. The set of measures is obtained from the cyclic process in Figure 3-1. This process comprises the selection of measures by repetitive feedback meetings with DHL as mentioned in section 1.4.2. The effects of the set of measures are investigated in order to examine which effects need additional research, since the effects of one measure may have larger impacts than another. The results of this investigation are submitted to DHL, where after certain effects are elaborated on more in-depth, in accordance with the desires of DHL. Subsequently a new set of measures develops by including or excluding measures and the cycle can be passed through again from the start. The cycle is passed through several times until enough insight in the possible effects of measures is gained and the demands of DHL are met, resulting in a satisfying set of measures.
Sustainable measures for the fleet of DHL Express

The starting point for the set of measures was a set which comprised alternative fossil fuels, electric and hybrid drivetrains, biofuels and aerodynamic improvements, since these are measures that offer viable opportunities for achieving harmful emission reductions (Nauclér and Enkvist, 2009). Three other measure categories have been added during the cyclic process described above, namely hydrogen drivetrains, driving behavioral measures and measures regarding a modal shift and consolidation of goods, in order to obtain a comprehensive set of measures. Aerodynamic improvements are combined with other vehicle measures such as rolling resistance and engine improvement measures under the fifth category 'other vehicle measures'. The set of measures that was obtained in the end is as follows:
This is a rough categorization, implying that these measures may comprise several sub-measures. An introduction is presented and the state of play is explained in the following sections for every measure. A more in-depth view is described in chapter 4, where the measures are assessed on the social welfare and operational criteria.

3.1 Alternative fossil fuels

Conventional fuels used for road transport vehicles are mainly gasoline and diesel oil which are fossil fuels. Fossil fuels are formed during processes which take millions of years and therefore sources become depleted. A transition from gasoline and diesel to LPG or natural gas as a fuel for road traffic vehicles may have benefits for certain contemporary environmental problems. However, liquefied petroleum gas (LPG) and natural gas are both fossil fuels and therefore the increasing scarcity of these fuels remains a matter of concern.

Compressed natural gas (CNG), liquefied natural gas (LNG) and LPG can be used as a fuel for petrol engines which are slightly adjusted or in dual-fuel diesel engines, where up to 80% diesel can be substituted. CNG and LNG are based on natural gas and consist mainly of methane, but also of residual gasses like nitrogen, propane and ethane (NaturalGas.org). LPG is synthesized by refining petroleum and consists mainly of propane and butane. CNG and LNG can easily be replaced by biogas (Stocchetti and Volpato, 2009), but currently there is no realistic green successor for LPG yet.

CNG is natural gas compressed to 200 bar and stored in compression tanks in gaseous state. Dual-fuel systems are available which offer the possibility to let the engine run on a mixture of diesel and CNG. These engines can also run on diesel solely which makes these vehicles less dependant on CNG refueling stations. CNG can also be mixed with hydrogen. Conventional engines can run on 20% hydrogen and 80% CNG. Another application of CNG is to integrate it in a hybrid-electrical drivetrain, which result in an even better emission performance (Edwards, 2006). CNG is already introduced amongst a small part of the fleet in the Netherlands. This part of the fleet consists of urban vehicles, namely Opels Combo and Iveco’s Daily and the vehicles operate well. Furthermore, CNG cars and vans are deployed at DHL in several other European and Asian countries amongst others. DPDHL states that CNG is most appropriate for urban fleets and trucks, but urban trucks are deployed for long-haul transport at night in the Netherlands, so the daytime advantages should be balanced with possible long-haul disadvantages.

LNG is natural gas which is cooled to around -150 degrees Celsius. LNG is stored uncompressed in liquid form by using a cooling process and cryogenic tanks and needs to be evaporated before it can be used in the engine. The fuel has the same energy density as diesel and gasoline, but less harmful matters are emitted when it is combusted. The processing of natural gas to LNG leads to a significant higher volume reduction than the compression of natural gas to CNG, thus the driving range of LNG vehicles is considerably larger when tanks of the same size are used (Stocchetti and Volpato, 2009). The storage
Sustainable measures for the fleet of DHL Express

temperature of LNG is between -120 and -170 degrees Celsius, which means that the storage tanks of a vehicle need to be cooled with a heat exchanger. The fuel is produced at 1 to 60 bar and the pressure is lowered after production in order to allow for storage and transportation of the fuel.

LPG is often confused with LNG and vice versa. Liquefied petroleum gas consists mainly of propane (C₃H₈) and butane (C₄H₁₀), and is primarily used for domestic and commercial applications (including as a vehicle fuel). The composition of LPG is 60% propane and 40% butane in summertime while in winter it is 70% propane and 30% butane. The reason for this that butane can be used when temperatures are above 0 °C, while propane can be used up to -42 °C. LPG is kept liquid by confining it under a high pressure. This contrasts with LNG which is liquid at atmospheric pressure but at a very low temperature (approx. 162 °C). Petroleum gas is much harder to compress than natural gas (Welink, 2010). The characteristics of LPG are also entirely different from those of LNG: natural gas is lighter than air so it rapidly disperses and becomes diluted in air, in contrast to the components of LPG which are heavier than air. The storage of LPG under pressure, in contrast to the storage of LNG at a very low temperature, necessitates the use of entirely different materials (different material properties, thicknesses, insulating materials) and standards.

The heat of combustion is the energy released as heat when a compound undergoes complete combustion with oxygen under standard conditions. The heat of combustion is a measure for the amount of energy per unit mass or per unit volume of a fuel and is sometimes referred to as the caloric value of a fuel. Generally this value is expressed as the higher heating value (HHV) or lower heating value (LHV), depending on whether the combustion products are cooled to 20°C and water is completely condensed (HHV) or whether they are cooled to a reference temperature and water will stay in gaseous state (LHV) (Welink, 2010). In practice and for engines the LHV is used (Claverton Energy Research Group), but both heating values can be used for comparing the energy per unit volume or per unit mass of a fuel. The HHV and LHV values per unit mass and per unit volume for several automotive fuels are shown in Table 3-1 (The Eclectic Site) (NIST Chemistry WebBook) (National Physical Laboratory) (Hofstrand, 2007). Values are approximations since fuel quality varies. An X means that the value could not be found in literature.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>LHV MJ/kg</th>
<th>LHV MJ/m³</th>
<th>HHV MJ/kg</th>
<th>HHV MJ/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>55</td>
<td>36</td>
<td>56</td>
<td>X</td>
</tr>
<tr>
<td>Natural gas</td>
<td>X</td>
<td>32</td>
<td>X</td>
<td>39</td>
</tr>
<tr>
<td>Biogas</td>
<td>50</td>
<td>20</td>
<td>X</td>
<td>26.500</td>
</tr>
<tr>
<td>LPG</td>
<td>45</td>
<td>24.500</td>
<td>50</td>
<td>X</td>
</tr>
<tr>
<td>Diesel</td>
<td>X</td>
<td>35.000</td>
<td>49</td>
<td>X</td>
</tr>
<tr>
<td>Gasoline</td>
<td>44</td>
<td>32.000</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

From this table it is clear that alternative fossil fuels offer promising energy-weight ratios compared to conventional fossil fuels, but the energy-volume ratio of gaseous fuels forms a problem, even when these gaseous fuels are compressed. This issue concerns CNG and compressed biogas (CBG) and is elaborated on in section 4.2.1 and 4.2.2, respectively. This issue is less relevant for liquefied gases (LNG, LPG and liquefied biogas (LBG)).

Dual fuel diesel-CNG engines operate in a mixed diesel/CNG mode. Up to 50% of diesel can be substituted with CNG (Gense, 2011, personal interview). The engine is able to switch to 100% diesel
Sustainable measures for the fleet of DHL Express

operation if CNG is unavailable, which makes it less dependent on infrastructure availability. Dual fuel projects currently focus especially on the truck sector. DHL and MAN have conducted tests in the Netherlands with dual-fuel. Results did not show satisfying CNG mix percentages (DHL and MAN Dual-fuel tests), because the routes were mostly urban. The highest mix percentages can be achieved on long-haul routes when the engine load is high for longer periods. As mentioned before, the DHL trucks are operated in long-haul routes at night for transport between the terminals, so dual-fuel may prove itself here.

Another form of fossil fuel use is gasification. A mixture of CO and hydrogen is produced by gasification or steam reforming of a feedstock and is called syngas, sometimes referred to as SNG (synthetic natural gas) or product gas. This syngas is a combustible gas and can be directly used as a gaseous fuel in Otto-engines. Any fuel can be gasified, for instance coal, but also different types of biomass waste. The drawback of using solid raw materials is that this material can not have high moisture content, i.e. less than 20% is desirable. Waste materials usually have large moisture content and therefore costly drying is necessary (Welink, 2010).

Syngas can also be used in the Fischer-Tropsch (FT) process. The FT process, a set of chemical reactions, converts syngas to a synthetic crude, which is then further refined into liquid fuels such as diesel and gasoline. The most famous feedstock materials used for FT conversion are coal, natural gas or biomass, also called coal-to-liquid (CTL), gas-to-liquid (GTL) and biomass-to-liquid (BTL) respectively. However, any fuel can be gasified as mentioned before.

3.2 Fuels from biomass

There has been a lot of effort to develop alternative fuels, which are widely seen as an important way to reduce both fossil fuel use and emissions. Especially in the segment of heavy goods vehicles (HGV's), they are key to realizing climate-friendly transportation. This is because promising new technologies (hybrid and electric vehicle technologies) will be considerably more effective in the smaller vehicle segment than for heavy-duty transportation. At the same time, trucks account for a large share of the logistics sector's carbon emissions. For example, while trucks represent just 20% of the entire DPDHL vehicle fleet, they account for 80% of the group's road emissions (DHL: Delivering Tomorrow, 2010). Biofuels play an important role in making road freight transport more sustainable. Road freight transport depends stronger on biofuels than passenger car transport, since the technical potential for emission reduction in road freight transport is in general smaller. Furthermore, biofuels are more suitable for long distance and heavy transport than (hybrid) electrical and hydrogen drivetrains, since the amount of biofuels is limited and other alternative energy sources are available for short distance and light transport (Hoen et al., 2009).

A fuel from biomass, or biofuel, is defined as solid, liquid or gas fuel derived from recently dead biological material and is distinguished from fossil fuels, which are derived from long dead biological material. A parallel can be drawn to the CO₂ cycle of these fuels: recently dead biological material recently absorbed CO₂ from the environment, long dead biological material absorbed CO₂ a long time ago. Both these absorbed amounts of CO₂ will be released in the environment again when the fuel is combusted. The CO₂ cycle of biofuels is thus referred to as short-cyclic, the cycle of fossil fuels as long-cyclic. Short-cyclic fuels logically contribute less to nothing to the world CO₂ problem.

In combustion terms, the amount of CO₂ generated by biofuels is similar to that of fossil fuels. Furthermore, the process of getting fuel from plants requires energy (heat and power) and in order to
obtain this energy CO₂ is generated, like with fossil fuels. However, raw material for biofuels has absorbed CO₂ before it reaches the processing plant but this absorption should not always be taken into account in the mass and energy balances. There is some controversy on this point as there are authors who maintain that the energy balance is negative while others say that it is positive. Sobrino et al. (2009) suggest taking into account the nature of the production of raw material. This is because it is not the same to create new crops than to use crop surpluses or to use waste when evaluating the mass balance and energy. In the first case the absorption of CO₂ in the mass balance must be taken into account but not in the second and third cases.

The biofuels discussed in this research are vegetable oils and animal fats, which are denoted with lipids from here, biodiesel, ethanol, Fischer-Tropsch (FT) biofuels, hydro-treated vegetable oils (HVO), dimethyl ether (DME) and biogas. This collection has been set up according to the range of biofuels discussed in literature (Edwards et al., 2006) (Ahlvik and Brandberg, 2002) (Baker et al., 2009). Biofuels can be categorized in first generation, second generation or even higher generation biofuels. Second generation and higher are sometimes referred to as advanced biofuels. Literature is inconclusive on the definitions, but generally first generation implies the (in)direct use of fuels produced from food-crops. Examples are biofuels based on vegetable oils, e.g. canola oil, palm oil, rape seed oil, soybean oil, and sun flower oil or biofuels made from sugar, corn or starch. Second and higher generation biofuels are generally produced from non-food crops, such as waste and/or cellulosic material like the stalks of wheat, corn or wood. Many second generation biofuels are under development.

First generation biofuels enhance the 3F problem. The world population is growing and this causes an increasing demand not only for energy, particularly with respect to transport, but also for food. When first generation biofuels are used, the raw materials can not be used for food production. This may lead to scarcity of these raw materials and subsequently in a large increase of food prices (Veringa Niemela et al., 2010). The 3F problem comprises multiple issues. There is not only less material available for food production but also for cattle feed production. Furthermore, there is a risk that more and more farmland land will be used for the cultivation of biofuels instead of growing food crops. This is called the land-use problem. Besides direct land-use change, there is also an indirect land-use change problem. Apart from production-chain emissions, biofuels from agricultural crops can generate greenhouse gas emissions by changes in the organic carbon content of soil, due to land-use change. This can occur directly in the field where crops are cultivated, but also indirectly. For example, corn used for ethanol that is planted on a country’s farmland that was formerly used for growing cereals may induce soil carbon losses through the conversion of forests into arable land elsewhere in the world, to maintain food production. Advanced second-generation biofuels cause significantly less fuel-food competition and average GHG-reductions are significantly better, but these fuels will only be available in large quantities from 2020. Furthermore land-use change may still be an issue with these fuels (Hoen et al., 2009). Direct and indirect land-use problems are complex investigation matters (Börjesson and Tufvesson, 2010) (Searchinger et al., 2008).

There are more environmental drawbacks concerned with biofuels. Sugar beet can cause soil erosion and the heavy machinery used for harvesting sugar beet can cause soil compaction in wet areas. Furthermore, continually removing straw instead of incorporating it in the soil will decrease the soil organic content, leading to poorer moisture retention. Another issue is that intensive agriculture using fertilizers tends to cause eutrophication and acidification. Increased crop production for biofuels would tend to exacerbate this problem. Regarding biodiversity, growing energy crops instead of permanent crops would decrease biodiversity (energy crops are plants grown as a low cost and low maintenance harvest used to make biofuels, or combusted for their energy content to generate electricity or heat). A 2004 study by the European Environmental Agency concluded that the negative
biodiversity impacts are high for rape, medium for sugar beet and low to medium for short rotation forestry. The use of wood residues was considered to have no impact. Pesticide use also affects biodiversity. Furthermore, the increased growth of crops requiring extensive irrigation in arid areas will put pressure on water resources and increased cultivation of trees can lead to a lowering of the water table, which can have significant impact on the natural environment in the area concerned (Edwards et al., 2006).

**Vegetable oils and animal fats (lipids)**

Most literature considers the term biodiesel as the esterified product of lipids (see next section), thus the direct use of lipids is not regarded as biodiesel in this report, but as a separate category of biofuels. Examples of lipids are canola oil, palm oil, sunflower oil and rape seed oil. Vegetable oil can be further categorized into waste vegetable oil (WVO), if it is the oil that was discarded from a restaurant or straight vegetable oil (SVO), also called pure plant oil (PPO) to distinguish it from biodiesel.

**Biodiesel**

The technical definition of biodiesel is a fuel suitable for use in compression ignition (diesel) engines that is made of fatty acid mono-alkyl esters derived from biologically produced oils or fats including vegetable oils, animal fats or microalgae oils. When biodiesel is produced from these types of oil using methanol, fatty acid methyl esters (FAME) are produced. Several vegetable oils are suitable for the production of FAME.

A well-known example of a FAME is RME (rapeseed methyl ester). Biodiesel fuels can also be produced using other alcohols, for example using ethanol to produce fatty acid ethyl esters. The properties of FAMEs approximate the properties of mineral diesel when a PPO is converted to biodiesel and they meet the requirements of being used in modern diesel engines (Diesel Büchli B.V.) (Nwafor, 2004).

**Ethanol**

Ethanol is traditionally produced by fermentation of sugars. The fermentation process produces alcohol at a fairly low concentration in the water substrate. Purification of the ethanol by distillation is fundamentally energy-intensive. In recent years there has been a lot of interest in processes to convert cellulose into ethanol via separation and breakdown of the cellulose into fermentable sugars. Such routes potentially make a much wider range of crops available including woody biomass in all shapes or form as well as by-products such as wheat straw or sugar beet pulp. These routes contribute considerably less to the 3F problem compared to using sugars. It must be realized that no such process has been proven at commercial scale. In such schemes the biomass input of the conversion plant includes non-cellulose material (e.g. the lignine of the wood) which is best used as an energy source. As the conversion energy represents most of the total energy requirement of the complete pathway, these pathways use very little external (fossil) energy (Edwards et al., 2006).

The European approval with specification EN228 allows for the use of ethanol up to a blend ratio of 5% ethanol (E5). It is generally accepted that engines developed and tuned for conventional gasoline can run with gasoline containing up to 5% ethanol without adverse short or long term effects (Edwards et al., 2006). However, ethanol is not only applicable in gasoline engines. Scania has developed an engine for buses, which is derived from a diesel engine and can run on a blend of 95% ethanol (E95). Furthermore, it is possible to use ethanol in conventional diesel engines. This fuel is called E-diesel and can be blended up to a percentage of 10% ethanol (Schone Voertuigen Adviseur). In theory, ethanol can be used in pure
Sustainable measures for the fleet of DHL Express

form for transport fuel. However, the reality is that most of today’s engines are not designed to use it (Shell International Limited, 2007).

FT

Any fuel can be gasified as mentioned in section 3.1, so also different types of biomass waste. The FT process can be used to convert the syngas mixture into liquid hydrocarbons. This synthetic crude is then further refined into liquid fuels such as diesel and gasoline, which is called biomass-to-liquid (BTL) when biomass is used as a feedstock. The pulp and paper industry may provide a promising route for making significant amounts of synthetic fuels from woody material. This is the so-called “black liquor” (BL) route. Black liquor is a by-product of paper pulping that contains the lignin part of the wood. The efficiency of the FT process is low in general: about 55% of the energy content of the raw material is converted into fuel (Welink, 2010).

HVO

Another renewable diesel similar to FT is hydro-treated vegetable oil (HVO), branded NExBTL by oil company Neste Oil, and is produced by hydro-treating vegetable or waste oils or animal fats. Feedstocks are rapeseed, palm oil, soybean and animal fat. As a hydrocarbon it corresponds to the chemical composition of traditional diesel. HVO’s are high-quality paraffinic diesels resembling synthetic fuel and similar to BTL (Murtonen and Aakko-Saksa, 2009). The process reduces hydrocarbons that make up HVO, and ensures that the diesel is free of oxygen and aromatic compounds. It can be produced flexibly from a mix of vegetable oils and waste animal fats sourced from the food industry (Neste Oil). Significant parts of the global warming potential (GWP) of HVO originate from emissions from soil during the agricultural phase (Edwards et al., 2007) (Johansson et al., 2008). Emissions from soil give a significant contribution to eutrophication, a larger contribution than all other processes combined. Emissions from soil also give a large contribution to acidification (Arvidsson et al., 2010).

DME

Dimethyl ether (DME) is produced in the same way as FT fuels (Larson and Tingjin, 2003). DME is to diesel what LPG is to gasoline. It is gaseous at ambient conditions but can be liquefied at moderate pressure. It has very attractive characteristics as a fuel for compression-ignition engines, burning very cleanly and producing virtually no particulates. DME is synthesised from syngas and can therefore be produced from a range of feedstocks. The most likely feedstock in the short term is natural gas but coal or wood can also be envisaged. The black liquor route is eminently suitable for DME and is in fact more likely to be developed to produce these fuels rather than BTL, chiefly in Scandinavia. The higher efficiency of the synthesis process gives DME a slight advantage on the synthetic diesel fuel from the same source. In the DME process, the sole product is DME which translates into high yield of fuel for diesel engines compared to FT diesel in the case of which other products (mostly naphtha) are also produced (Edwards et al., 2006). A pilot with DME for heavy trucks has commenced in the autumn of 2010 at DHL Sweden.

Biogas

Earlier in this report it was mentioned that, in the long run, CNG is often regarded as a transition option. It is regarded as a predecessor for more sustainable and long-term options, such as biogas. Biogas can be produced from landfills or from digestion of biomass residues, for instance at water treatment
installations, and can be upgraded to natural gas quality by removing the H₂S and the greater part of the carbon dioxide. This upgraded gas is called green gas and can be used as a transport fuel, but it is also available for electricity generation or for heating and cooking in the built environment by inserting it in the low pressure local gas network. Some sources claim that the availability for making transport fuel is much less than the availability for energy use (Edwards et al., 2006), but other sources argue that (Gense, 2011, personal interview). Biogas as a transport fuel needs to be compressed (CBG) or liquefied (LBG). The specific energy per unit volume and per unit mass of CBG is shown in Table 3-1 in section 3.1 and is elaborated on in section 4.2.2.

3.3 Hydrogen

Hydrogen can be used in a fuel cell, as a fuel or as a supplementary fuel in modern spark ignition engines without major changes. Furthermore, hydrogen has been shown to be an excellent additive in relatively small concentrations, to some common fuels such as methane. Fuel cells convert the chemical energy of hydrogen into electrical energy that can be used to power the vehicle and the by-products are virtually only water and heat (it is an exothermic reaction). Another application for fuel cell technology on heavy-duty trucks could be auxiliary power units for managing hotel loads. Producing hydrogen demands energy and in order to consider the whole life cycle, it is necessary to take into account the CO₂-emissions when generating this energy. These emissions depend on the way this energy is produced. Various pathways for producing hydrogen are shown in Figure 3-2 (Baker et al., 2009). According to Hoen et al. (2009), the amount of CO₂-emissions depends strongly on the possibility of CO₂ capture and the developments of wind energy.

![Figure 3-2: Hydrogen production pathways (Baker et al., 2009)](image)

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3.4 Electric and hybrid drivetrains

A hybrid vehicle is a vehicle that uses two or more distinct power sources to move the vehicle. The term refers to hybrid electric vehicles (HEV's) in this report, which combine an internal combustion engine and one or more electric motors. Several categories are mentioned in literature regarding HEV's. Jeon (2010) claims that there are three different types of HEV's: mild hybrids, full hybrids and stop-start systems. The main difference between the first two types is that a full hybrid can be propelled by the electric motor only. Plug-in hybrid electric vehicles (PHEV's) can be plugged into an external electric power source, such as the electrical grid for charging. Current HEVs reduce fuel consumption under certain circumstances primarily by using five mechanisms (Jeon, 2010):

1. Reducing wasted energy during idle/low output, generally by turning the internal combustion engine (ICE) off.
2. Recapturing waste energy (i.e. regenerative braking)
3. Reducing the size and power of the ICE, and hence inefficiencies from under-utilization by using the added power from the electric motor to compensate for the loss in peak power output from the smaller ICE.
4. Moving the vehicle by using the electric motor
5. Charging the battery via the grid instead of by using the conventional combustion engine

Any combination of these five primary hybrid advantages may be used in different vehicles to realize different fuel usage, power, emissions, weight and cost profiles. It must be noted that mechanism one is also applicable on conventional ICE's. The ICE in an HEV can be smaller, lighter and more efficient than the one in a conventional vehicle, because the combustion engine can be sized for slightly above average power demand rather than peak power demand. The drive system in a vehicle is required to operate over a range of speed and power, but an ICE's highest efficiency is in a narrow range of operation, making conventional vehicles inefficient. In contrast, in most HEV designs, the ICE operates closer to its range of highest efficiency more frequently. The power curve of electric motors is better suited to variable speeds and can provide substantially greater torque at low speeds compared with internal-combustion engines. Most designs combine a large electrical generator and a motor into one unit, often located between the combustion engine and the transmission, replacing both the conventional starter motor and the alternator. To store power, a hybrid uses a large battery pack with a higher voltage than the normal automotive 12 volts. Accessories such as power steering and air conditioning are powered by electric motors instead of being attached to the combustion engine. This allows efficiency gains as the accessories can run at a constant speed, regardless of how fast the combustion engine is running. The benefits of electric motors mentioned in this section also apply for full electric vehicles.

A thorough life cycle impact assessment of PHEVs would potentially estimate acidification, eutrophication, photochemical smog, terrestrial and aquatic toxicity, resource depletion, land and water use, and perhaps additional impact categories. While the environmental fate and toxicity of current battery technology materials are not similar to those of lead-acid batteries, potential toxicity during materials procurement and battery manufacturing, and a strategy to deal with the recovery, recycling, and disposal of vehicle batteries should be part of the dialogue in a transition to large-scale adoption of storage batteries in vehicles (Hoen et al., 2009) (Samaras and Meisterling, 2008).

The ICE and the friction brakes are replaced with an electric motor in full electric vehicles. Electric motors offer the same advantages to delivery vehicles as most of the mechanisms in the enumeration for
Sustainable measures for the fleet of DHL Express

hybrids, mentioned earlier in this section. Furthermore, there is no need for gearing which reduces friction losses between the engine and wheel.

Various types of batteries are available for electric and hybrid vehicles. Lithium-ion and sodium-nickel chloride are the better ones regarding environmental impact (Matheys et al., 2006). Vehicle-to-grid technology (V2G) technology would make it possible for utilities to use the storage capacity in the batteries of parked vehicles to make the grid more reliable. In a V2G system, utilities would compensate plug-in electric vehicle owners for the use of their batteries, and set up systems that would ensure that the cars are fully charged when their owners need them. The large amount of electricity storage capacity that plug-in vehicles would provide could make it possible to use more wind and solar power than our grid can currently support (Kaplan and Sargent, 2010).

3.5 Other vehicle measures

A large number of sustainable measures for vehicles is available besides the measures that were discussed in the previous sections. Some of these measures will be presented in this section. These measures are generally less drastic than the measures in the previous sections.

The fuel consumption of a truck can be categorized into various energy consuming processes. Figure 3-3 (Filippone and Mohamed-Kassim, 2009) shows a graph where fuel consumption is split up according to these processes. Fuel consumption is shown on the vertical axis in liter per 100 km and driving cycles are shown on the horizontal axis, where LHDC stands for Long-haul Driving Cycle and NEDC for New European Driving Cycle (i.e. an urban driving cycle). Two trucks are visualized: one with a mass of 40 tons and another one which weighs 20 tons. It turns out that aerodynamic drag and rolling resistance account for a large share of fuel consumption. Joseph-Bachman et al. (2005) indeed show that at a steady speed of 65 miles per hour on a flat road, aerodynamic drag and rolling resistance account for 21% and 13%, respectively, of the total energy used by a class 8 heavy-duty tractor trailer. Measures regarding aerodynamic drag and rolling resistance will be discussed in this section. Vehicle measures that concern driving behaviour, for instance speed or revenue limiters and intelligent technologies using vehicle telematics, are categorized under driving behavioural measures in section 3.6.
Sustainable measures for the fleet of DHL Express

Conventional diesel engine technologies can be further improved. Another engine-related measure is ecotuning. This comprises a different configuration of the engine management in order to obtain a better fuel economy. Furthermore, small losses occur in the transmission and axles in the powertrain. Although some friction reduction is possible, the biggest gains are available by deploying smart, advanced transmissions carefully matched to the engine and truck (Sperling and Cannon, 2010).

Significant progress has been made recently in advancing low rolling resistance and single-wide truck tires. Since about 30 percent of a truck’s energy demand is due to rolling resistance, every 3 percent reduction in rolling resistance translates into 1 percent vehicle fuel savings. The lowest rolling resistance is accomplished by replacing dual wheels on the rear tractor axles and trailer axles with wide single wheels and tires. Dual wheels are currently used in order to spread the load and to obtain enough grip and comfort. Replacing a set of dual wheels by one single wide tire with a lower height/width ratio and a lower profile on an axle results in a lower weight (and therefore offering a higher payload) and a height saving of 30 mm. Furthermore, heat is generated in only two tire sidewalls instead of four, resulting in less energy losses. Compared to conventional tires, single wide tires have the same axle loading and a comparable wear rate, but a lower rolling resistance and a reduction in fuel consumption. Higher gains in fuel economy are expected, but care must be taken to avoid loss of tire safety, durability, and traction (Sperling and Cannon, 2010).

Tyre pressure monitoring systems (TPMS) measure tyre air pressure with sensors attached to the tyre, wheel, or valve stem and let the driver know when tyres are under-inflated, so that corrective measures can be taken. Underinflated tyres can run hot and result in excess fuel consumption due to increased rolling resistance. It also causes tyres to wear more quickly and in extreme cases may cause crashes by causing tyre blow outs or reduced grip or stability. Some systems may be integrated with tyre pressure equalizer or maintenance systems that monitor and automatically inflate tyres to pressure suitable for the operating conditions (Christensen et al., 2010).

Optimizing the aerodynamics is important, because up to 30% of the truck’s fuel consumption is caused by the aerodynamic drag. For trucks traveling at high speed, the aerodynamic drag becomes even more relevant. There are various aerodynamic measures available. One is the Teardrop Trailer. This is a trailer with a special teardrop-like shape that guides the airflow in a more efficient way. Furthermore, there are less radical measures such as spoilers and side skirts. The company Ephicas produces a side skirt under the name Sidewing and DHL has conducted tests with these Sidewings.

Figure 3-3: Fuel consumption categorization for two trucks in two driving cycles (Filippone and Mohamed-Kassim, 2009)
Another vehicle measure is the longer and heavier truck (LHV), which is ‘langere zwaardere vrachtautocombinatie’ in Dutch (LZV). These vehicles use more fuel than regular trucks, but this is overcompensated by the larger amount of goods that can be transported, since fewer trucks are needed when higher volumes of goods need to be transported.

3.6 Driving behaviour

Truck drivers have a major influence on the fuel economy of a truck. Driving behaviour can be influenced with various strategies. Figure 3-4 from Reimer et al. (2009) provides an overview of deployable management systems. These are systems which:

- prioritize information delivery
- reduce workload
- alert the inattentive or fatigued driver of the need to attend to an immersing situation
- take over automatic control of braking or steering as appropriate for the context such as an imminent collision.

Behavioral measures can be advisory or enforcing and technical or non-technical. Examples of advisory measures are driving trainings (non-technical) and feedback to the driver via systems that log all kinds of driving characteristics, e.g. acceleration and deceleration rates or engine revolutions (technical). Examples of enforcing measures are a speed limiter and a throttle pedal with variable resistance giving haptic feedback. Intelligent vehicle systems that log driving characteristics are sometimes referred to as telematic systems, though telematic systems pertain more to the technology of sending, receiving and storing information via telecommunication devices in conjunction with effecting control on remote objects. Intelligent vehicle systems are sometimes also referred to as Onboard Monitoring and Reporting Systems (OBMS). Information about the driving behaviour can allow truck drivers to significantly reduce
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fuel consumption, improve their attentiveness and enhance their driving safety performance. Also other potential benefits may be identified, such as a less stress (Christensen et al., 2010).

3.7 Modal shift and consolidation

Intermodal freight systems are commonly defined as freight transport systems consisting of two or more modes of transport used in door-to-door trips for consolidated loads (i.e. containers, swap bodies, and trailers or semi-trailers). Figure 3-5 (Kim and van Wee, 2008) represents a geographic distinction of intermodal freight systems and truck-only systems based on the door-to-door container trip. Intermodal freight systems have three main stages: drayage, terminal operation (transshipment), and long-hauling. Drayage is the movement of loads to or from an intermodal terminal for collection from shippers and distribution to consignees by trucks. At an intermodal terminal, loads are transshipped from truck to wagons, and vice versa. Long-hauling is the transportation of loads from the intermodal terminal of origin to the destination intermodal terminal. A considerable reduction in emissions can be achieved on these long-haul stretches by using another mode than truck, but also by using a longer and heavier truck (LHV). These longer and heavier trucks are not appropriate for small streets and high density traffic area's (e.g. inner cities) due to their weight and dimensions, but most regional roads and freeways do not cause problems. The door-to-door distance in an intermodal system for a container movement is different from the truck-only system. Intermodal freight transportation systems are regarded to be more environmentally friendly than truck-only freight systems, particularly for long-distance haulage based on vessel (short sea or inland waterway) or rail and in terms of CO₂-emissions.

Figure 3-5: Conceptualization of intermodal freight transport system and truck-only systems (Kim and van Wee, 2008)
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The option for intermodal transport may only be feasible at night for the long haul terminal to terminal traffic. A complete modal shift from truck to rail or to barge is not feasible, since the DHL terminals in the Netherlands are badly connected to the railways and waterways network (Jacobs and van der Kolk, 2011, personal interview). There used to be a railway connection to a considerable amount of terminals in the past when DHL the Netherlands was Van Gend en Loos, but many of those connections have disappeared. Nowadays trucks would have to drive to an intermodal transshipment terminal where containers can be transferred from truck to train and vice versa. Generally, heavy equipment such as cranes and straddle carriers are needed to perform these transshipment operations, making these terminals complex and expensive and therefore these terminals can not be found everywhere. However, loading and unloading operations from truck to train and vice versa could also be performed with smaller-scale systems such as the ACTS system. ACTS is the Dutch abbreviation for ‘Afname Container Transport Systeem’. An illustration of the system is shown in Figure 3-6. Intermodal transport may be more feasible for DHL when transshipment terminals using smaller-scale systems like the ACTS system are used, since these terminals are less complex, less expensive and they could be closer to a DHL terminal.

![Figure 3-6: ACTS working principle](image)

The ACTS-system is made up of three elements:

1. wagons with 3 swivel frames each
2. a lorry with a hook- or chain system
3. ACTS containers

With help of the hook or chain the containers are pulled on or pushed off the wagon. During the loading/unloading procedure, the swivel frames are opened to an angle of 37 to 45 degrees. At the side of the wagon a space of around 12 meters width is needed for the movement of the truck. The whole operation takes not more than 2 minutes (ACTS, 2010).

An estimation is made with calculations using data of DHL that there are around 46.000 km’s of nighttime long-haul transport on distances of 100 km or more on one stretch per night, which means that there are opportunities for intermodal transport by truck, rail and barge. However, options for DHL the Netherlands strongly depend on the time criticality of transported goods. For instance, transportation schedules for food products are tight and longer travel times as a result of intermodal transport are not allowed. Rail transport is used at DHL in Belgium and Germany, but in Belgium it concerns long-distance international transport. Germany can not be compared with the Netherlands, since transportation distances are considerably larger there.

Consolidation of goods is the bundling of several smaller shipments from different companies in one vehicle. The shipments are assembled and shipped together to achieve better load factors, amongst
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others. Goods can be consolidated at the client deliveries and pickups at day time, which is sometimes referred to as last-mile transport. Consolidating last-mile goods may reduce inner city traffic. The terminal to terminal transport in the night may also be suitable for consolidation of goods.

3.8 Summary and conclusions

Summary

The sustainable measures for the DHL heavy goods fleet that are investigated in this research were presented in this chapter. A cyclic process comprising surveys with DHL was used to obtain a set of measures. The following set resulted from this process:

1. Alternative fossil fuels
2. Fuels from biomass
3. Hydrogen
4. Electric and hybrid drivetrains
5. Other vehicle measures
6. Driving behaviour
7. Modal shift and consolidation

This is a rough categorization, implying that these measures may comprise several sub-measures. An introduction to these measures was presented and the state of play was explained in this chapter.

Conclusions

The repetitive improvements and elaboration on the measures resulted in a comprehensive set of measures with state-of-the-art characteristics. Difficulties emerged in which measure to include and which not, but the final set of measures complied with the demands of DHL and comprised a considerable amount of measures which are regarded promising amongst measures found in literature. Interviews with experts from the field confirmed that no relevant measures were omitted (Gense, 2011 personal interview) (ten Tuynte, 2011, personal interview).
4 Assessment of measures: specification of criteria and application on measures

This chapter provides an answer on the second and third sub research question, together with chapter 3 and chapter 5. This chapter and chapter 5 together form a multi-criteria analysis for the inventory of measures. First, an introduction is presented wherein it is explained why the MCA is conducted. The criteria are described in section 4.1 and the inventory of measures is assessed on these criteria in section 4.2. A two-stage multi-criteria analysis (MCA) evaluation is conducted in chapter 5 to review the assessment from this chapter with a brief overview and to make a selection of the measures.

Multi-criteria analysis is a methodological approach for the comparative assessment of alternative actions with respect to multiple and possibly conflicting evaluation aspects (Perimenis et al., 2011). MCA techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities. Multi-criteria analysis establishes preferences between options by reference to an explicit set of objectives that a decision making body has identified, and for which it has established measurable criteria to assess the extent to which the objectives have been achieved (Dodgson et al.). The aim of the MCA in this report is to rank sustainable measures for the heavy goods fleet of DHL the Netherlands, in order to make a selection of these measures. The measures which will remain after this selection will be elaborated on in the design phase of the research in chapter 6.

The assessment in this chapter is used to set up a decision tree for DHL. This decision three forms an aid for the decision-process of purchasing new large goods vehicles, which may use technologies from the sustainable measures that are assessed in this chapter. The information from section 4.2 is used as a basis for the decision tree. The tree itself is not part of research and thus not included in this report.

4.1 Criteria

The key criteria on which the sustainable measures are assessed can be divided in two categories: criteria which are related to social welfare and criteria that are imported for the operational management of DHL. The first category comprises five criteria, namely well-to-wheel greenhouse gas emissions, PM and NO\textsubscript{X} emissions, the 3F and land-use problem, safety issues and noise nuisance. An elaborate view on these criteria is presented in sections 4.1.1 to 4.1.5, respectively. The second category also comprises five criteria: costs, availability, usability, lock-in problems and public perception, which are elaborated on in sections 4.1.6 to 4.1.10, respectively.

Social welfare criteria

4.1.1 Well-to-wheel greenhouse gas emissions

Well-to-wheel greenhouse gas (GHG) emissions are the GHG emissions over the whole chain of a measure, thus including e.g. emissions from fuel-making processes and emissions from power plants generating electricity for electric vehicles. The primary research objective of this thesis concerns the
emission of CO₂. The most important greenhouse gas is CO₂ as explained in chapter 1 and therefore the assessment focus is primarily on this greenhouse gas, but other greenhouse gases and harmful emissions are not omitted. Emissions playing an important role locally are discussed in the next section. An important instrument to assess sustainable measures is the life cycle analysis (LCA) method. LCA is a method to map the influence of products and human activities on the environment (RIVM, 2010). The entire life cycle of a product or activity is investigated in an LCA, from the extraction of raw materials via production and (re)use up to disposal. In other words: from cradle to grave. LCA is considered as a type of chain analysis since a chain of processes is investigated. Closely related to LCA is the well-to-wheel (WTW) approach. A WTW approach is the specific LCA used for transport fuels and vehicles. The analysis is often broken down into stages entitled well-to-tank and tank-to-wheel. The first stage incorporates the feedstock or fuel production and processing and fuel delivery or energy transmission, the second stage deals with vehicle operation itself. The well-to-wheel analysis is commonly used to assess total energy consumption or energy conversion efficiency and emissions impact of e.g. motor vehicle, marine vessels and aircrafts emissions, including their carbon footprint and the fuels used in each of these transport modes. The LCA and WTW method have been used for assessing greenhouse gas emissions in this report. Examples of aspects that have to be included in the LCA or WTW assessment of measures are transportation of fuels, machinery used for cultivation of crops and refinery operations.

4.1.2 PM and NOx emissions

Particulate matter (PM), also known as particulates, fine particles or soot, and NOx, nitrogen oxides are both emissions produced during combustion and are harmful to people above certain levels. The problems resulting from PM emissions have nearly been resolved in the Netherlands. However, Beijk et al. (2007), state that the decrease of PM levels can not be determined for the last seven years. Wesseling and Beijk (2008) also mention inconclusive measurement results for PM and NOx emission trends on street level in the period 2000 to 2007. Conventional vehicles hardly emit any PM. The emission of NOx is still a problem in the Netherlands even though NOx emissions have been decreasing from 570 kiloton in 1990 to 400 kiloton in 2002 (Janssen et al., 2006). The problem is even bigger than was assumed because truck performance results from practice are not satisfying compared to results from approval tests. This mainly holds for Euro 5 and enhanced environmentally friendly vehicles (EEV), where EEV is a stricter version of Euro 5. The world harmonized duty cycle (WHDC) is used for heavy-duty engine validation. NOx emissions are measured at the exhaust exit, consisting of the relevant emissions NO and NO2 since NO3 and NO4 do not remain in the air but bond easily. NO emissions are harmless to humans since it transforms into NO2 in the open air which takes approximately one hour and is then diluted enough not to be harmful for people. However, direct NO2 emissions are harmful. A problem is that NO2 is measured in the open air while NOx is measured at the exhaust exit. The consequence is that NO2 and PM emissions decreased but the share of NO2 in exhaust fumes is considerably high, compared to the past when mainly NO was emitted (Gense, 2011, personal interview). A dilemma is the balancing of fuel consumption (and thus CO2 emission) and NOx emission. Keeping the engine temperature low yields low NOx emissions, but also deteriorates the engine efficiency and thus fuel consumption. The Dutch government now emphasizes more on NO2 for reasons mentioned above. An example of this policy is the introduction of environmental zones in large cities, where trucks should meet certain emission standards in order to be granted access. A sustainable measure which scores well on the criterion in this section may thus offer opportunities for DHL regarding city entrance allowance. Several technical measures have reduced emissions from diesel trucks in the past years, e.g. high injection pressures for cleaner and more efficient combustion and exhaust gas recirculation (EGR) systems in order to decrease NOx emissions. These systems are implemented on nearly every new truck. At the end of the nineties, oxidation catalytic converters have been introduced to decrease hydrocarbon
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and small amounts of PM emissions. Recently particulate filters have been implemented resulting in considerably low PM emissions. The focus today is on NO, and CO\textsubscript{2}. Urea is injected in the engine with selective catalytic reduction (SCR) systems. Urea, for which the trade name is AdBlue, decomposes into water and ammonia, which reacts with NO, resulting in water and nitrogen. SCR systems are already used in the fleet of DHL. However, a major drawback is the lack of AdBlue infrastructure resulting in detours and thus more fuel consumption. The EEV norm is feasible for trucks with less than 300 horsepower (hp) by using intensive EGR and a particulate filter. SCR systems will be required for larger engines to meet Euro 5 and EEV. Nearly every truck will be required to have an SCR system to meet the future Euro 6 standard. The relevance of emissions other than CO\textsubscript{2} is clear. The main criterion for assessing the sustainable measures is the emission of CO\textsubscript{2}, but NO, en PM are not omitted, nor other environmental impacts.

4.1.3 The 3F and land-use problem

When raw vegetable materials are used for producing biofuels, they can not be used for food production. This may lead to scarcity of these raw materials and subsequently in a large increase of food prices. The competition between food and biofuels is also known as the 3F problem: fuel with food or forest, where forest is sometimes referred to as fiber (Veringa Niemela et al., 2010). Directly related to the 3F problem is the land-use problem. There is a risk that more and more farmland land will be used for the cultivation of biofuels instead of growing food crops. The 3F-problem, land-use change problem and the DHL strategy regarding these problems are elaborated on in chapter 2 and 3. Sustainable measures should comply with the vision of DHL regarding these problems. This implies that there should be no competition with food supply and no increase of greenhouse gas emissions as a result of direct or indirect land-use change.

4.1.4 Safety issues

Maintaining a safe work environment is part of the triple bottom line concept. A sustainable measure should not only allow for safe operations for DHL employees such as terminal personnel and drivers, but also for other traffic participants and concerned actors, e.g. residents living nearby a refueling station. Operations that should be conducted in a safe way are amongst others transportation and storage of fuel, which may be accomplished by using adequate staff training.

4.1.5 Noise nuisance

DHL has no problems to comply with noise regulations in the Netherlands, since the vehicles do not enter the city at night. However, noise regulations are subject to continuously changing policies and noise is universally perceived as a negative factor affecting human well-being. Noise sources plague everyday activities, making life less pleasurable and slowly eroding overall health in ways that are difficult to observe in the short term. Attempts to quantify the health damages caused by traffic noise yielded valuable results from an academic point of view (Franco et al., 2010). Therefore noise nuisance should be kept as low as possible, also where regulation lacks or falls short. The potential allowance of entering areas at specific times also remains a benefit of producing less noise.
Operational criteria

4.1.6 Costs

The cost criterion can be summarized as the return on investment: costs and savings in the time-span of vehicle ownership. Costs play an important role in the decision making process. Measures may be adopted or excluded depending on their financial performance. It can be hard to allocate costs to a measure which comprises areas which are not yet explored thoroughly, e.g. measures using advanced technology. Furthermore, initial purchasing costs may be high, but these can be compensated by savings during the usage phase of the vehicle, for instance low fuel prices or a high fuel efficiency of the vehicle. Therefore, the total cost of ownership (TCO) is an important concept for the cost criterion. Examples of TCO elements are purchase costs, maintenance costs, (environmental) taxes or subsidies, fuel costs and insurance costs amongst others. It should be noted that the value after depreciation of most vehicles with state-of-the-art technology is a difficult issue, since no experience is gained yet on this topic in general.

4.1.7 Availability

The availability criterion is used to assess measures on last-stage difficulties before implementation. The availability criterion is a go/no go criterion and therefore the multi criteria analysis only deals with measures that are available at present or in the short term. Information about longer-term developments is thus only included in this chapter as background information.

Sustainability is a very actual topic. Recent developments, e.g. the documentary ‘An Inconvenient Truth’ presented by Al Gore in 2006, have led to a mind change amongst the public opinion and sustainable developments sped up. However, sustainable measures for transportation are often still in their infancy. This does not hold only for the technical field, but also legally and regarding standardization many steps may have to be taken. Other availability issues may also affect the implementation of measures. This criterion is thus an indication for the implementability of a measure. Lacking or inadequate legislation may prevent the implementation of measures. An example of inadequate legislation is the directive of the RDW (Rijksdienst voor het Wegverkeer) regarding the fuel that an engine is allowed to run on. According to this directive, vehicles are allowed to run on only one type of fuel. Recently this is changed which means that innovative engines are allowed now, e.g. dual fuel diesel-CNG engines. An issue with lacking standardization is that it can be hard to compare measures with each other, for instance on their environmental performance. Another example of an issue that is comprised by the availability criterion in this analysis is the effort that has to be taken to implement a measure. An example of this is the extensive cooperation between stakeholders that is necessary for successful implementation of certain measures.

4.1.8 Usability

The usability of a vehicle is determined by the extent of deployment and the reliability of these vehicles. Many factors are of influence on the extent of deployment and reliability of a vehicle. An infrastructure may be needed for e.g. alternative fuels or electricity charging points. A complex and extensive infrastructure leads to high costs, but a minimum coverage ratio should be attained to allow for efficient operations. The coverage ratio of an infrastructure is closely related to the driving range of a vehicle, which should be long enough to avoid frequent refueling stops and to make sure the longest distances of the concerned DHL network can be travelled. The HGV’s that are investigated in this research should be
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able to cover a range of around 150 km. in daytime. However, the articulated lorry tractor-trailer combinations and the LHV's that are deployed for the nocturnal linehaul (i.e. terminal to terminal) transport have to cover continuous stretches of up to 400 km. The HGV's that are only deployed in daytime are the rigid lorries with cargo carrying capacity. Another usability element is that vehicles should not require intensive maintenance schedules and measures should be easy to use for DHL personnel. The implementation of sustainable measures should neither lead to unreliable vehicle operations. Technology will have to be developed to an acceptable level in order to obtain a low rate of unforeseen breakdowns.

4.1.9 Lock-in problems

Significant investments in sustainable measures might cause a phenomenon similar to technology lock-in. Technology lock-in means that chances are diminishing for new promising measures, due to earlier large investments in other measures which therefore gained substantial market shares (Hoen et al., 2009). The phenomenon that could occur at DHL is that it can be difficult to change a strategy once significant investments have been done. In other words: the flexibility in making strategic decisions will decrease when measures with a high lock-in risk are implemented. An example is the large investment needed for a certain fuel infrastructure. It may be impossible to switch to another fuel once the decision is made to use a certain fuel and a large number of refueling stations have been installed at several DHL terminals, since adapting the entire infrastructure to another fuel could be too costly.

An issue regarding lock-in is a policy change of the authorities and the timeframe wherein this can occur. Policy changes of relevance are regulations regarding harmful emissions or noise, amongst others. DHL may adjust its strategy to certain governmental directives, but sudden policy changes may urge the need to switch to another strategy, e.g. using certain vehicles which are allowed in inner city centers. Switching to another strategy can be difficult for DHL due to lock-in reasons.

4.1.10 Public perception

This criterion is used to assess measures on the perception of the general public on these measures. Sustainable measures should comply with the corporate social responsibility (CSR) vision of DHL, which is based on the TBL (triple bottom line) concept that is explained in section 2.2. This vision is reflected by the criteria in section 4.1.1 to 4.1.5 and it is important for DHL to propagate this vision to their client market, in order to create a positive image of the company amongst that market. However, the prevalent opinion of the public on sustainable measures can deviate from the factual sustainable developments, for instance because the society bases its opinion on various media. There is always a subjective aspect in the information provision by media and for some media this is more the case than for others. This criterion is therefore included in the operational criteria, in order to allow for assessment of a measure on whether it complies with the prevalent public opinion and thus whether a positive corporate image is propagated. It must be noted that there is a lack of information amongst the public regarding a considerable amount of measures. This and the fact that it is hard to determine public perception of various measures make it difficult to attribute scores for the measures on this criterion. Therefore, the weight factors are low for public perception. The weighting procedure is explained in chapter 5.
4.2 Assessment

In this section the measures are assessed on the key criteria mentioned in the previous sections. It is important for the reader to bear in mind that two converging multi-criteria analysis evaluations are conducted in chapter 5. The remaining selection of measures will be investigated more in-depth in chapter 6. The sections 4.2.1 to 4.2.7 are therefore not discussed in too much detail.

The measures are assessed based on their performance on the social welfare criteria by giving them a score for every criterion. These scores are presented on a qualitative ranking scale relative to the current situation, which is a conventional diesel Euro V drivetrain, varying from worse [-] to similar [0] to better [++].

For every operational criterion, again all measures are given a score, but now the scores are given on a quantitative ranking scale relative to the current situation, varying from better [1] to similar [3] to worse [5]. This is done in order to have the possibility of multiplying these scores with weights, which is carried out in chapter 5. The scores are mentioned between square brackets in the text of sections 4.2.1 to 4.2.7 and these scores are evaluated in chapter 5.

Some measures comprise one or more sub-measures and therefore several scores may be found in the next measure assessment sections within one section. A more fair comparison can be set up by splitting measures, e.g. splitting the measure ‘fuels from biomass’ in the three sub-measures 1st generation liquid biofuels, 2nd generation biofuels and biogas in section 4.2.2. These split-ups are shown in the evaluative overview of the scores which is presented in the two-stage MCA evaluation in chapter 5.

The measures are assessed on the criteria according to their current state of development, which means that the measures are investigated on a short-term. However, information on future developments is included in the sections of this chapter as background information.

4.2.1 Alternative fossil fuels

Well-to-wheel greenhouse gas emissions

LNG and CNG have comparable characteristics regarding emissions (Stocchetti and Volpato, 2009). Schmögnerová (2003) states that while natural gas vehicles (NGV’s) do emit methane, another principal greenhouse gas, any slight increase in methane emissions would be more than offset by a substantial reduction in CO₂ emissions compared to other fuels. This is an important statement, since the GWP of methane is 21 times higher than the GWP of CO₂ (Baker et al., 2009). NGV’s also emit very low levels of carbon monoxide and volatile organic compounds (VOC). CO and VOC’s are not themselves greenhouse gases, but they play an important role in helping to break down methane and some other greenhouse gases in the atmosphere, and thus increase the global rate of methane decomposition. This more rapid breakdown could more than offset the small increase in direct methane emissions from NGV’s. According to Baker et al. (2009), the CO₂ benefit of spark-ignited CNG engines over a Euro 5 diesel engine is a 10 to 15% reduction [+]. The origin of natural gas and the supply pathway are critical to the overall WTW energy and GHG balance. Transport distance has a significant impact, representing about 25% of the well-to-tank (WTT) energy (Edwards et al., 2006). Fischer-Tropsch fossil fuels are GTL and CTL. CTL does not result in better GHG emissions when the well-to-wheel pathway is examined compared to conventional fuels, GTL only offers slight better GHG effects in a very optimistic scenario (Jaramillo et al., 2008).
PM an NOx

In the previous section it was mentioned that LNG and CNG have comparable characteristics regarding emissions. CNG has a significant advantage in improving local air quality, due to lower emissions of PM10 and NOx. The new CNG buses of HTM in The Hague, for instance, emit up to 90% less NO2 compared to the old diesel versions (Kadijk and Bos, 2008) [++] . However, Rijkeboer et al. (2003) state that advanced exhaust control in conventional vehicles can have the same effect. Although the GoGreen vision of DHL does not include specific targets other than CO2, several tests and implementation of natural gas vehicles in the Dutch fleet show the willingness of DHL to contribute in tackling local environmental problems. When syngas from gasificated feedstocks is used, it is important to keep the chlorine and sulfur in the gas as low as possible, since chlorine and sulfur damage the environment (Welink, 2010).

3F problem

The 3F problem is not an issue for fossil fuels [0], since these raw materials can not be used for food production. Land-use neither is an issue since fossil fuels are located subterranean.

Safety

Natural gas (CNG and LNG) is lighter than air so it rapidly disperses and becomes diluted in air, in contrast to the components of LPG or conventional diesel which are heavier than air. CNG and LNG thus offer more safety in situations when leakage occurs [+]. The biggest issue with LNG is the boil-off problem, which means that the gas slowly evaporates. Too much pressure builds up in the tanks after 10 days of standstill and gas has to be flared or gas will escape. Since methane is a considerably stronger greenhouse gas than CO2 this should be avoided. The gas can be flared with a device on the vehicle, but another solution is to use vehicles with combined LNG/CNG tanks, so released LNG can be fed into the CNG tank via a compressor. These systems are used already, but detailed information lacks and Gense (2011, personal interview) states this is still non-proven technology. Another issue with LNG is its inability to contain artificial odours and therefore methane detectors are necessary to ensure that leakages are noticed (Krupnick, 2010).

Noise

CNG engines are quieter than diesel engines [+] (Miura et al., 2000).

Costs

CNG vehicles are more expensive than conventional vehicles, since the tanks are expensive amongst others (Ahman, 2009). Furthermore CNG gas stations are expensive when a CNG storage tank is used according to (Eftekhari and Farzaneh-Gord, 2009), since an expensive compressor is needed. However, Spanish cities have positive experience with CNG refuse trucks regarding return on investment (Stocchetti and Volpato, 2009). Gense (2011, personal interview) also states that higher vehicle costs will be earned back [2]. Maintenance costs for NGV's and conventional vehicles are difficult to compare. There are various experiences so Krupnick (2010) assumes that the costs are the same as for diesel vehicles. Natural gas is cheaper than petrol and diesel. Currently the price of natural gas is around 80 eurocent per kg, though 1 kg of natural gas contains the same amount of energy as 1 liter diesel. The gap between natural gas en the oil price will grow in the future in favour of natural gas, but on the other
hand natural gas prices showed instability in the past (Krupnick, 2010). LPG is financially not attractive, in contrast with natural gas.

Availability

CNG and LNG HGV's vehicles are available. In the long run, a pressing issue is the availability of natural gas. World natural gas reserves are very large but European production is set to decline from around the end of this decade so that the share of imports in the European supply will steadily increase. The Netherlands is likely to become a net importer of natural gas around 2030, and replacing an oil dependency with a dependency on natural gas could be a disadvantage (Hoen et al., 2009). Therefore, CNG is often regarded as a transition option, a predecessor for more sustainable, long-term options such as green gas. However, volumes that can reasonably be expected to find their way into road fuels within the timeframe of the study conducted by Edwards et al. (2006) would only represent a small fraction of the total European natural gas consumption (a 5% share of the 2020 European road fuels market would represent about 2.5% extra gas demand). For a road fuel market penetration up to the 10% mark, it is generally accepted that sufficient capacity would be available in the existing (natural gas) grid according to (Edwards et al., 2006). Recently another issue has been resolved concerning dual-fuel engines. The Dutch road transport authority RDW (Rijksdienst voor het Wegverkeer) did not allow a motor vehicle to run on more than one fuel, but legislation has been changed and now dual-fuel vehicles are allowed [3].

Usability

The most pressing issue is the lack of a refueling station infrastructure. An infrastructure still has to be developed, but the amount of stations is growing. The driving range of CNG trucks is an issue, since the tanks take up a considerable amount of space, but dual-fuel engines may be a solution for this. Furthermore, there are routes in daytime performed by DHL that cover relative short distances, as mentioned in section 4.1.8. Another issue is the slow filling rate of the tank at the refueling station (Hoen et al., 2009). Fast-fill systems are available but there is a risk on under-filling of the tank when these systems are used (Eftekhari and Farzaneh-Gord, 2009), deteriorating the driving range even more. Furthermore, a disadvantage of CNG is the loss in payload. However, Spanish cities have positive experience with the reliability of CNG trucks (Stocchetti and Volpato, 2009). The earlier mentioned boil-off problem is an issue for LNG vehicles which may have a negative influence on the usability. When syngas from gasified feedstocks is used, it is important to keep the ash content in the gas and chlorine and sulfur in the gas as low as possible. Ashes can clog the engine and chlorine and sulfur damages the engine.

The findings of a GTL test with a new transit bus owned and operated by the Metropolitan Tulsa Transit Authority (MTTA) show that no fuel-related operational problems occurred (Bergin and Farkas, 2010).

Lock-in

The only lock-in problems related to CNG, LNG or LPG drivetrains are infrastructure investments. CNG gas stations are expensive when a CNG storage tank is used since an expensive compressor is needed (Eftekhari and Farzaneh-Gord, 2009). The density of natural gas refueling stations in the Netherlands becomes higher, but the lack of an infrastructure can be tackled partly by installing gas stations on or near DHL terminal sites. Meetings with fuel suppliers for agreements are in progress and appear to be successful (Kers en Verhulst, 2010, personal interview). However, some terminals are close to existing natural gas refueling stations, for instance the DHL terminal in The Hague.
This lock-in problem is less relevant when dual-fuel or combined natural gas-hybrid drivetrains are used, since these solutions offer improved driving ranges. Dedicated CNG engines can run on a mix of hydrogen and CNG and LNG and CNG can be replaced by biogas, offering future strategy change opportunities for DHL. However, Hoen et al. (2009) state that CNG is not a predecessor for hydrogen because there are too many differences between these gases and their infrastructure.

Public perception

Alternative fossil fuels are received in various ways by the public. Characteristics that give NGV’s a positive image are their low level of noise nuisance and low levels of the harmful emissions PM and NOx, but it can be doubted if the general public is aware of that. Safety issues are a source of great concern to the public regarding CNG (4), but duel-fueled vehicles help relieve many public apprehensions (Department of Natural Resources, 2010).

4.2.2 Fuels from biomass

Well-to-wheel greenhouse gas emissions

The GHG savings of conventionally produced bio-fuels such as biodiesel are critically dependent on the feedstock, country of origin, manufacturing processes and the fate of by-products. The GHG balance is particularly uncertain because of nitrous oxide emissions from agriculture (Edwards et al., 2006). According to Diesel Büchli B.V., the well-to-wheel CO2 reduction of FAME (Fatty Acid Methyl Ester) is 30% compared to fossil fuels (+). A decrease in fuel consumption could not be proven after a DHL test in Hamburg and Kiel.

The life cycle global warming potential (GWP) of HVO (hydrotreated vegetable oil) is half the GWP of conventional diesel (+). The feedstock for HVO generating the lowest GWP is palm oil provided that methane is produced from the palm oil mill effluent and combusted for energy production (Arvidsson et al., 2010). A test with HVO is conducted at DHL Germany. The vehicles are reported to run smoothly and lower tailpipe emissions were detected. Biogas can result in very large greenhouse gas emission reductions. Methane emissions from anaerobic digestion (or fermentation) of biomass, manure, sewage etc. have a large impact on the greenhouse effect due to the large GWP of methane. Using this methane as a fuel may result in considerable less greenhouse gas emissions (++).

PM and NOx

The Federal Transit Administration (FTA), belonging to the U.S. Department of Transportation, conducted tests with Fischer-Tropsch fuel in buses. The results show a reduction of around 22% for NOx emissions and a reduction of around 35% for PM emissions compared to diesel (+) (Bergin and Farkas, 2010). The use of biodiesel generally leads to reduced PM emissions, but also to increased NOx emissions [0] (Murtonen and Aakko-Saksa, 2009). DHL Mail Germany has conducted a test with 2 Ivecos EuroCargo 75E 15P and 4 Ivecos Stralis AT 260 retrofitted for rape oil from 2006 to 2008. The permitted NOx emissions were exceeded during winter and summer. A test that is conducted by DHL with HVO shows that lower tailpipe emissions were detected, there were even better properties than diesel experienced during winter. Recent commercial vehicle trials have suggested NOx emissions are lower and PM emissions decreased to virtually nothing (Baker et al., 2009). Biogas emissions are similar to natural gas emissions (++).
When syngas from gasified feedstocks is used, it is important to keep the chlorine and sulfur in the gas as low as possible, since chlorine and sulfur damage the environment (Welink, 2010).

**3F problem**

One of the major issues regarding first-generation fuels from biomass is the 3F problem which is explained in section 2.2 [---]. Advanced second-generation biofuels cause significantly less fuel-food competition, but these fuels will only be available in large quantities from 2020 (Hoen et al., 2009). Furthermore land-use change may still be an issue with these fuels [---]. Biogas is one of the few biofuels where the 3F- and land-use problem are generally of less importance, since biogas producing activities not always take up large amounts of space (e.g. at sewage water treatment plants) [0].

**Safety**

Liquid biofuels have similar safety characteristics compared to current used liquid fossil fuels [0] and biogas has similar safety characteristics compared to NGV’s [+].

**Noise**

Liquid biofuels have similar noise characteristics compared to current used liquid fossil fuels [0] and biogas has similar noise characteristics compared to CNG, implying that biogas vehicles are quieter than conventional used diesel vehicles. Biogas vehicles are quieter than LPG and petrol fuelled lorries (Plombin, 2003) [+].

**Costs**

The production and consumption of biofuels is not cost effective nowadays due to state of the art technology and costs (Sobrino et al., 2009). However, other sources claim different facts. Regarding vegetable oils, the costs savings depend on price difference between conventional diesel and vegetable oils, but forecasting of prices is very difficult due to volatility of the market. The test at DHL Germany with rapeseed oil, described earlier in this section, showed that the oil filter had to be changed each month instead of all three months due to inferior quality, leading to a cost increase. The costs of producing Fischer-Tropsch fuel are currently still too high to allow a general introduction (Christensen et al., 2010) (Edwards et al., 2006). In spite of the higher distribution cost for DME (dimethyl ether) in comparison to liquid fuels, the cost is lower than for FT diesel. This might be considered a remarkable finding but is due to the fact that the production cost for DME will be significantly lower than for FT diesel (Ahlvik and Brandberg, 2002). Murtonen and Aakko-Saksa (2009) state that no investments in the current fuel infrastructure or vehicles are needed when using high blend ratios of BTL or HVO. The cost of biogas is mostly related to the cost of production as the organic waste feedstock is essentially free (except for a small transport charge). Biogas plants are not very complex technologically, but they still tend to be expensive compared to their gas production. The reason for this is that they have to handle a lot of biomass to produce comparatively small amounts of biogas, particularly when upgraded gas is required. These plants cannot support high feedstock costs such as may be associated with long-distance transport (Edwards et al., 2006). DHL states that using biogas not only leads to increased vehicle costs, but also to increased maintenance costs [4].
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Availability

A considerable amount of biofuel types are technologically not ready to enter the market yet. Many second generation biofuels are under development such as biomethanol, bio-DME (dimethylether), FT diesel, and biohydrogen diesel. Some second generation biofuel feedstocks are available but in scarce amounts and larger quantities of NExBTL are available only in 2015. FT technology with sustainable feedstocks is not available for the coming years (Gense, 2011, personal interview). Biofuels can be produced from a considerable amount of sources in almost every place in the world compared to fossil fuels. The wide availability results in less dependence on a small group of countries in the possession of fossil fuels, but the dependence on other countries for the import of feedstocks is still an issue regarding biofuels (Sobrino et al., 2009). First generation biofuels and biogas are already used in some places. Regarding biogas, there is a lot of suitable biomass feed around, although the problem is to estimate what proportion of the total available could be used and at what cost. Although municipal waste or sewage can play some role, the main potential feedstock is manure (Edwards et al., 2006). FAME biodiesel is available as B5, B20 and B100 which means a 5%, 20% and 100% share of FAME respectively. It is allowed to produce B5 biodiesel under the current European specification EN590:2004. A European standard for FAME quality is developed which is the EN14214 standard, but today no other EU or worldwide biofuel quality standard exists. An approval from the original equipment manufacturer (OEM) is required for the use of most biofuels and a regulatory framework for biogas distribution in the natural gas network is missing. Furthermore, insertion of biogas in the natural gas network is difficult. The gas in this network consists of other substances than methane for at least 14% (nitrogen, ethane, propane, butane, helium and xenon), while biogas consists for 99% of methane. Different compositions mean different handling characteristics of the gas, such as pumping or liquefaction installations.

Usability

Besides the 3F problem, the additional need for vehicle modification and an increasing number of maintenance needs are other main reasons for DHL for not supporting first generation biofuels. There is a risk on engine lockup or clogged filters when using a 100% lipid fuel, partly due to micro organisms which start to grow in the tank after around 2 weeks. For engines designed to burn diesel fuel, the viscosity of lipids must be lowered to allow for proper atomization of the fuel, otherwise incomplete combustion and carbon build up will ultimately damage the engine. Lowering of the viscosity is possible by blending fossil diesel with lipids, but this is risky since the blending ratio has a direct relation with the viscosity thus blending should be executed carefully (Diesel Büchli B.V.).

DHL Mail Germany has conducted a test with 2 Ivecos EuroCargo 75E 15P and 4 Ivecos Stralis AT 260 retrofitted for rape oil from 2006 to 2008 in Hamburg and Kiel. The outcomes of these tests were not satisfying, since unsteady quality of the rape oil caused blocked filters and oil filters had to be changed each month instead of three months due to inferior fuel quality. The quality depends on seasonal fluctuation. Furthermore, the density of gas stations is very low, but the chicken-and-egg problem does not apply to biodiesel, since no changes to refueling infrastructure are required. All in all advantages to conventional diesel could not be shown from an operational point of view. Other drawbacks of using vegetable oils for biodiesel are corroding, soiling and plugging effects and FAME has a tendency to freeze in harsh conditions. More drawbacks are the risk on damage of the paintwork, adverse effects on the injection system (a deteriorating effect on seals such as gaskets and rubbers), dissolving of fuel tank residues and inoperability after 6 months (Murtonen and Aakko-Saksa, 2009).
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FT fuels can be blended with conventional diesel. No adaptations in the current fuel infrastructure or vehicles are needed when using high blend ratios of BTL (Murtonen and Aakko-Saksa, 2009). DHL Germany is conducting a test with 10 Mercedes-Benz trucks, 5 Actros 26 tons and 5 Atego 12 tons, running on NExBTL with palm oil as feedstock. The vehicles travelled 1 million km. without issues. The engine and exhaust characteristics are measured, the engine wear is monitored and the vehicles have regular service intervals and are operated in summer and winter conditions. The vehicles are reported to run smoothly. There were even better properties than diesel experienced during winter. A drawback mentioned is that using the fuel is only feasible with special fuel cards.

The use of DME would require a dedicated distribution infrastructure very similar to that of LPG as well as specially adapted vehicles (fuel storage and injection system). DME and FT diesel are well adapted for diesel engines and therefore, these two fuel candidates are primary options for diesel fuel substitution (Ahlvik and Brandberg, 2002). DME is the “superior” fuel of the two but it is more difficult to distribute and cannot be used for low-blending. Furthermore, DME may affect certain kinds of plastics, elastomers and rubbers after some time (Howes, 2009).

Similar to BTL, no adaptations in current fuel infrastructure or vehicles are needed when high blend ratios of HVO are used (Murtonen and Aakko-Saksa, 2009). Biogas on the other hand has some operational drawbacks: a limited access to refueling infrastructure and a loss in payload. Furthermore, CBG vehicles have a limited driving range, similar to CNG vehicles [4]. LBG vehicles have similar characteristics to LNG vehicles. A driving range of 1200 km is claimed for LBG trucks and a range between 500 – 1000 km for a truck running on 25% diesel and 75% liquefied methane gas (a combination of LNG and LBG) (AMT 2010) (Volvo Trucks, 2010). A problem with ethanol is that it absorbs water, which can cause engine corrosion.

Lock-in

There are no lock-in problems for DHL regarding biofuels, except for the lack of a DME or biogas refueling station infrastructure and this can be tackled partly by installing gas stations on or near DHL terminal sites [4]. A more general lock-in problem is that adopting large shares of biodiesel before 2020 may hold the risk of lock-in of other biofuels, since the production process greatly differs between first and second generation fuels (Hoen et al., 2009).

Public perception

Green vehicles are received well in general. The term ‘green’ fits perfectly with biofuels and accounts for more credibility when used in biofuel marketing compared to other alternative drivetrains. However, there are some issues with public biofuel reception. Recently skepticism emerged in Germany amongst motorists after reports on possible engine damage when using petrol mixed with ethanol (Trouw, 2011). Other issues concern the 3F and land use problems. The influence of these problems on the general public may be limited though, due to unawareness and a lack of information amongst the public (Morrone et al., 2008) (Sawvanidou et al., 2010). The public perception of biogas is assumed to be similar to fossil natural gas perception [4].
4.2.3 Hydrogen

Well-to-wheel greenhouse gas emissions

Many potential hydrogen production routes exist and the GHG balance is critically dependent on the pathway selected. It has been shown that when using wind generators or hydraulic power plants with an overall process efficiency higher than 30% or a nuclear power plant with an efficiency greater than 40%, the process of producing hydrogen to be used in internal combustion engines is cost effective and generates less CO₂ emissions than the use of diesel (Sobrino et al., 2009). However, regarding fuel cell vehicles, the well-to-tank chain for electricity from hydrogen is much more inefficient than other electricity producing chains, thus resulting in more greenhouse gas emissions (Bossel, 2006) (Svensson et al., 2005). This is also illustrated in Figure 4-1. Nevertheless, high reductions in CO₂ emissions are possible.

![Figure 4-1: Battery electric vehicle versus hydrogen electric vehicle](image)

PM and NOₓ

For fuel cells, the only by-product of hydrogen reacting with oxygen is due to the presence of nitrogen in the air, as certain hydrogen-air mixtures produce oxides of nitrogen (Sobrino et al., 2009). When hydrogen is used in an internal combustion engine, the high temperature combustion process results in the production of traces of NOₓ, but these are practically insignificant. These emissions can be further reduced e.g. through a lean burn strategy (Edwards et al., 2006).

3F problem

The 3F problem is not an issue for hydrogen.

Safety

The safety aspect is an important issue regarding hydrogen. Safe management of fuel cells themselves seems possible, but hydrogen is very inflammable and is particularly subject to leakage because of its
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low viscosity and low molecular weight (this accounts for both fuel cell (FC) and ICE hydrogen systems) (Socolow and Thomas, 1997). Also when cryogenic tanks with liquid hydrogen are used there will be a gradual loss of hydrogen. For the refueling stations, considerations similar to those applicable to CNG apply but with much more challenging engineering constraints. Several prototypes of hydrogen dispensers have been built and tested. There is a level of confidence that these can be made to operate safely and reliably in a public environment, although considerable development work is needed to get to that stage. Ensuring reliably fast and safe refueling, at pressures as high as 70 MPa, is a challenge (Edwards et al, 2006).

Noise

With no moving parts, fuel cells using hydrogen yield low noise levels compared to conventional diesel trucks (Sobrino et al., 2009). A quieter operation is also obtained when hydrogen is used in combustion engines, due to less cyclic variations. However, another source claims that hydrogen ICE engine operation may be associated with increased noise and vibrations, mainly due to the high rates of pressure rise resulting from fast burning (Karim, 2003).

Costs

Costs are a major issue regarding hydrogen propulsion. The technology is not affordable, components are complex and expensive and there is a lack of demand for fuel cells. The need for a specific and technically challenging infrastructure for distribution, storage and use of hydrogen leads to high costs (Edwards et al., 2006). The production of some components requires a high cost due to the absence of a large scale market. Due to the low demand, the unit price cannot compete with conventional technologies. It is expected that prices will be lower as demand increases. Hydrogen cannot be used directly in vehicles. In order to use hydrogen the vehicle needs to be adapted and this means a higher cost. In the short term, natural gas is the only potential and cheapest source of large-scale hydrogen. When an on-board reformer is used, virtually all costs are shifted onto the vehicles. As a “reverse economy of scale” effect this is likely to result in high costs. DHL also states that fuel cells are expensive. The total cost of ownership is typically three to six times as high as of a conventional vehicle.

Availability

Hydrogen can in principle be produced from virtually any primary energy source, which means that the fuel is available on a large scale. The result is that a fuel cell vehicle never runs down as long as there is fuel to produce electricity. Technologically, hydrogen can be produced but not on a commercial scale yet, due to lacking legislation and standards (Edwards et al., 2006). Fuel cell technology has successfully been demonstrated in city buses. At least one European developer plans to market a fuel cell hybrid 7.5 t truck but since production volumes will initially be low, this will be a niche product. Furthermore, the earlier mentioned safety issues show that hydrogen is not available in the short term.

Usability

The tanks of a hydrogen vehicle take up a considerable amount of space since hydrogen has a low lower heating value (LHV) per unit of volume, where the LHV is a measure for the heat of combustion. This results in a poor driving range, which means that in combination with a lacking infrastructure and slow refueling rates, hydrogen vehicles are not suitable for long distance transport (Hoen et al., 2009). This is
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a problem for the DHL linehaul transport, but there are routes in daytime that cover relative short distances, as mentioned in section 4.1.8. Fuel cell powered vehicles have no moving parts, allowing a simpler design, greater reliability and functionality being less prone to breakdowns. However, as an emerging technology, there are certain problems that have not yet been resolved and that affects functioning, especially in the operating life (e.g. the complexity of transportation and storage) (Sobrino et al., 2009). Since the overall weight of the fuel cell system (including hydrogen storage tanks and batteries) is heavier than the conventional diesel drivetrain, less capacity for payload is available. Furthermore, staff training is required to ensure safe handling of the hydrogen fuel and fuel cell systems.

Lock-in

The only lock-in problems related to hydrogen are infrastructure investments. The lack of an infrastructure can be tackled partly by installing gas stations on or near DHL terminal sites. The lock-in problem is less relevant when the driving range is improved due to blending of hydrogen with conventional fuel (Al-Janabi and Al-Baghdadi, 1999). As mentioned before, CNG is not a predecessor for hydrogen because there are too many differences between these gases and their infrastructure (Hoen et al., 2009).

Public perception

The term ‘zero emission’ is often used and fits well with hydrogen powered vehicles. It is a credible term, since other traffic participants will not experience exhaust fumes. Furthermore, the lack of noise and marketing stunts with water from the exhaust give an image of a very innovative, clean fuel. On the contrary, hydrogen is also well known for its safety characteristics, especially its high inflammability. Frequently the link is made with the Hindenburg disaster from 1937. However, a research in the Netherlands showed that hydrogen is perceived more as an environmentally friendly and inexhaustible fuel than as a dangerous fuel. Furthermore, it showed that respondents have quite a positive attitude toward hydrogen applications (Zachariah-Wolff and Hemmes, 2006).

4.2.4 Electric and hybrid drivetrains

Well-to-wheel greenhouse gas emissions

DHL research shows that hybrid trucks offer a CO₂-reduction potential of up to 15%, but this percentage decreases to 3% for long distance trucks, since regenerative braking energy is not available during long stretches at constant speed and due to the negative impact of heavy hybrid drivetrain components. FedEx, a third party logistics provider, claims that tests show that gasoline hybrid trucks of 6,3 tons offer substantial lower emissions and they are around 20% more fuel efficient than a diesel variant when they are deployed in routes with many stops [+] (Barnitt, 2010). Full electric trucks offer a 30% reduction for German and UK based grid electricity, up to 100% when renewable electricity is used according to DHL [++] . However, regarding full electric vehicles, the amount of life cycle CO₂-emissions is not lower then those of conventional drivetrains when an unsustainable electricity grid is used. Furthermore, these grids and their components have a considerable lifetime, making it harder to adapt or replace them (Samaras and Meisterling, 2008). An issue for full electric vehicles is that the engine does not develop heat, which means that an extra heating supply needs to be installed consuming a considerable amount of energy (Barreto, 2008).
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PM and NOx

Using electric vehicles can result in lower PM and NOx emissions (Baker et al., 2009). FedEx conducted a test in California with three gasoline hybrid electric parcel delivery trucks (gHEV) and three diesel trucks. Three different drive cycles were used and according to Barnitt (2010), the results show decreased emissions of 99.8% for PM, 83.2% for NOx, 79.2% for CO and 96.6% for total HC on average [++].

3F problem

The 3F problem is not an issue for electric and hybrid drivetrains [0].

Safety

Plug-in cars are just as safe as conventional cars, both in terms of crash safety and the safety of the battery as compared with gasoline. Extensive testing of the batteries used today in plug-in cars has shown that they are safe (Kaplan and Sargent, 2010). If safe electric drivetrains can be developed for cars, it should be possible to develop safe drivetrains for trucks [0]. The nickel-hydride batteries used in hybrid cars have not had any safety problems in the 10 years they have been on the road. Newer batteries, such as lithium-ion batteries, pose different challenges. Early lithium-ion batteries occasionally caught on fire when they were first used in laptops and cell phones (Buchmann, 2007). However, the early safety problems with lithium-ion batteries have largely been addressed, and sound engineering and the addition of safety features can reduce the risks even further (Kaplan and Sargent, 2010). Another source also claims that safety is ensured, from both internal short circuits and external forces such as a crash (Christensen et al., 2010). Furthermore, it is unlikely that reliance on batteries will pose dangers to drivers beyond those already posed by internal combustion vehicles (Kaplan and Sargent, 2010). An issue that has to be taken into account is the low noise level of electric and hybrid vehicles which may be of hazard in areas with high numbers of pedestrians who will not hear an oncoming vehicle (Baker et al., 2009).

Noise

Electric powered vehicles are quieter than conventional vehicles, since electric motors are much quieter than internal combustion engines [++] (Kaplan and Sargent, 2010). A reduction in noise pollution can be achieved with vehicles operating near silently, which may be a benefit for early morning vehicle operations (Baker et al., 2009). However, hybrid vehicles are not quieter at higher speeds [+].

Costs

Full electric vehicles are expensive. A cost increase of 100% or more compared to incumbent technologies is expected [5]. Lifecycle costs such as fuel and maintenance are not included in this number (Baker et al., 2009). DHL states that battery technology is improving but needs further development to achieve the cost and performance (weight) requirements of the transportation industry. The total cost of ownership (TCO) for an electric vehicle is said to be typically twice as high as an ICE equivalent, amongst others due to the minimum need of two batteries in eight years lifetime. However, fewer moving parts should reduce maintenance costs and the variable cost per mile is circa 25% of an ICE equivalent vehicle.
The extra costs of purchase for hybrid trucks over conventional vehicle technology are 75% (Baker et al., 2009). DHL states that cost savings of up to 20% for urban and up to 3% for rural hybrid vehicles can be achieved, but tests in Germany are revealing that investment costs currently cancel out the savings. Barnitt (2010) reported that the total operating cost per mile is US$ 0.59 per mile for the gHEV’s and US$ 0.57 for the diesel vehicles on average [4].

Availability

Hybrid trucks with a gross vehicle weight (GVW) of up to 18 tons are available [3] (Logistiek.nl, 2011). Full electric vehicles are currently limited up to 12 tons and need further development to achieve the cost and performance (weight) requirements of the transportation industry [4] (Baker et al., 2009). Battery technology is improving: the power to weight ratio from the Toyota Prius batteries has improved with 108%, the energy content to weight ratio 37% in the period 1997 to 2003 (Kobayashi et al, 2009). Furthermore, hybrid and plug-in hybrid electric vehicles (PHEV) using the same battery technology as future full electric battery powered vehicles are currently available (Hoen et al., 2009). Regarding lithium depletion, Kroon (2008) indicates that the desired increased production levels of batteries should not present fundamental problems, given the global availability of lithium, and the current and expected annual production.

Usability

The most pressing issue for full electric trucks is the driving range, which is typically limited to around 160 km. between 4 to 8 hours of recharging [4]. Another source claims that the driving range is around 250 km. (Francke et al., 2009). However, there are routes in daytime performed by DHL that cover relative short distances, as mentioned in section 4.1.8. The vehicle charge time needs to be planned carefully and even then difficulties may arise, especially for the long-haul terminal to terminal transport in the night. A recharging infrastructure is currently lacking, but the network is growing. Hybrid vehicles have similar usability operations to conventional vehicles except for some other characteristics, for instance a better acceleration and less brake and clutch wear as claimed by DAF with their LF Hybrid [2] (DAF, 2011).

Lock-in

For full electric vehicles, a lock-in risk exists when large investments in recharging Infrastructure are done [4]. These recharging facilities may become obsolete when another sustainable strategy is pursued in the future. Furthermore, electric and hybrid powered vehicles are currently subject to continuously changing policies in the Netherlands regarding subsidies, taxes and indirectly accessibility in certain areas, e.g. city centers. Accessibility may be allowed or prohibited depending on their environmental performance, but it is hard to anticipate on future legislation regarding harmful emissions. Another consequence of this is the uncertainty that rises when determining the residual value of BEV’s and HEV’s [4].

Public perception

The overall picture of electric drivetrains is positive [2]. These vehicles are considered as clean, silent, innovative solutions. Furthermore, these drivetrains are clustered under the most promising sustainable alternatives for conventional vehicles. However, less attention is paid to the whole energy chain in
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general. People tend to forget the fact that electricity has to be generated, which may undo the environmental advantages of electric vehicle use. Plug-in hybrid vehicles (PHEV’s) draw mixed reviews from consumers as they consider ecological issues amongst others [3]. Another research also states that consumers see more sustainable opportunities for BEV’s than PHEV’s (Bronchard et al., 2011).

4.2.5 Other vehicle measures

**Greenhouse gas emissions**

As explained in chapter 3, there are several vehicle measures that can provide emission reductions. Most measures in this section concern fuel consumption reduction, which is proportional to CO2 emission reduction (Febiac, 2011). The well-to-wheel method is not used in this section, because no information is provided in literature about this method.

Test with DHL trucks using the Sidewing side skirts of Ephicas show a fuel consumption reduction of 7.25% on average. Filippone and Mohamed-Kassim (2009) mention several measures which offer improvements between 2.1% and 8.8% of fuel consumption for 20 tons long distance trucks. These measures comprise aerodynamic drag reducing devices such as cab roof and side fairings, tractor chassis skirts, trailer-front fairings, gap splitters, trailer skirts, boat tails and base flaps. Another source claims that experiments with various spoilers and panels for tractors and trailers confirmed a fuel consumption decrease of 7% (Christensen et al., 2010). An average reduction of CO2-emissions of 10% is feasible when a Teardrop trailer is used. This reduction is 11.3% for box vans (Baker et al., 2009). A fuel consumption reduction of approximately 3% is claimed by using single wide tires compared to a typical dual wheel and tire system. Improvements in fuel economy of 3 to 18% are reported after a test with single wide tires and aerodynamic trailer adaptations (Joseph Bachman et al., 2005). Further incremental improvements of conventional internal combustion engine technologies until 2050 could result in maximum efficiency gains of about 50% (Hoen et al., 2009). According to CE Delft (2008), CO2-emission reductions of 15 to 20% are feasible when longer and heavier trucks are used.

**PM en NOx**

There is a clear relation between fuel economy and NOx emissions as explained in chapter 3, thus the fuel consumption improvement rates mentioned in the previous section will also lead to improvements of NOx emissions [+]. The U.S. Department of Energy (2000) also claims that total vehicle emissions are a function of the power output of the engine (and thus fuel economy) and therefore reductions in power requirements should be expected to result in a corresponding reduction in vehicle emissions. This is more likely the case for emissions of oxides of nitrogen (NOx), as opposed to emissions of particulate matter (PM). NOx is primarily a function of power output, whereas PM is controlled by a more complex set of factors in addition to power output, including fuel composition, and transient engine properties, such as air/fuel ratio, oil leakage through piston rings, and exhaust gas temperature. Joseph Bachman et al. (2005) found decreases in NOx emissions of 9 to 45% after conducting a test with single wide tires and aerodynamic trailer adaptations, which led to reductions in power requirements.

**3F problem**

The 3F problem is not relevant for the measures in this section [0].
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Safety

Aerodynamic improvements on trucks generally not affect road safety in a negative way. In fact, side skirts like the Ephicas Sidewing not only improve fuel economy, it is also claimed that they prevent other vehicles or road users from getting trapped underneath the trailer and that water spray is reduced when driving on wet roads (Ephicas, 2009). Tires offering less rolling resistance can deteriorate road safety. A trade-off between safety (braking distance, aquaplaning) and energy-efficiency exists when these tires are used. Care must also be taken with single wide tires to avoid loss of tire safety (Sperling and Cannon, 2010). Tire pressure monitoring systems (TPMS) for commercial motor vehicles can facilitate the task of drivers and fleet operators in maintaining normal tire pressure in all tires for optimum safety and fuel consumption and uninterrupted operation of the vehicle (Christensen et al., 2010). Using longer trucks can affect road safety. Studies have shown that longer truck combinations can actually improve safety, if done with proper equipment and trained drivers. However, there are still many concerns about safety for cars passing such long trucks (Sperling and Cannon, 2010).

Noise

No relation between improved aerodynamics and noise is found in literature, neither a relation between the energy efficiency and the noise production of tires.

Costs

A reduction in fuel consumption can lead to a reduction in costs depending on fuel prices. The extra costs for a teardrop trailer are 30% on average, depending on the trailer type and a package of aerodynamic fairings, deflectors, skirts and collars for tractor and trailer will result in extra costs of 2 to 10%. Furthermore, retrofitting of single wide tires may not be cost-effective, but fitting them to new trucks results in fuel savings beginning immediately (Baker et al., 2009), which may lead to overall cost savings.

Availability

All measures mentioned previously in this section are technologically available. Legal issues are neither a problem for implementation, except for longer and heavier trucks (LHV’s), which are only allowed on certain road stretches. Another issue for longer and heavier trucks is formed by the difficulties that arise at (un)loading the vehicle. Longer and heavier vehicles always have two or more cargo bodies, as shown in Figure 4-2. Quick unloading from the first body behind the driver’s cabin is impossible, since the trailer or dolly behind it has to be uncoupled to reach the cargo doors. Therefore, LHV’s can seldom be deployed by DHL in daytime. There are more opportunities at the nocturnal long-haul routes, but vehicles deployed at night should also be deployed in daytime according to DHL’s policy, which reduces the opportunity for LHV’s. Regarding fuel efficient tires, rolling resistance guidelines for tire manufacturers are missing.
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Figure 4-2: Common LHV types

Usability

Some truck drivers of DHL mention that the driving behaviour of a trailer is negatively affected by the Sidewings of Ephicas (Sterk, 2011, personal interview). Other DHL employees mention that side skirts often get damaged when trucks hit objects alongside the road, for instance when a parking or turning maneuver is performed. Apart from that there are no usability issues for the measures in this section [3].

Lock-in

There are no lock-in problems for DHL regarding the measures in this section [3].

Public perception

The public opinion on other vehicle measures is not very distinctive. These measures therefore offer safe areas of innovation opportunities for DHL [2].

4.2.6 Driving behaviour

Greenhouse gas emissions

Driving behavioral measures are meant to provide fuel consumption reduction, which is proportional to CO₂ emission reduction (Febiac, 2011). Driving behaviour has a considerable influence on the fuel consumption of a truck. According to Duurzaam op weg (2011), savings of up to 20% and average savings of around 10% are feasible by adopting the program ‘Het Nieuwe Rijden’. Fuel economy improvements of 10 to 20% are reported in the short term and 5 to 10% in the mid term for this program [+]. Immediately after an eco-driving training, average fuel economy and CO₂ emission improvements of 5 to 15% were recorded for trucks. The best results for individual drivers showed 20-50 per cent improvements in fuel economy under test conditions. Over the mid-term (<3 years) average fuel savings
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of around 5% have been shown in cases where there is no support beyond the initial training and with continuous feedback this can be improved to about 10%. There is little evidence available regarding the long-term impacts (>3 years) of eco-driving training but a few studies have been conducted on companies with truck and bus fleets that provided one-off training with no follow-up incentive programs, recording a 2-3% residual improvement in fuel consumption (International Transport Forum, 2007) (Christensen et al., 2010).

Regarding technical measures, Panis et al. (2010) investigated various emission reductions resulting from a speed limit reduction from 90 to 80 km/h. The results are shown in Figure 4-3. Trucks are allowed to drive up to 80 km/h in the Netherlands, but nowadays limiters are set to 90 km/h and that is the speed driven by most truck drivers.

![Speed limit emission reductions](image.png)

**Figure 4-3: Relative emission changes for different trucks for a speed limit reduction from 90 to 80 km/h**

(Panis et al., 2010)

**PM and NOx**

There is a clear relation between fuel economy and NOx emissions as explained in chapter 3, thus the fuel consumption improvement rates mentioned in the previous section will also lead to improvements of NOx emissions [ ]. As can be seen in Figure 4-3 from Panis et al. (2010), NOx emissions decrease substantially when a speed limit is implemented. The reduction of PM emissions by this measure depends heavily on the truck type and is even an increase for the 30 ton MAN.

**3F problem**

The 3F problem is not relevant for driving behaviour related measures [ ].

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Safety

Driving economically and safe driving are closely related, since fuel efficient driving implies a careful, anticipating and calm driving style. Truck drivers who apply an eco-driving style will thus contribute to increased road safety [+] (Duurzaam op weg, 2011). Hazardous situations will be noticed earlier and there is more time for the driver to react. Furthermore, other aspects of improved driving behaviour also result in better safety perspectives. Checking the tires regularly, for instance, results in a lower risk on under inflation and blowouts.

Noise

Improving driving behaviour will not only lead to a better fuel efficiency, but also to less noise nuisance [-1]. A calm driving style will lead to less sudden acceleration and braking maneuvers. The rate of acceleration is directly related to driving behaviour and is an important parameter greatly affecting the emitted noise (Lelong and Michelet, 2001). Furthermore, reduced speeds result in less noise pollution (Christensen et al, 2010).

Costs

Technical measures virtually always lead to cost reductions in the long run, because initial investment costs are often low. Implementing a speed reduction from 89 to 85 km/h for instance means a small initial investment but will eventually lead to cost savings.

It is difficult to determine if non-technical measures provide cost savings. Driver training is expensive and the amount of fuel that can be saved heavily depends on future effectiveness of driving trainings or instructions (Sperling and Cannon, 2010). Initially drivers will consume less fuel, but future savings depend on the extent to which drivers hold on to the eco-driving procedures and methods they have been taught. However, another effect that should not be overlooked is the decrease in damage costs. Eco-driving leads to safe driving and thus fewer damages will occur when drivers use an eco-driving style. Fewer damages will lead to decreased repair costs and lower damage insurance premiums [2].

Availability

All non-technical measures discussed in the driving behaviour sections are available. Technical measures are also available to a large extent [3]. Legal and certification issues do not play a role for most driving behaviour measures. However, there are operational issues regarding a speed reduction. This measure will have a considerable effect on emissions at the nocturnal line-haul routes, but travel times will be longer. Additional research should be performed to investigate the effects on shifts in arrival times and the consequences for the terminal processes. Jacobs and van der Kolk (2011, personal interview) indicate that a speed reduction is not feasible due to the reasons mentioned in this section.

Usability

There are no usability issues except for the resistance from drivers. Drivers are generally very sceptical about technical measures like a speed limit, telematic systems registering all kinds of driving data or a throttle pedal which gives haptic feedback. Installing these systems may not only lead to a bad working atmosphere where drivers feel restricted in their working operations, sometimes it even leads to
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sabotage of the installed equipment. This resistance issue also exists at driver trainings. Not every driver has the mindset for successful results when attending a driver training [4].

**Lock-in**

Lock-in problems are not relevant for behavioural measures [3].

**Public perception**

The public opinion on improved driving behaviour is not very distinctive, since it comprises elements that are hardly visible for the public. However, the program ‘Het Nieuwe Rijden’ is widely announced by the Dutch government. People are familiar with this program and using this program within DHL will probably result in hardly any negative criticism [2].

4.2.7 Modal shift and consolidation of goods

**Greenhouse gas and PM and NOx emissions**

It is clear that there are opportunities for this measure regarding emissions, when other modes than truck are considered for the 46,000 kilometers travelled every night in the Netherlands [+]. However, making an estimation on greenhouse gas emission and other emissions is too complex. There are many factors and parties involved in intermodal transport, a modal shift or consolidation of goods, making it impossible to obtain significant emission numbers for the DHL fleet, given the time-frame of this research.

**Safety**

The safety of operations is similar to that of the current operations, since the same vehicles are used, except for a long-distance stretch covered by another modality [0].

**3F problem**

The 3F problem is not relevant for this measure [0].

**Noise**

Noise nuisance is not an issue, since the same vehicles are used, except for a long-distance stretch covered by another mode [0].

**Costs**

There used to be a railway connection to a considerable amount of terminals in the past when DHL the Netherlands was Van Gend en Loos, but many of those connections have been disappeared. A huge investment would be needed to restore those railway stretches (Jacobs and van der Kolk, 2011, personal interview) (Mathijsen, 2011, personal interview). Costs for intermodal truck transport or for a modal...
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shift are assumed to be higher than the current business operations, due to necessary drayage and low load factors of trains or barges. Furthermore, trucks are currently used at daytime and nighttime. This means that when another mode is used at nighttime, trucks will stand still, resulting in inefficient use of resources.

Availability

The most pressing issue for intermodal transport and consolidation of goods is the type of demand imposed by DHL customers. Most transported goods by DHL Express are time critical goods and customers will not accept a delay (Mathijsen, 2011, personal interview). It is impossible to omit delays when the current terminal to terminal legs in the night are (partly) replaced by other modes or when goods are consolidated with goods from other companies. Consolidation of goods for the truck transport in the night is not considered feasible anyhow, since high load factors are already achieved at the long haul traffic in the night (Jacobs and van der Kolk, 2011, personal interview). On some routes empty return legs are avoided by cooperation with other companies, but this is not a form of consolidation and it occurs rarely. Another drawback of consolidation of goods is the offered level of service. Customers may get confused when their DHL shipment is delivered by an employee of another company. Furthermore, load factors of trains or barges should be high enough to achieve a sound environmental and financial performance. Average load factors for rail and barge are assumed to be 0.75 and 0.8 respectively (Kim and van Wee, 2008). It can be hard to obtain these load factors, since extensive cooperation between many stakeholders is necessary. Here the relation of intermodal transport with consolidated transport becomes clear. Freight trains can haul up to around 75 twenty foot equivalent units (TEU) (Kim and van Wee, 2008), which means that a considerable amount of companies needs to cooperate to make a train run efficient.

Usability

The usability criterion is not relevant for this measure.

Lock-in

A lock-in problem that could occur is a shortage of vehicles. The size of the DHL fleet can decrease when large volumes of goods are transported by other modes or vehicles that are not owned by DHL. Once agreements with collaborators end or go wrong and goods have to be transported by DHL's own fleet, a shortage of vehicles may arise and sudden investments in new vehicles could be unavoidable. This depends on the extent to which a solid cooperation with other parties involved develops.

Public perception

The public opinion on the measures from this section is not very distinctive, which may be the result of the complexity of the measures.
4.3 Summary and conclusions

Summary

Chapter 4 and chapter 5 provide an answer on the second and third sub research question, together forming a multi-criteria analysis for the inventory of measures. It was explained in this chapter why the MCA is conducted. The criteria were described and the inventory of measures was assessed on these criteria. The measures were assessed based on their performance on the criteria by giving them a score on a qualitative ranking scale relative to the current situation for the social welfare criteria and on a quantitative ranking scale relative to the current situation for the operational criteria. The measures were assessed on the criteria according to their current state of development, which means that the measures were investigated on a short-term. However, information on future developments was presented in this chapter as background information.

Conclusions

From the assessment in this chapter it can be concluded that assessing the sustainable measures is not straightforward. Several measures comprise sub-measures with different mutual characteristics. Therefore, the measures have been split up in sub-measures, but logically not every sub-measure could be assessed on every criterion, due to the time constraint of this research. Assessing every sub-measure on every criterion demands a much more detailed investigation. Furthermore, such an investigation would cross the scope of the research. The rapid developments of certain sustainable measures also form difficulties for assessing these measures. Literature is not always unambiguous on the current state of development. The difficulties that arose at the assessment in this chapter should be born in mind when using the results of this assessment.

Another conclusion is that all measures score relatively well, especially on greenhouse gas emissions, which is the result of the initial selection of measures in chapter 3. This initial selection has come about with literature and surveys with DHL, as explained in chapter 3. First and second generation liquid biofuels are the only measures that score worse than conventional vehicles on a criterion.
Sustainable measures for the fleet of DHL Express

5 Evaluation of the assessment

In this chapter the selection process of the sustainable measures is performed by presenting a brief evaluative overview of the assessment in chapter 4. A two-stage MCA is conducted to assess the measures on the set of criteria, which forms the answer on sub research question two. In section 5.1, the measures are assessed on the criteria that are related to social welfare in the first MCA. A selection of measures is made with the conclusions of this MCA and this selection is assessed on the criteria that are important for the operational management of DHL in the second MCA in section 5.2. The conclusions of this MCA are used to make a second selection of measures. The remaining measures will be investigated in detail in the next chapters.

5.1 Stage 1: Evaluation of the social welfare assessment

5.1.1 Evaluation matrix

The sustainable measures are evaluated in this section on the social welfare criteria, based on their performance on these criteria in chapter 4. All measures are given a score for every criterion. The scores for the social welfare criteria are presented on a qualitative ranking scale relative to the current situation, which is a conventional diesel Euro V drivetrain, varying from worse (--) to similar (0) to better (++). The result for the social welfare criteria is the overview presented Table 5-1. Some measures have been split up in sub-measures in order to allow for a fair comparison. The measures are assessed on the criteria according to their current state of development and short-term opportunities. Information about future developments can be found in chapter 3 and 4. The main focus of this research is on greenhouse gas reduction, i.e. the WTW GHG criterion.

Second generation liquid biofuels and hydrogen powered vehicles are not included in the MCA evaluation because they are not available in the short term. The measure 'modal shift and consolidation of goods' comprises a considerable amount of stakeholders and other factors of influence, making it very complex. The investigation of a modal shift and consolidation requires an amount of time that is not available in the time-span of this research. Addressing scores to the measure is difficult for a considerable amount of criteria, as explained in section 4.3. Furthermore, the measure is partly beyond the scope of this research. It is therefore omitted in the MCA evaluation in this chapter and, together with second generation biofuels and hydrogen, omitted from further research.

<table>
<thead>
<tr>
<th></th>
<th>WTW GHG</th>
<th>PM and NOx</th>
<th>3F and land-use</th>
<th>Safety</th>
<th>Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative fossil fuels</td>
<td>+</td>
<td>++</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Liquid biofuels 1st generation</td>
<td>+</td>
<td>0</td>
<td>--</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Biogas</td>
<td>++</td>
<td>++</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Full electric</td>
<td>++</td>
<td>++</td>
<td>0</td>
<td>0</td>
<td>++</td>
</tr>
<tr>
<td>Hybrid drivetrains</td>
<td>+</td>
<td>++</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Other vehicle measures</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Driving behaviour</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
5.1.2 Explanation of the matrix

The scores in the matrix of Table 5-1 are explained in this section. An explanation is needed, since measures can comprise sub-measures with different characteristics and since a measure may comprise positive and negative aspects for one criterion. The availability criterion for instance comprises a considerable amount of sub-criteria as explained in section 4.1.7, which results in difficulties when attributing scores to the measures for this criterion. The line of reasoning that has been followed and the assumptions that have been made, which are used for the coming about of the scores in Table 5-1 are presented in this section. A similar explanation is presented for the operational management criteria matrix in section 5.2.2.

Most measures score a 0 on the 3F criterion. The 3F criterion is therefore a criterion that distinguishes to a certain extent. A 0 may seem an average score, but it actually means that an enhancement of the 3F problem is avoided, since the current situation neither enhances the 3F problem. It is the rising implementation of measures like first generation biofuels which does enhance the problem. Implementation of these measures thus should be avoided.

The scores of the measure ‘alternative fossil fuels’ are based on dedicated CNG and LNG vehicles. A note with the WTW GHG and safety criterion is the exclusion of the LNG boil-off problem, since solutions for that issue are available. However, it is questionable when these solutions can actually be used (see section 4.2.1), so the boil-off problem may form a barrier for the implementation of LNG fuelled vehicles. Full electric trucks are currently available with a GVW up to 12 tons. The HGV’s of DHL are mostly 18 tons trucks, but a 12 ton truck may also be deployed for certain routes and therefore full electric drivetrains are included in this evaluation chapter. More information on this can be found in section 4.1.8 and 4.2.4.

It is assumed that electricity is generated with a considerable share of renewable energy for the score of full electric drivetrains on the WTW GHG and PM and NOx criterion. Renewable energy develops fast (see Figure 5-1) and only with this assumption a significant decrease in emissions can be obtained. The measure ‘other vehicle measures’ comprises an aerodynamic package and fuel efficient tires. It is assumed that the tires do not deteriorate safety, as some fuel efficient tires may do. In that case the score on the safety criterion turns out lower. The measure ‘driving behaviour’ only comprises driver trainings. A speed reduction is not included, since the feasibility of implementation of this measure at DHL is questionable (see section 4.2.6).

![Graph showing the share of renewable energy of total electricity consumption from 1990-2007 (CBS, 2011)]
5.1.3 Selection of measures

A selection of the measures can be made with the results in Table 5-1. The Pareto efficiency concept is used to make this selection (Herbener, 1997). This implies that improving a criterion should not lead to deterioration of another criterion when avoidance of decreasing social welfare is pursued. Since the primary focus of the research is on decreasing greenhouse gas emissions, the question is which measures can be used for reducing greenhouse gas emissions without e.g. deteriorating safety or increasing noise emissions. The Pareto concept indicates that compensation or mitigation measures can be used to deal with deterioration of a criterion (i.e. negative effects for a certain group of people), but these measures are not taken into account in this analysis. Furthermore, the measures are assessed on the criteria according to their current state of development and short-term opportunities, as mentioned in section 4.2.

First generation liquid fuels from biomass have an adverse effect on the 3F and land-use problem. Therefore, and also with the guidelines for using biofuels set up by DPDHL in mind, this measure can not be implemented. The 3F problem is less of an issue for second generation liquid biofuels, but land-use problems still exist and these fuels are not available yet. It can be argued whether the 3F and land-use problem is of concern to DHL. However, using first generation liquid biofuels will lead to an enhanced 3F problem in the end, which might cause a negative atmosphere connected to DHL. The drawbacks of this measure can then be found in a poor score on the public perception criterion. However, this line of reasoning is not captured in the conducted MCA.

There are no minuses in the matrix except for first generation liquid biofuels. This means that regarding the social welfare criteria, the other measures can be implemented with positive WTW GHG results and without decreasing social welfare, according to the Pareto efficiency concept. The measures that remain and that are evaluated in the next section are presented in the following list:

- Alternative fossil fuels
- Biogas
- Full electric drivetrains
- Hybrid drivetrains
- Other vehicle measures
- Driving behaviour

5.2 Stage 2: Evaluation of the operational management assessment

5.2.1 Evaluation matrix

The assessment from chapter 4 is evaluated for every operational criterion in this section. All measures are given a score for the operational criteria on a quantitative ranking scale relative to the current situation, varying from better (1) to similar (3) to worse (5). This is done in order to have the possibility of multiplying these scores with weights, which is carried out in the next section. The results are presented in Table 5-2. Measures will not score better than 3 for availability and lock-in, since the current situation scores best on those criteria. However, a distinction can be made on when a measure can actually be used in practice and how many lock-in risks exist, providing possible scores between 3 and 5 for both criteria.
Sustainable measures for the fleet of DHL Express

Table 5-2: MCA stage 2: operational management criteria

<table>
<thead>
<tr>
<th></th>
<th>Costs</th>
<th>Availability</th>
<th>Usability</th>
<th>Lock-in</th>
<th>Public Perception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative fossil fuels</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Biogas</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Full electric drivetrains</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Hybrid drivetrains</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Other vehicle measures</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Driving behaviour</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

5.2.2 Explanation of the matrix

The scores from the evaluation of the operational management criteria in Table 5-2 are explained in this section. The scores in the matrix in Table 5-2 are fairly low. This may imply that there is no point in implementing the investigated measures, but this is not the case. The measures do score high in the first stage on several criteria, but the general problem with sustainable measures is to fit them into the current business practices. This general problem becomes clear in the scores in stage 2.

Alternative fossil fuels score well on the costs criterion. This is caused by the lower fuel price and the assumption that investments in refueling infrastructure are earned back. Alternative fossil fuels score worse than a conventional vehicle on usability. This is because of the low range and loss in payload for CNG vehicles. These issues are not relevant for LNG vehicles, but the measure is assessed as LNG and CNG together in the MCA, as mentioned in section 5.1.2. Therefore the lower score for CNG is taken, as a worst case solution, so that expectations can not be too high. It should be noted that the CNG range can form a barrier for implementation on certain DHL routes, but further investigation should clarify this. Dual-fuel systems could solve the range issue, but dedicated CNG and LNG are assessed in this chapter. Several scores would turn out different when dual-fuel systems would be assessed. Emissions reductions, for instance, are lower for dual-fuel. The score on lock-in is attributed with the assumption that investments in infrastructure for CNG and LNG are needed, which results in a low flexibility for changing strategies. It must be noted that a better score for the lock-in criterion may be achieved when existing refueling stations close to the terminal sites can be used. The score on the criterion public perception is based on public perception on CNG, assumed that the perception on LNG is similar. The performance on the lock-in criterion of biogas is comparable to alternative fossil fuels, thus with the assumption that investments in refueling infrastructure are needed. Biogas scores similar to conventional technology on availability, with the assumption that there are no difficulties with insertion of biogas in the natural gas network and with the assumption that a regulatory framework for biogas distribution in the natural gas network will exist soon.

The measure ‘other vehicle measures’ comprises an aerodynamic package and fuel efficient tires as mentioned before. This measure scores similar to conventional technology on availability under the assumption that rolling resistance guidelines for tire manufacturers are drawn up in the near future. Driving behaviour usability is based on resistance of drivers to trainings. Not every driver has the mindset for successful results when attending a driver training. Changing this mindset means changing the company culture. This may be seen as an implementation issue which should be included in the availability criterion, but it is included in the score for the usability criterion in this MCA, since the measure is ready to be implemented.

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It must be noted that there is a lack of information amongst the public regarding a considerable amount of measures. This and the fact that there is not much literature available on public perception (especially for other vehicle measures and driving behaviour) make it difficult to attribute scores for the measures on this criterion. Therefore, the weight factors are low for public perception. The weighting procedure is explained in the next section.

5.2.3 Weighting procedure and selection of measures

The priorities of DHL are expressed by means of attributing criteria weights to the operational management criteria, in order to determine the relative importance of each criterion. The method followed for this weighting procedure is a pair wise comparison with a preferential ranking of two components (Breijing, 1997) and the weight factors are determined using information from interviews with concerned DHL employees. Six DHL managers from the operation field have been interviewed in order to obtain a representative overall picture of what is considered important for DHL. The criteria that were to be ranked and the accompanying information were presented in Dutch to these employees, since the interviewed people are Dutch. This is done in order to avoid misunderstanding and resulting erroneous criteria weights. More elaborate information on ranking the operational criteria on importance can be found in Appendix A: Weighting factors.

An example of a ranking order of the criteria is the following list, where criterion 1 is the most important and criterion 4 is the least important and where two criteria, availability and usability, share the second best position:

1. Costs
2. Availability, usability
3. Public perception (PP)
4. Lock-in

The weights of the criteria can now be established for this particular ranking sequence using the pair wise comparison with a preferential ranking of two components. The pair wise comparison is based on that:

- if A is more important than B, this is reflected with a “+” and A receives 3 points
- if A is equally important to B, this is reflected with a “0” and A receives 2 points
- if A is less important than B, this is reflected with a “−” and A receives 1 point.

The weighting procedure is presented in Table 5-3 for the above mentioned ranking sequence example. The points, that a criterion scores, are translated into weights, which determine the relative importance of each criterion. This is done by dividing the points of a criterion by the total points of all the criteria together, which is 40 in this case. For instance, availability and usability score 2 plusses, 1 minus and one zero, which means 2x3, 1x1 and 1x2 respectively, resulting in a total score of 9 points.
According to the performance on the operational criteria (i.e. the qualitative score in Table 5-2) and the relative importance of them (i.e. the weight factor from Table 5-3), the measures receive a total score by multiplying the qualitative score with their respective weights and adding up these values. An example of this procedure is shown in Table 5-4, again for the above mentioned ranking sequence example.

A selection of measures can be made with the total scores from Table 5-4. Six lists of total scores are available since six DHL managers have provided a ranking sequence and these results are shown in Appendix A: Weighting factors. When comparing these results, it becomes clear that there are two measures which end up with the highest scores amongst every ranking, namely driving behaviour and other vehicle measures. These two measures achieve final weighted scores for the operational management criteria that are lower than 3 in every ranking, implying that these measures score similar or better than the current situation on these criteria. Furthermore, the scores of hybrid drivetrains and alternative fossil fuels are close, but the measure hybrid drivetrains scores slightly better. Three measures are investigated further due to the time constraint. The three measures that thus remain after the second MCA stage are:
1. Driving behaviour
2. Other vehicle measures
3. Hybrid drivetrains

5.3 Summary and conclusions

Summary

Two selection steps have been performed in sections 5.1 and 5.2 providing a selection of measures. The results after the two MCA stages showed the three measures that scored best and that are investigated further. The other measures are excluded from further research due to the time constraint of this research. More information on opportunities for these measures can be found in the recommendations section 7.2. Several barriers have come up during the evaluation in this chapter, due to assumptions that were necessary to keep the MCA between the bounds of the research. These assumptions and barriers should be born in mind when making decisions on sustainable measures for the fleet. Furthermore, sustainable innovations should be watched closely, since rapid developments in this field will provide solutions for the drawbacks that are brought up in this research.

Conclusions

The Pareto efficiency concept proved to be an effective concept to emphasize the greenhouse gas emissions criterion. The weighting procedure from Breijing (1997) turned out to be effective in attributing weights to the operational management criteria, pursuing the vision of DHL on these criteria. It can be concluded that the measures driving behaviour, other vehicle measures and hybrid drivetrains are the most feasible measures for implementation at DHL. These measures not only score well on social welfare criteria, but also on criteria that are important for operational management at the company.
6 Case study terminal Amsterdam: modeling effects

6.1 Introduction

A two-stage multi-criteria analysis (MCA) evaluation has been performed in chapter 5, providing a selection of measures. The results after the two MCA stages showed the three measures that scored best and that are investigated further.

The fourth, fifth and sixth sub research questions are answered in this chapter. The operation of the heavy goods fleet at DHL terminal Amsterdam is investigated in a case study: routes are analyzed by data analysis with GPS data from the vehicles. This is done in order to obtain emission data from the operations and to investigate which levels of CO₂-emission reduction can actually be achieved with the three sustainable measures. Costs are not investigated in the case study. Not enough insight could be gained in all the cost elements of the sustainable measures. Depreciation and taxes, for instance, are very uncertain and may change rapidly depending on government policy amongst others. The data analysis is performed with a calculation tool that has been created in the spreadsheet software Microsoft Excel 2003. This program is the most used spreadsheet program in the world and is therefore compatible with a considerable amount of computers. This is important if DHL wants to expand the created tool or calculate other scenarios.

The case study is conducted with the measures in this chapter. First, the measures are briefly elaborated on with background information from literature in section 6.2. Next, the actual case study with the calculation tool and results are presented in section 6.3. General conclusions are presented in the last section of this chapter, section 6.4.

6.2 Modelled measures

The measures that remained after the two-stage MCA are elaborated on in this section. A brief overview with the current state of practice is presented for every measure. Furthermore, the sources of the parameters that are used in the Excel tool, which are not mentioned in chapter 4, are discussed.

6.2.1 Driving behaviour

The measure driving behaviour that is assessed in the MCA only comprises driver trainings. A speed reduction is not included, since the feasibility of implementation of this measure at DHL is questionable (see section 4.2.6). Several experts that are involved in the field of driving behaviour have been contacted. A project manager at the DHL Solutions & Innovations center (DSI) in Germany mentioned that a division in Germany achieved 10% improvement on fuel consumption after an incentive based program for better driving. Truck manufacturer Scania offers the Scania Drivers Training which consists of a day program with a morning and afternoon session. The participant drives a route applying his regular driving style in the morning, an instructor joins the driver in the afternoon and advises the driver on how to use the cruise control, coasting with the vehicle, choosing gears and using the retarder. A service engineer of Scania Beers B.V. states that there is a difference in fuel consumption of 10%
between the morning and afternoon session. However, he mentions that drivers tend to return to their former driving behaviour and a long-term benefit of 2 to 5% fuel consumption reduction remains.

### 6.2.2 Other vehicle measures

The measure 'other vehicle measures' comprises an aerodynamic package and fuel efficient tires. It is assumed that the tires do not deteriorate safety, as some fuel efficient tires may do. An R&D engineer at Ephicas, a company that creates aerodynamic solutions for trailers, trucks and buses, is contacted to gain more insight in aerodynamic and rolling resistances at trucks. Figure 6-1 from Ephicas shows the relation between rolling resistance (green line) and aerodynamic resistance (blue line) in 1000 Newton at the y-axis for varying truck speed at the x-axis. The engineer furthermore states that measurements at Ephicas showed that aerodynamic drag accounts for around 40% and rolling resistance for around 45% of the total losses for trucks at cruising speed. The remaining losses are mechanical losses (e.g. engine heat losses and gearbox friction losses).

![Figure 6-1: Truck resistance for varying vehicle speed (Ephicas)](image)

Engineers at Ephicas only take speeds of over 70 km/h into account for calculations, since aerodynamic improvements hardly have any effect at lower speeds. The company states that a fuel consumption reduction of 1.5 L/100 km on average can be achieved at speeds above 70 km/h. Furthermore, Rose (1991) states that if the aerodynamic drag reduces with 10%, fuel consumption will decrease with 3% to 5%. 
The project manager at the DSI in Germany states that pilot tests in Germany on standard aerodynamic kits (i.e. roof spoilers, side fairings etc.) showed a fuel consumption improvement of 6% in line haul operations.

Tire manufacturer Continental states that higher speeds increase rolling resistance, but it is unclear with what amount (Continental, 2011). The higher fuel consumption is the result of more tire deformations due to more rotations of the tire. Tire manufacturer Michelin states that rolling resistance has a significant influence, being responsible for one third of total fuel consumption (Michelin, 2011).

A Finnish research showed a difference in fuel consumption between their tested tires of 5.16% at its greatest, see Figure 6-2 (Nylund, 2008). The pink line indicates the rolling resistance. The reference tire was the Michelin XZA2 Energy and a Scania 124G Euro 3 truck was used for the measurements, using a highway cycle. A test from the research with a bus in an urban environment showed a difference of 2.6% at its greatest.

![Figure 6-2: Differences in fuel consumption and rolling resistance between tires (Nylund, 2008)](chart.png)

### 6.2.3 Hybrid drivetrains

A test has been conducted with a DAF LF hybrid 12 ton truck at DHL terminal Utrecht. This vehicle has only driven in the inner city of Utrecht. The test is not considered successful due to the frequent occurring malfunctions. However, the vehicle performed well during the seldom moments of deployment. The project manager at the DSI in Germany states that savings for hybrid trucks are between 6% in line-haul operation and 12% in urban traffic. Mercedes-Benz claims that their Axor hybrid will consume between 4% and 10% less fuel than a conventional Axor, depending on route and driving style.
6.3 Calculation tool

A data analysis calculation tool has been developed in Excel in order to indicate possible CO$_2$-emission reductions and the methodologies from the tool are presented in this section. The three measures are applied on the routes of DHL terminal Amsterdam, where all trucks are equipped with GPS data loggers. Sub-research question four is answered with the application of the tool. Sub-research questions five and six will be answered with the outcomes of the tool.

6.3.1 Calculation methodology

6.3.1.1 Requirements

CO$_2$-emissions can be reduced with hybrid vehicles, but higher reductions can be obtained when the vehicle is deployed in underlying road network traffic with a considerable level of start-stop traffic, then when the vehicle is deployed in long-haul freeway traffic with long stretches of driving at constant high speeds. Driving behaviour improvements will also have more effect in start-stop traffic than in freeway traffic, since more actions of the driver are demanded. Aerodynamic improvements will result in satisfying CO$_2$-emission reductions when the vehicle drives at high speeds frequently, i.e. above 70 km/h. Rolling resistance improvements will only have a slight better effect at higher speeds. It is thus necessary to determine the amount of freeway and underlying road network traveled kilometers and traveled kilometers with speeds above 70 km/h in order to give an indication on possible CO$_2$-emission reductions.

It must be noted that traffic jams, which may reduce the emission reduction differences between underlying road network and freeway traffic, are not taken into account. Furthermore, operations in daytime are performed with rigid lorries with cargo carrying capacity as well as with articulated lorry tractor-trailer combinations, where a tractor unit tows a semi-trailer through a fifth wheel coupling. The nocturnal line-haul transport between the DHL terminals, however, is only executed with the articulated lorries, which return to terminal Amsterdam after their operations. It is thus necessary to take the distinction between the two vehicle types into account, in order to achieve realistic emission reduction possibilities with the calculation tool. Therefore, emission reductions for the two truck types have to be calculated separately.

The measure characteristics result in the following tool requirements:

1. The tool should provide the amount of kilometers traveled on the underlying road network and on freeways, where the two large goods vehicle types of terminal Amsterdam are distinguished, on a representative day.
2. The tool should provide the amount of kilometers traveled with speeds above 70 km/h, where the two large goods vehicle types of terminal Amsterdam are distinguished, on a representative day.

The day that is investigated should be representative regarding driven kilometers in order to be able to generalize results, so that the error of yearly results is kept as small as possible. The operations manager of terminal Amsterdam reviewed a range of dates and confirmed that Tuesday June 21$^{st}$ 2011 is a day with representative operations. This implies that there are no disturbances, for instance a sorter malfunction in the terminal which results in drivers departing late or adapted routes because e.g. a driver has to leave early for a private appointment. Other factors that could influence the
Sustainable measures for the fleet of DHL Express

representativeness are national holidays, of which June 21st is not a part. No high errors due to distance variations per day can thus be expected when the resulting distances from the calculation tool are extrapolated to a year. A time span of 07:00 to 21:00 has been investigated in order to include all truck routes on June 21st. The GPS output data showed that all trucks were at the terminal before 07:00 and after 21:00.

Fuel consumption with and without sustainable measures can be calculated when the above requirements are met. This fuel consumption can be converted into CO₂-emissions and the amount of savings can be calculated. An overview of the tool is presented in Figure 6-3. The elements of this figure are elucidated in the next sections.

Figure 6-3: Structure of the calculation tool

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6.3.1.2 Raw data and transforming process

The raw data for the tool from DHL mainly consists of export files of the GPS trackers that are installed in the vehicles of terminal Amsterdam. These GPS trackers measure various vehicle characteristics every minute. The data elements that are used from the export files are GPS coordinates (latitude and longitude in WGS-84 notation), momentaneous speed and time.

Other raw data that is used are reference coordinates of the freeway stretches of five main routes. These reference coordinates are compared with the GPS coordinates in order to check on which freeway segments trucks have driven. This will be discussed in the next section, wherein the modeling step of attributing the routes of terminal Amsterdam to five main routes is discussed. The reference coordinates are obtained from an online route planner and are also in WGS-84 notation.

A transformation from the WGS-84 coordinates to Rijksdriehoeks-coordinates (RD) is performed with formulae from Schreutelkamp and Strang van Hees. Both the GPS output coordinates from the vehicle tracker and the looked up reference coordinates from the routes are converted from WGS-84 to RD. The RD coordinate system is a system that is used in the Netherlands on a national level as a basis for geographical designations and files, for instance in geographical information systems (GIS) and for various (national) topographical maps. The transformation calculations can be used to convert the data from the GPS trackers to a form that is more customary in the Netherlands. It is hard to perform calculations with WGS-84 coordinates, but RD coordinates are expressed in meters and this makes performing calculations more straightforward. Distances in the tool, for instance, are calculated with RD coordinates. The formulae used for the transformation from are:

\[ d\varphi = 0.36 \cdot (\varphi - \varphi_0) \]
\[ d\lambda = 0.36 \cdot (\lambda - \lambda_0) \]
\[ X = X_0 + \sum_p \sum_q R_{pq} \cdot d\varphi^p \cdot d\lambda^q \]  
(Schreutelkamp and Strang van Hees, 2002)
\[ Y = Y_0 + \sum_p \sum_q S_{pq} \cdot d\varphi^p \cdot d\lambda^q \]

The coefficients \( \varphi \) and \( \lambda \) are the WGS-84 input coordinates and \( X \) and \( Y \) are the RD output coordinates. The coefficients \( \varphi_0, \lambda_0, X_0 \) and \( Y_0 \) are reference coordinates of a basis point in Amersfoort. The coefficients \( R \) and \( S \) from the formulae depend on varying values for \( p \) and \( q \) and are shown in Table 6-1.
The raw data is transformed into data on which calculations can be performed, as explained in the previous section. The next step in Figure 6-3 is the check and distance methodology. This methodology comprises two sub-methodologies, namely:

- The determination of freeway distance driven per truck, comprising a check whether trucks have driven on a certain freeway stretch
- The determination of distance driven with speeds of 70 km/h and higher

First the determination of the freeway distance is discussed, subsequently the determination of the distance driven with speeds of 70 km/h and higher.

**Determination of freeway distance**

There are 31 trucks at terminal Amsterdam, of which 20 rigid cargo body lorries and 11 articulated lorries. There is no data of three vehicles, one vehicle drove a route for terminal Hoofddorpe and five vehicles were not used on June 21st. The result is that data of fourteen rigid cargo body lorries and eight articulated lorries can be used, thus 22 vehicles in total. There are ten vehicles with a GVW of 12 tons and four vehicles with a GVW of 18 tons amongst the fourteen rigid cargo body lorries. The eight articulated lorries all have a GVW of 18 tons. Since it takes a considerable amount of time to investigate routes on individual truck level and the results can not be generalized then, a method has been found to aggregate the route data of June 21st for investigation of the amount of underlying road network and freeway traffic. Five main routes are determined to which all truck routes can be assigned. These main routes are:

1. Amsterdam city center
2. Zaandam and Wormerveer
3. Haarlem city center and Zwanenburg
4. Amsterdam South East, Diemen and Weesp
5. Schiphol, Badhoevedorp and Uithoorn

All trucks can be assigned to these routes, implying that 100% of the routes is covered. Trucks may call at these destinations more than once a day and at several of the five destinations. Furthermore, more trucks may drive to one destination. Most of the destinations include a freeway stretch. The amount of
kilometers driven on a freeway stretch is checked for every truck, which is explained in the next paragraphs. The freeway stretches on which the trucks have driven and that are investigated are shown in Figure 6-4, together with the location of DHL terminal Amsterdam.

A check is performed whether a truck has driven on a certain freeway stretch for the freeway stretches that are part of the routes to the five destinations. A considerable amount of reference check-coordinates which are part of the freeway stretch have been looked up with an online route planner and these coordinates are compared to the output coordinates of the GPS tracker. Since trucks can reach speeds up to around 90 km/h and the GPS tracker takes measurements every minute, a measurement can lay in a stretch of 1.5 km. However, the check margin should not be too large, because otherwise secondary roads close to the freeway may be checked. Therefore, the reference check-coordinates are located every 500 meters. It is then checked whether a truck GPS coordinate lies in the margin of 250 meters before and 250 meters after the check-coordinate. Since the distance between the GPS coordinates may be up to 1.5 km, a truck will not be checked at every check-coordinate, but at around one out of three check-coordinates.

It is also checked whether a truck could be located on a road close to the freeway or actually on the freeway and whether the truck is checked within a short time interval. This is necessary because trucks often travel a freeway stretch in one direction in the morning and in the other direction when they return to the terminal, which results in multiple checks. These two checks are captured in a formula in which the next three freeway segments are checked. It is checked whether the truck has been located on one of these three segments one minute in the future and one minute in the past. The assumptions have been made that a truck was actually on the freeway on a certain coordinate and the location was part of
Sustainable measures for the fleet of DHL Express

one trip, if a truck is checked on one of the three following freeway coordinates one minute before or one minute later.

Next, the distance is calculated on the freeway stretches with the GPS coordinates if the truck has been checked on these stretches. These distances are summed in order to obtain the total distance driven on freeways by a truck. This total distance on freeways is compared with the actual distance, which is obtained from route print-screens on a map from the GPS data. It appeared that there were consequent small errors. The total distances calculated by the tool were slightly shorter than the actual distances. This can be explained by the fact that trucks were checked on one of the three following freeway coordinates one minute before or one minute later, thus freeway segments are missed at the point where the truck leaves the freeway. The error varies between 500 m and 1,5 km per freeway stretch, since the check-coordinates are located every 500 m.

Determination of distance driven with speeds of 70 km/h and higher

The determination of distance driven with speeds of 70 km/h and higher is captured in another part of the tool. This methodology contains calculations on travelled speeds, which are used to determine emission reductions from aerodynamic and rolling resistance improvements. The amount of kilometers driven at a speed of 70 km/h or higher is calculated, since aerodynamic improvements only have effect above this speed. Effects of fuel efficient tires are also assumed to have a larger impact at higher speeds due to increased rolling resistance, which is explained in section 6.2.2.

The GPS measured speeds of 70 km/h or higher are summed for every truck. This results in a number of minutes that a truck drove 70 km/h or faster and this is converted into distance traveled with a speed of 70 km/h or higher, by using the average of the speeds that were measured above 70 km/h. The distance traveled with 70 km/h or higher is used in the output analysis. The accuracy of these distances is determined by the fact that measurements are taken every minute by the GPS vehicle tracker. Errors are attempted to be kept small by using average speeds between two measurement points. The distances can also be calculated with the GPS tracker output coordinates, but the same line of reasoning holds for the accuracy due to measurements taken every minute. A short calculation shows that the difference between distances derived from coordinates or from speeds is 0,003%.

The distance driven with speeds of 70 km/h and higher is also determined for the nocturnal line-haul terminal to terminal transport. The night from Tuesday June 21st to Wednesday June 22nd is investigated, since this night is considered to have a more regular transport pattern (regarding transport volumes and disturbances) then the night from Monday June 20th to Tuesday June 21st, according to the operations manager of terminal Amsterdam. Five articulated lorries drove from terminal Amsterdam to several other terminals and returned to terminal Amsterdam that night. The distance is calculated with the GPS tracker output coordinates from the vehicles and it is assumed that speeds are mainly above 70 km/h, since the DHL terminals are located close to freeways and there is generally no heavy traffic at night. This assumption is founded with a check that is performed, which shows that the speed was above 70 km/h at 86% of the measurements in the investigated night.

The measures improved driving behaviour and hybrid drivetrains are not investigated for the nocturnal line-haul transport operations, because literature and expert analysis are found to be inconclusive on potential savings of these measures on long freeway stretches at constant speed.

6.3.1.4 Output analysis

The transformation of raw data to distances is discussed in the previous section and comprises distance driven on freeway stretches and distance driven with speeds of 70 km/h or higher. The next step in
Figure 6-3 is the analysis of the output with calculations in order to obtain results and is presented in this section.

As can be seen in Figure 6-3, the tool output is combined with raw data (daily mileages) and input parameters from literature. The raw data is extracted from the Route Day Card sheets from DHL and comprises the mileage at the start and at the end of the day and the fleet numbers and license plate numbers of the vehicles. The start mileage of the trucks is subtracted from the end mileage to obtain total kilometers driven on June 21st per truck. The fleet and license plate numbers are combined with another fleet data sheet from DHL with fleet numbers and vehicle types, i.e. articulated lorries with a GVW of 18 tons (which are also deployed at night) and rigid cargo lorries with a GVW of 12 and 18 tons. This way the total driven kilometers of a truck per vehicle type are obtained. The distance driven on the underlying road network is determined by subtracting the freeway distance of the total distance for every truck.

Obtaining the fuel consumption parameters of conventional large goods trucks in different traffic types is not straightforward. Several truck manufacturers have been contacted but without success. Truck manufacturer Scania mentioned a general value of 32 L/100 km for long distance trucks. Ephicas, a company specialized in aerodynamic solutions for trucks, mentioned 22 L/100 km on average for a certain truck deployed in nocturnal line-hauls and 35 L/100 km on average for that truck deployed in daytime. Since the fuel consumption for conventional large goods trucks at terminal Amsterdam turns out to be 35.17 L/100 km on average with calculations, a value of 40 L/100 km for the underlying road network and 33 L/100 km for freeway traffic are assumed, taken into account that considerably more kilometers are driven on the freeway, particularly as a result of the nocturnal line-hauls.

The input parameters from literature furthermore comprise the fuel consumption values for freeway traffic and underlying road network traffic for the three modeled measures, which are discussed in section 4.2 and section 6.2. The values are presented in percentages fuel consumption reduction compared to conventional vehicles in these sections, but they are converted into L/100 km. It must be noted that the values for hybrid drivetrains and improved driving behaviour in freeway traffic are partly established by an educated guess, since literature and expert analysis are found to be inconclusive on potential savings of these measures on long freeway stretches at constant speed.

An average fuel consumption reduction of 15% has been assumed for improved driving behaviour for underlying roads and 5% for freeways, taken into account a range of 2-20% potential reductions from literature, depending on short or long-term effects. No difference in values for underlying roads and freeways could be found in literature, but it is assumed that higher reductions can be obtained on underlying roads (see section 6.3.1.1). Hybrid drivetrains are assumed to perform 16% better on underlying roads and 6.5% better on freeways, taken into account an efficiency improvement range of 12-20% and 3-10%, respectively. A truck with improved aerodynamics and fuel efficient tires is assumed to perform 10.1% better on road stretches where the speeds were 70 km/h or higher, taken into account an efficiency improvement range of 2.1-18%. It is assumed that a conventional vehicle has the same fuel consumption rate as a vehicle equipped with better aerodynamics and fuel efficient tires on underlying road traffic. The resulting fuel consumption values that are used in the tool are shown in Table 6-2.
Table 6-2: Fuel consumption parameters for underlying road network and freeway traffic

<table>
<thead>
<tr>
<th>Measure</th>
<th>Fuel consumption underlying road network traffic (L/100 km)</th>
<th>Fuel consumption freeway traffic (L/100 km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional vehicle</td>
<td>40</td>
<td>33</td>
</tr>
<tr>
<td>Improved driving behaviour</td>
<td>34</td>
<td>31.35</td>
</tr>
<tr>
<td>Hybrid drivetrain</td>
<td>33.6</td>
<td>30.86</td>
</tr>
<tr>
<td>Improved aerodynamics and rolling resistance</td>
<td>40</td>
<td>29.68</td>
</tr>
</tbody>
</table>

The results in Figure 6-3, i.e. consumed fuel in liters with and without the measures and resulting savings compared to the current vehicles, can now be obtained by combining distances and fuel consumption parameters. First a sensitivity analysis is conducted in the next section, in order to investigate the robustness of the tool.

6.3.2 Sensitivity analysis

The robustness of the calculation tool is investigated with a sensitivity analysis in this section. A sensitivity analysis is used to determine what happens to the output of the model if a particular change to an input parameter is made. The analysis shows how sensitive the result is to a small change of an input parameter. If a small change in an input parameter results in relatively large changes in the outcomes, the outcomes are said to be sensitive to that parameter or not robust. The input parameters that are varied here are certain fuel consumption parameters from Table 6-2 and the check-speed of 70 km/h for aerodynamic and rolling resistance improvements. The fuel consumption parameters are varied with 5%, the check speed is varied from 70 km/h to 75 km/h, i.e. a variation of 7%. These variations are assumed to be realistic variations on the parameters.

The results of the sensitivity analysis are shown in Appendix B. It can be concluded from these results that the calculation tool is not very sensitive to the mentioned varied parameters. No extreme values resulted from the sensitivity analysis, thus the tool shows robustness to a certain extent.

6.3.3 Results

The results from the calculation tool comprise consumed fuel in liters with and without the measures and resulting savings compared to the current vehicles. The results have first been separated for daytime operation (June 21st 07:00 to 21:00) and for a space of twenty-four hours (June 21st 07:00 to June 22nd 07:00). The results of all three measures for all large goods vehicles at terminal Amsterdam are included in the daytime results, the results of improved aerodynamics and rolling resistance for the five articulated lorries are included in the twenty-four hour period. The daytime results are the results for all main routes combined and are shown in Table 6-3.
Sustainable measures for the fleet of DHL Express

Table 6-3: Results for daytime operation

<table>
<thead>
<tr>
<th></th>
<th>Conventional vehicle</th>
<th>Improved driving behaviour</th>
<th>Hybrid drivetrain</th>
<th>Improved aerodynamics and rolling resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumed fuel (L)</td>
<td>727.04</td>
<td>633.78</td>
<td>625.74</td>
<td>708.25</td>
</tr>
<tr>
<td>Savings</td>
<td>12.83%</td>
<td>13.93%</td>
<td></td>
<td>2.58%</td>
</tr>
</tbody>
</table>

The results for improved aerodynamics and rolling resistance for the twenty-four hour period are shown in Table 6-4.

Table 6-4: Results for improved aerodynamics and rolling resistance for 24 hours

<table>
<thead>
<tr>
<th></th>
<th>Conventional vehicle</th>
<th>Improved aerodynamics and rolling resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumed fuel (L)</td>
<td>902.80</td>
<td>827.32</td>
</tr>
<tr>
<td>Savings</td>
<td>8.36%</td>
<td></td>
</tr>
</tbody>
</table>

The results in Table 6-3 and Table 6-4 are separated because DHL division Express organizes transport operations in daytime and DHL division Freight organizes the nocturnal line-haul transport between the terminals at night (with the vehicles of DHL Express, as explained in section 2.1). Decisions on sustainable measures can be made per division or in mutual deliberation with these separated results.

Aggregated results for all vehicles in a twenty-four hour period are also relevant for DHL. A complete overview for all large goods vehicles of terminal Amsterdam in the twenty-four hour space is presented in Table 6-5. The measures hybrid drivetrains and improved driving behaviour are not investigated at night as mentioned in section 6.3.1.3.

Table 6-5: Results for all large goods vehicles in the twenty-four hour space

<table>
<thead>
<tr>
<th></th>
<th>Conventional vehicle</th>
<th>Improved driving behaviour</th>
<th>Hybrid drivetrain</th>
<th>Improved aerodynamics and rolling resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumed fuel (L)</td>
<td>1.407.46</td>
<td>1.314.20</td>
<td>1.306.16</td>
<td>1.320.22</td>
</tr>
<tr>
<td>Savings</td>
<td>6.63%</td>
<td>7.20%</td>
<td>6.20%</td>
<td></td>
</tr>
</tbody>
</table>

The calculation tool seems to provide results that are not unrealistic, when the saving percentages from Table 6-3, Table 6-4 and Table 6-5 are compared to the efficiency parameters from 6.3.1.4. This yields a validation for the algorithms that form the calculation tool.

From the results in Table 6-3 it can be seen that a hybrid drivetrain provides the most promising results in daytime operation, but the high savings for hybrid drivetrains and improved driving behaviour decrease to the values in Table 6-5 when the consumed fuel at night is included in the results. It must be noted that these savings will become higher when the benefits of hybrid drivetrains and driving behaviour are included in the nocturnal line-haul transport, but fuel consumption parameters of these measures on freeways are inconclusive in literature in the time that this research was conducted.

It can also be seen that the low scores of improved aerodynamics and rolling resistance in daytime (Table 6-3) improve once the results from the nocturnal line-haul transport are analyzed (Table 6-4 and Table
Sustainable measures for the fleet of DHL Express

6-5). Long stretches of freeway are traveled at night, forming opportunities for aerodynamic and rolling resistance improvements. The fuel savings are proportional to CO₂-emission reduction, as mentioned before in section 4.2.5 and 4.2.6 and a factor of 2.7 kg CO₂ per consumed liter diesel can be used (Febiac 2011). This results in savings of, for instance, 0.274 ton CO₂ per day (twenty-four hours) when a hybrid vehicle would have been deployed at DHL terminal Amsterdam.

The results from the tool can be extrapolated to other days, since a representative day without disturbances and holidays is investigated. A year comprises 52*5 = 260 working days, but transport volumes and resulting driven kilometers will be lower due to e.g. holidays, Mondays and Fridays which are days with lower volumes and disturbances at the terminal. Therefore, the point of departure for the extrapolation to a year is 240 working days. Table 6-6 shows yearly savings in tons CO₂, fuel savings in euro and the payback time for the three measures. The values for improved aerodynamics and rolling resistance are based on application of the measure on all large goods vehicles of terminal Amsterdam that were used from June 21st 07:00 to June 22nd 07:00 (i.e. 22 vehicles), the values between brackets are based on application of the measure only on the five trucks that were deployed at daytime and in the night. A fuel price of € 1.39 per liter diesel and the earlier used diesel to CO₂-factor of 2.7 are used (Febiac, 2011) (United Consumers, 2011). Furthermore, the additional costs for the measures have been determined with literature and information from DHL. Other calculations show that the current CO₂-emissions in a year are 912 tons for all large goods vehicles at terminal Amsterdam.

Table 6-6: Results for one year and payback period

<table>
<thead>
<tr>
<th></th>
<th>Conventional vehicle</th>
<th>Improved driving behaviour</th>
<th>Hybrid drivetrain</th>
<th>Improved aerodynamics and rolling resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumed fuel (L)</td>
<td>337.791,31</td>
<td>315.408,53</td>
<td>313.479,87</td>
<td>316.853,04 (321.362,20)</td>
</tr>
<tr>
<td>CO₂ savings (ton)</td>
<td></td>
<td>60,43</td>
<td>65,64</td>
<td>56,53 (44,36)</td>
</tr>
<tr>
<td>Fuel savings (€)</td>
<td>€ 31.112,05</td>
<td>€ 33.792,90</td>
<td></td>
<td>€ 29.104,19 (€ 22.836,45)</td>
</tr>
<tr>
<td>Payback period (months)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The payback period is calculated with initial costs for all three measures, additional yearly costs for maintenance of hybrid drivetrains and for follow-up driver trainings and additional yearly benefits due to decreasing damage costs for the measure driving behaviour.

The results show that the measure improved driving behaviour and improved aerodynamics and rolling resistance have the shortest payback periods, especially when only the line-haul trucks are equipped with improved aerodynamics and rolling resistance tires. The highest CO₂-savings can be achieved with hybrid vehicles, but against a payback period which is considerably longer than for the other two measures.

Extrapolation of the results to other terminals is not performed, since the amount of freeway traffic is very specific per terminal. Terminal Roosendaal, for instance, comprises routes to the whole province of Zeeland amongst others, resulting in considerably more kilometers driven with higher speeds. Using the results of terminal Amsterdam for terminal Roosendaal would thus lead to inaccurate results.
6.3.4 Limitations

The Excel calculation tool is a simplification of reality, thus the tool has some limitations. Firstly, only a distinction has been made between an underlying road network and a freeway traffic type, with respective fuel consumption parameters. The extent of braking and acceleration is thus approximated. The second limitation is that the time of day is not included. A certain amount of traffic is assumed and this is captured in the fuel consumption parameters for underlying road network and freeway traffic, which are mentioned in section 6.3.1.4. Traffic jams are thus not included. The GPS tracker provides measurements every minute, which is the third limitation. When measurements are taken more frequently, more detailed information can be obtained since the tool can calculate distances more accurately. The fourth limitation comprises tool methodology errors. The distance traveled on freeways is slightly too short for every freeway stretch, the distances traveled with speeds of 70 km/h or higher and the checks whether a truck drove where are determined with a certain margin, as explained in 6.3.1.3. The fifth limitation is the accuracy of the fuel consumption parameters. These parameters have been found in literature and by consulting field experts, thus general values and not specific for the trucks and operation conditions (e.g. weight of the loaded cargo) at DHL terminal Amsterdam. They are neither specified for the three different truck types at terminal Amsterdam. Lastly, no distinction has been made in speeds above 70 km/h regarding aerodynamic and rolling resistances. It thus does not matter whether a truck drives 70 km/h or 80 km/h on a certain stretch. The last two limitations are partly analyzed in the sensitivity analysis in section 6.3.2, where the driving behaviour fuel consumption parameters are varied and several speeds above 70 km/h are investigated.

6.4 Summary and conclusions

Summary

Sub-research four, five and six have been answered in this chapter. Creating a calculation methodology for the measures that remained after the MCA on the process of DHL was successful for terminal Amsterdam. The checks on whether a truck drove where and the distances provided by calculations performed in the tool appeared to approach actual values with small errors. The current amount of CO2-emissions amongst the large goods fleet of DHL Express is 912 tons per year. The potential savings that can be achieved with the three sustainable measures compared to the current vehicles range from 44,36 to 65,64 ton CO2 per year, while the payback period ranges from 1 to 3 months.

Conclusions

It can be concluded that improved driving behaviour and improved aerodynamics and rolling resistance are the most promising measures from the calculation tool with the shortest payback period and yielding favourable yearly CO2-savings. It must be noted that the benefits of improved driving behaviour fade away as time elapses and when no follow-up trainings are provided. Hybrid drivetrains seem not feasible for implementation due to their high investment costs and resulting long payback period.
7 Conclusions and recommendations

The conclusions of the research and recommendations for further research are presented in this chapter. First, the general conclusions are presented in section 7.1. Next, the recommendations are presented in section 7.2. Lastly, the reflections of this research are discussed in section 7.3.

7.1 Conclusions

The conclusions are presented according to the research questions that have been set up. The main research question can be answered with the six sub-research questions. First, answers are provided for these sub-research questions, where after the main research question is answered.

Sub-research question one was answered by setting up a set of sustainable fleet measures, using feedback sessions with DHL and literature. The repetitive improvements and elaboration on the measures resulted in a comprehensive set of measures with state-of-the-art characteristics. Difficulties emerged in which measure to include and which not, but the final set of measures complied with the demands of DHL and comprised a considerable amount of measures which are regarded promising amongst measures found in literature. Interviews with experts from the field confirmed that no relevant measures were omitted.

Sub-research questions two and three were answered by conducting a two-stage MCA assessment on the set of measures. It can be concluded from the assessment part of the multi-criteria analysis in chapter 4 that assessing the created set of sustainable measures is not straightforward. Several measures comprise sub-measures with different mutual characteristics, e.g. fuels from biomass comprise biogas and biodiesel. Therefore, the measures have been split up in sub-measures, but assessing every sub-measure on every discussed criterion would demand considerably more time than available for this research, due to the high level of detail required.

The Pareto efficiency concept, used to evaluate the MCA, proved to be a helpful aid in order to emphasize the greenhouse gas criterion. The pairwise-comparison with a preferential ranking of two components weighting procedure turned out to be effective in attributing weights to the operational management criteria, pursuing the vision of DHL.

All measures score relatively well, especially on greenhouse gas emissions, which is the result of using the Pareto efficiency concept and the initial selection of measures in chapter 3. The literature study and surveys with DHL used for the initial selection thus proved to be appropriate. First and second generation liquid biofuels are the only measures that score worse than conventional vehicles on a criterion in the MCA. It can be concluded that the measures driving behaviour, other vehicle measures and hybrid drivetrains are the most feasible measures for implementation at DHL. These measures do not only score well on social welfare criteria, but also on criteria that relate to smooth operations at the company.

An issue was that potential barriers came up during the MCA-evaluation, which were not reflected by the scores. The rapid developments of certain sustainable measures also form difficulties for assessing these measures. These barriers and developments should be born in mind when using the results of this assessment.
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Sub-research four, five and six have been answered in a data analysis case-study for DHL terminal Amsterdam, which not only serves the city center, but also the Amsterdam region. Creating a calculation methodology for the measures that remained after the MCA, in order to estimate the effects of these measures, was successful. The checks on whether a truck drove where and the distances provided by calculations appeared to approach actual values with small errors.

The current amount of CO₂-emissions amongst the large goods fleet of DHL Express is 912 tons for terminal Amsterdam per year. The potential savings that can be achieved with the three sustainable measures compared to the current vehicles range from 44.36 to 65.64 ton CO₂ per year, while the payback period ranges from 1 to 3 months. The results showed that a hybrid drivetrain provides the most promising results in daytime operation with more start-stop traffic, but the high savings for hybrid drivetrains and improved driving behaviour decrease when the consumed fuel at night is included in the results, due to the long distances traveled at constant speed at night. The results also showed that that the low scores of improved aerodynamics and rolling resistance in daytime improve once the results from the nocturnal line-haul transport are analyzed. The long stretches of freeway traveled at night form opportunities for aerodynamic and rolling resistance improvements.

It can be concluded that improved driving behaviour and improved aerodynamics and rolling resistance are the most promising measures from the calculation tool with the shortest payback period and yielding favourable yearly CO₂-savings. It must be noted that the benefits of improved driving behaviour fade away as time elapses and when no follow-up trainings are provided. Hybrid drivetrains seem not feasible for implementation due to their high investment costs and resulting long payback period.

The main research question was formulated as follows:

'To what extent can the transport of large goods of DHL the Netherlands be optimized from the perspective of CO₂-reduction and under which conditions will a reduction in CO₂-emission in practice actually occur?'

The implementation of the measure improved driving behaviour or improved aerodynamics and rolling resistance will lead to satisfying results. These measures combine a considerable decrease in CO₂-emissions and an attractive financial performance: a win-win situation for DHL and the environment and an example for other transport companies.

7.2 Recommendations

Recommendations for the future are presented in this section. As mentioned before, developments in the field of sustainable technologies should be watched closely. Furthermore, developments should be monitored on a cross-measure level. CNG and LNG developments, for instance, may stimulate a hydrogen economy. Another interesting opportunity is the combination of measures, e.g. combining a CNG and a hybrid drivetrain in one vehicle. This may result in promising emission reductions compared to conventional vehicles.

The test-drive cycle is of major importance for determining fuel efficiency of sustainable measures. All WHDC-validation and measurement programs carried out so far only covered diesel engines. For throttled engines (otto-cycle LPG and CNG for heavy-duty purpose), the applicability of the ISO procedure is not proven yet. Furthermore, the assessment of sustainable measures should be linked to the deployment characteristics at DHL. A vehicle with good results tested in a LHDC may not provide
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good results when it is mainly deployed in urban traffic. This is also pointed out in section 6.3.3, wherein the results of the case study at the Amsterdam region are presented.

A recommendation on the strategy of DHL is to set up targets for emissions other than CO₂. PM and NOₓ are especially forming problems in the Netherlands, and including these emissions in e.g. the GoGreen program may result in a better environmental performance.

The influences on the logistic processes of DHL of implementing measures have not been investigated with much detail in this research. The influences that are investigated are chiefly captured by the usability criterion from the MCA. However, more research should be performed on the influences on e.g. route planning, size and weights of the goods that are currently transported by DHL and on operational influences. The effects of implementation of measures on the whole logistics chain of DHL should be mapped.

Several recommendations can be given for the calculation tool from the case study and related issues. The GPS tracker could be adjusted differently, providing measurements more often than once per minute. This will lead to more accurate data and thus more accurate calculations. Furthermore, the time of day could be included in the tool. A more realistic traffic type will be obtained with more realistic shares of start-stop and constant speed traffic. Traffic jams due to rush hour, for instance, can then also be included. Another recommendation is to make more distinctions in traffic types then the two types that have been used now. It must be noted that this is only possible if fuel consumption parameters for the investigated measures can be obtained for these traffic types. It was mentioned in chapter 6 that this can be difficult.

7.3 Reflections

This chapter closes off with reflections on the research process. The first step in the research (after determining the research problem and setting up the research questions) was creating the set of sustainable measures that were to be investigated. Putting together this set lead to small problems regarding which measures to include, but sets with promising measures could be found in literature and the repetitive feedback sessions with DHL helped to indicate which measures to include and which to omit. Interviews with experts from the field confirmed that no relevant measures were omitted.

However, the assessment of the set of measures for the MCA was not straightforward. Several measures comprise sub-measures with different mutual characteristics. Therefore, the measures have been split up in sub-measures, but logically not every sub-measure could be assessed on every criterion, due to the time constraint of the research. Setting up a detailed assessment was pursued, but time could have been saved by not going into too much detail with the assessment.

This line of reasoning also holds for the MCA evaluation. Several barriers came up during the evaluation, due to assumptions that were necessary to keep the MCA between the bounds of the research. Too much time was spend on pursuing an elaborate and detailed evaluation, but assumptions could not be avoided in the end and should have been made earlier.

The case study for the Amsterdam region worked out well. Creating a calculation methodology for the measures that remained after the MCA, in order to estimate the effects of these measures, was successful.
Sustainable measures for the fleet of DHL Express

References

List of interviews

<table>
<thead>
<tr>
<th>Type of company</th>
<th>Company name</th>
<th>Contact person</th>
<th>Function</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck and bus import</td>
<td>PON</td>
<td>Gense, R.</td>
<td>Manager Sustainable Development</td>
<td>Emissions, CNG, LNG</td>
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<td>DHL</td>
<td>Greeven, M.</td>
<td>Unknown</td>
<td>Route planning</td>
</tr>
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<td>DHL</td>
<td>Jacobs, H.</td>
<td>Coordinator Euronet Domestic Benelux</td>
<td>Line-haul transport</td>
</tr>
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<td>DHL</td>
<td>Kers, H.</td>
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<td>Sustainable measures</td>
</tr>
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<td>DHL</td>
<td>van der Kolk, G.</td>
<td>Projectmanager Euronet Domestic</td>
<td>Line-haul transport</td>
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<td>DHL</td>
<td>Mathijsen, W.</td>
<td>manager QSE DHL Freight NL</td>
<td>DHL Freight, linehauls</td>
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<td>DHL</td>
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<td>Project Manager</td>
<td>Route planning</td>
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<td>DHL</td>
<td>Sterk, R.</td>
<td>Truck driver</td>
<td>Sustainable measures, driving behaviour</td>
</tr>
<tr>
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<td>MAN</td>
<td>ten Tuynte, I.</td>
<td>Product manager</td>
<td>Sustainable measures</td>
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<td>DHL</td>
<td>Verhulst, C.</td>
<td>Terminal Employee</td>
<td>Sustainable measures</td>
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</table>

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Appendices

Appendix A: Weighting factors

The operational management criteria that were used in the second stage of the MCA have been attributed a weight factor and these weight factors have been set up with the preferences of DHL. Six DHL managers from the operation field have been interviewed in order to obtain a representative overall picture of what is considered important for DHL:

Manager 1: The Operations Support Manager of DHL the Netherlands
Manager 2: The Terminal Manager of terminal Alkmaar
Manager 3: The Operations Engineering & Equipment Manager of DHL the Netherlands
Manager 4: The Terminal Manager of terminal the Hague
Manager 5: The Ground Operations Manager Day Definite (International) of DHL the Netherlands
Manager 6: The Managing Director Strategy & Business Development of DHL the Netherlands

These six managers were asked to rank the operational criteria on relative importance. This ranking sequence is used in a weighting procedure, i.e. a pair-wise comparison with a preferential ranking of two components (Breijing, 1997), in order to determine the criteria weights. These criteria weights are then multiplied with the corresponding criteria grades, resulting in total weighted scores for the sustainable measures. The six ranking sequences, weighting procedures with resulting weights and overviews with weighted scores are presented in Table A-1 to Table A-18 for all six managers. Green cells indicate a score better than a conventional vehicle, E.V. means full electric vehicle.

Table A-1: Ranking sequence for manager 1

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Availability</td>
</tr>
<tr>
<td>2</td>
<td>Costs</td>
</tr>
<tr>
<td>3</td>
<td>Usability</td>
</tr>
<tr>
<td>4</td>
<td>Public Perception</td>
</tr>
<tr>
<td>5</td>
<td>Lock-in</td>
</tr>
</tbody>
</table>

Table A-2: Criteria weights with ranking of manager 1

<table>
<thead>
<tr>
<th></th>
<th>Costs</th>
<th>Avail.</th>
<th>Usab.</th>
<th>Lock-in</th>
<th>PP</th>
<th># +</th>
<th># -</th>
<th># 0</th>
<th>Points</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td></td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>0,25</td>
</tr>
<tr>
<td>Avail.</td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>0,3</td>
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<tr>
<td>Usab.</td>
<td>-</td>
<td>-</td>
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<td>+</td>
<td>+</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>8</td>
<td>0,2</td>
</tr>
<tr>
<td>Lock-in</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>4</td>
<td>0</td>
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<tr>
<td>PP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td></td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>6</td>
<td>0,15</td>
</tr>
<tr>
<td>Total</td>
<td></td>
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<td></td>
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<td></td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
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</tbody>
</table>
Table A-3: Total weighted scores with ranking of manager 1

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<th></th>
<th>Costs</th>
<th>Avail.</th>
<th>Usab.</th>
<th>Lock-in</th>
<th>PP</th>
<th>Weighted Score</th>
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</thead>
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<tr>
<td>Alt. foss.</td>
<td>grade</td>
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<td>3</td>
<td>4</td>
<td>4</td>
<td>3,2</td>
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<tr>
<td></td>
<td>weight</td>
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<td>0,3</td>
<td>0,2</td>
<td>0,1</td>
<td>0,15</td>
</tr>
<tr>
<td>Biogas</td>
<td>grade</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3,7</td>
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<tr>
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<td>0,2</td>
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<td>0,15</td>
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<td>E.V.</td>
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<td>0,15</td>
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<td>2</td>
<td>4</td>
<td>3,15</td>
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Table A-4: Ranking sequence for manager 2

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<td>Costs</td>
</tr>
<tr>
<td>3</td>
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<td>4</td>
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<td>Lock-in</td>
</tr>
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Table A-5: Criteria weights with ranking of manager 2

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<th>Avail.</th>
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<th>Lock-in</th>
<th>PP</th>
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<th># -</th>
<th># 0</th>
<th>Points</th>
<th>Weight</th>
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</thead>
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<td>-</td>
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<td>+</td>
<td>+</td>
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</table>
Sustainable measures for the fleet of DHL Express

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<th>Lock-in</th>
<th>PP</th>
<th>Weighted Score</th>
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<td>4</td>
<td>4</td>
<td>3,2</td>
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<td>0,1</td>
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<td>grade</td>
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<td>0,15</td>
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<td>E.V.</td>
<td>grade</td>
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<td>4</td>
<td>4</td>
<td>4</td>
</tr>
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<td>0,2</td>
<td>0,25</td>
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<td>3</td>
<td>2</td>
<td>4</td>
<td>3,15</td>
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<td>0,2</td>
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<td>0,25</td>
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<td>0,15</td>
</tr>
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<td>grade</td>
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<td>3</td>
<td>3</td>
<td>2</td>
<td>2,8</td>
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<td>0,15</td>
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<table>
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<th>Table A-7: Ranking sequence for manager 3</th>
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<tbody>
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</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table A-8: Criteria weights with ranking of manager 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Costs</td>
</tr>
<tr>
<td>Avail.</td>
</tr>
<tr>
<td>Usab.</td>
</tr>
<tr>
<td>Lock-in</td>
</tr>
<tr>
<td>PP</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

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Table A-9: Total weighted scores with ranking of manager 3

<table>
<thead>
<tr>
<th></th>
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<th>Avail.</th>
<th>Usab.</th>
<th>Lock-in</th>
<th>PP</th>
<th>Weighted Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alt. foss.</td>
<td>grade</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3,15</td>
</tr>
<tr>
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<td>3</td>
<td>4</td>
<td>4</td>
<td>4,1</td>
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<td>0,25</td>
<td>0,15</td>
<td>0,1</td>
<td>3,25</td>
</tr>
<tr>
<td>E.V.</td>
<td>grade</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
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<td>4</td>
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</tr>
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<td>0,25</td>
<td>0,15</td>
<td>0,1</td>
<td>2,8</td>
</tr>
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<td>2</td>
<td></td>
</tr>
<tr>
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<td>weight</td>
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<td>0,25</td>
<td>0,15</td>
<td>0,1</td>
<td></td>
</tr>
<tr>
<td>Behaviour</td>
<td>grade</td>
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<td>3</td>
<td>4</td>
<td>3</td>
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</tr>
<tr>
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<td>weight</td>
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</tr>
</tbody>
</table>

Table A-10: Ranking sequence for manager 4

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<tr>
<th>Ranking</th>
<th>Criterion</th>
</tr>
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<td>Costs</td>
</tr>
<tr>
<td>2</td>
<td>Usability</td>
</tr>
<tr>
<td>3</td>
<td>Availability</td>
</tr>
<tr>
<td>4</td>
<td>Lock-in</td>
</tr>
<tr>
<td>5</td>
<td>Public Perception</td>
</tr>
</tbody>
</table>

Table A-11: Criteria weights with ranking of manager 4

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<th>Costs</th>
<th>Avail.</th>
<th>Usab.</th>
<th>Lock-in</th>
<th>PP</th>
<th># +</th>
<th># -</th>
<th># 0</th>
<th>Points</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
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<td>+</td>
<td>+</td>
<td>+</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>0,3</td>
</tr>
<tr>
<td>Avail.</td>
<td>-</td>
<td>-</td>
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<td>+</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>8</td>
<td>0,2</td>
</tr>
<tr>
<td>Usab.</td>
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<td>+</td>
<td>+</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>0,25</td>
</tr>
<tr>
<td>Lock-in</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>1</td>
<td>3</td>
<td>0</td>
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<tr>
<td>PP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>0,1</td>
</tr>
<tr>
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<td></td>
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<td></td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>
Sustainable measures for the fleet of DHL Express

Table A-12: Total weighted scores with ranking of manager 4

<table>
<thead>
<tr>
<th></th>
<th>Costs</th>
<th>Avail.</th>
<th>Usab.</th>
<th>Lock-in</th>
<th>PP</th>
<th>Weighted Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alt. foss.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>grade</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3,2</td>
</tr>
<tr>
<td>weight</td>
<td>0,3</td>
<td>0,2</td>
<td>0,25</td>
<td>0,15</td>
<td>0,1</td>
<td></td>
</tr>
<tr>
<td>Biogas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,8</td>
</tr>
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<td>grade</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td>0,3</td>
<td>0,2</td>
<td>0,25</td>
<td>0,15</td>
<td>0,1</td>
<td></td>
</tr>
<tr>
<td>E.V.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4,1</td>
</tr>
<tr>
<td>grade</td>
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<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>weight</td>
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<td>0,25</td>
<td>0,15</td>
<td>0,1</td>
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</tr>
<tr>
<td>Hybrid</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>3,2</td>
</tr>
<tr>
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<td>2</td>
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<td>0,25</td>
<td>0,15</td>
<td>0,1</td>
<td></td>
</tr>
<tr>
<td>Other v.m.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,9</td>
</tr>
<tr>
<td>grade</td>
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<td>3</td>
<td>3</td>
<td>3</td>
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<td></td>
</tr>
<tr>
<td>weight</td>
<td>0,3</td>
<td>0,2</td>
<td>0,25</td>
<td>0,15</td>
<td>0,1</td>
<td></td>
</tr>
<tr>
<td>Behaviour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,85</td>
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<tr>
<td>grade</td>
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<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>weight</td>
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<td>0,25</td>
<td>0,15</td>
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</tr>
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</table>

Table A-13: Ranking sequence for manager 5

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Usability</td>
</tr>
<tr>
<td>2</td>
<td>Costs</td>
</tr>
<tr>
<td>3</td>
<td>Availability</td>
</tr>
<tr>
<td>4</td>
<td>Lock-in</td>
</tr>
<tr>
<td>5</td>
<td>Public Perception</td>
</tr>
</tbody>
</table>

Table A-14: Criteria weights with ranking of manager 5

<table>
<thead>
<tr>
<th></th>
<th>Costs</th>
<th>Avail.</th>
<th>Usab.</th>
<th>Lock-in</th>
<th>PP</th>
<th># +</th>
<th># -</th>
<th># 0</th>
<th>Points</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td></td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>0,25</td>
</tr>
<tr>
<td>Avail.</td>
<td>-</td>
<td></td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>8</td>
<td>0,2</td>
</tr>
<tr>
<td>Usab.</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td></td>
<td>+</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>0,3</td>
</tr>
<tr>
<td>Lock-in</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>6</td>
<td>0,15</td>
</tr>
<tr>
<td>PP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>0,1</td>
</tr>
<tr>
<td>Total</td>
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<td></td>
<td></td>
<td></td>
<td>40</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
### Table A-15: Total weighted scores with ranking of manager 5

<table>
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<th>Costs</th>
<th>Avail.</th>
<th>Usab.</th>
<th>Lock-in</th>
<th>PP</th>
<th>Weighted Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alt. foss.</td>
<td>grade</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3,3</td>
</tr>
<tr>
<td></td>
<td>weight</td>
<td>0,25</td>
<td>0,2</td>
<td>0,3</td>
<td>0,15</td>
<td>0,1</td>
</tr>
<tr>
<td>Biogas</td>
<td>grade</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3,8</td>
</tr>
<tr>
<td></td>
<td>weight</td>
<td>0,25</td>
<td>0,2</td>
<td>0,3</td>
<td>0,15</td>
<td>0,1</td>
</tr>
<tr>
<td>E.V.</td>
<td>grade</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4,05</td>
</tr>
<tr>
<td></td>
<td>weight</td>
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<td>0,2</td>
<td>0,3</td>
<td>0,15</td>
<td>0,1</td>
</tr>
<tr>
<td>Hybrid</td>
<td>grade</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3,1</td>
</tr>
<tr>
<td></td>
<td>weight</td>
<td>0,25</td>
<td>0,2</td>
<td>0,3</td>
<td>0,15</td>
<td>0,1</td>
</tr>
<tr>
<td>Other v.m.</td>
<td>grade</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2,9</td>
</tr>
<tr>
<td></td>
<td>weight</td>
<td>0,25</td>
<td>0,2</td>
<td>0,3</td>
<td>0,15</td>
<td>0,1</td>
</tr>
<tr>
<td>Behaviour</td>
<td>grade</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2,95</td>
</tr>
<tr>
<td></td>
<td>weight</td>
<td>0,25</td>
<td>0,2</td>
<td>0,3</td>
<td>0,15</td>
<td>0,1</td>
</tr>
</tbody>
</table>

### Table A-16: Ranking sequence for manager 6

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Costs</td>
</tr>
<tr>
<td>2</td>
<td>Availability</td>
</tr>
<tr>
<td>3</td>
<td>Usability</td>
</tr>
<tr>
<td>4</td>
<td>Public Perception</td>
</tr>
<tr>
<td>5</td>
<td>Lock-in</td>
</tr>
</tbody>
</table>

### Table A-17: Criteria weights with ranking of manager 6

<table>
<thead>
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<th></th>
<th>Costs</th>
<th>Avail.</th>
<th>Usab.</th>
<th>Lock-in</th>
<th>PP</th>
<th>#+</th>
<th># -</th>
<th># 0</th>
<th>Points</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>0,3</td>
</tr>
<tr>
<td>Avail.</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>0,25</td>
</tr>
<tr>
<td>Usab.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>8</td>
<td>0,2</td>
</tr>
<tr>
<td>Lock-in</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>0,1</td>
</tr>
<tr>
<td>PP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>6</td>
<td>0,15</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>40</td>
<td>1</td>
</tr>
</tbody>
</table>
### Table A-18: Total weighted scores with ranking of manager 6

<table>
<thead>
<tr>
<th></th>
<th>Costs</th>
<th>Avail.</th>
<th>Usab.</th>
<th>Lock-in</th>
<th>PP</th>
<th>Weighted Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alt. foss.</strong></td>
<td>grade</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>2,15</td>
</tr>
<tr>
<td></td>
<td>weight</td>
<td>0,3</td>
<td>0,25</td>
<td>0,1</td>
<td>0,15</td>
<td></td>
</tr>
<tr>
<td><strong>Biogas</strong></td>
<td>grade</td>
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<td>3</td>
<td>4</td>
<td>4</td>
<td>3,75</td>
</tr>
<tr>
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<td>weight</td>
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<td>0,25</td>
<td>0,1</td>
<td>0,15</td>
<td></td>
</tr>
<tr>
<td><strong>E.V.</strong></td>
<td>grade</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>weight</td>
<td>0,3</td>
<td>0,25</td>
<td>0,1</td>
<td>0,15</td>
<td></td>
</tr>
<tr>
<td><strong>Hybrid</strong></td>
<td>grade</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3,25</td>
</tr>
<tr>
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<td>0,25</td>
<td>0,1</td>
<td>0,15</td>
<td></td>
</tr>
<tr>
<td><strong>Other v.m.</strong></td>
<td>grade</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2,85</td>
</tr>
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<td>weight</td>
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<td>0,25</td>
<td>0,1</td>
<td>0,15</td>
<td></td>
</tr>
<tr>
<td><strong>Behaviour</strong></td>
<td>grade</td>
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<td>3</td>
<td>4</td>
<td>3</td>
<td>2,75</td>
</tr>
<tr>
<td></td>
<td>weight</td>
<td>0,3</td>
<td>0,25</td>
<td>0,1</td>
<td>0,15</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B: Sensitivity analysis

The sensitivity analysis consists of two parts. The check-speed parameter for the measure improved aerodynamics and rolling resistance is varied in the first part. The check-speed is used in the calculation model for the determination of the distance travelled with a speed higher than 70 km/h. When this check-speed is raised to 75 km/h, lower potential savings are achieved as expected, since a shorter distance is travelled with lower fuel consumption. The results are shown in Table B-1. The results show no extreme values, thus the calculation tool is not very sensitive to this parameter.

Table B-1: Results for aerodynamic and rolling resistance improvements for one year with varying check-speeds

<table>
<thead>
<tr>
<th>Check-speed (km/h)</th>
<th>Consumed fuel (L)</th>
<th>Savings (%)</th>
<th>CO₂-savings (ton)</th>
<th>Fuel savings (€)</th>
<th>Payback period (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>316.853,04</td>
<td>6,20 %</td>
<td>56,53</td>
<td>€29.104,19</td>
<td>1</td>
</tr>
<tr>
<td>75</td>
<td>319.091,45</td>
<td>5,54 %</td>
<td>50,49</td>
<td>€25.992,80</td>
<td>1</td>
</tr>
</tbody>
</table>

Two fuel consumption parameters are varied in the second part of the sensitivity analysis. First, the fuel consumption rate of a conventional vehicle in underlying road network traffic is raised with 5% from 40 L/100 km to 42 L/100 km. The results are shown in Table B-2. Higher savings are achieved for the three sustainable measures as expected, resulting in shorter payback periods.

Table B-2: Results for one year with varying fuel consumption for conventional vehicles

<table>
<thead>
<tr>
<th>Fuel consumption conventional vehicle on underlying roads (L/100 km)</th>
<th>Conventional vehicle</th>
<th>Improved driving behaviour</th>
<th>Hybrid drivetrain</th>
<th>Improved aerodynamics and rolling resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumed fuel (L)</td>
<td>40*</td>
<td>337.791,31</td>
<td>315.408,53</td>
<td>313.479,87</td>
</tr>
<tr>
<td>42*</td>
<td>344.620,43</td>
<td>315.408,53</td>
<td>313.479,87</td>
<td>316.853,04</td>
</tr>
<tr>
<td>Savings (%)</td>
<td>40*</td>
<td>6,63 %</td>
<td>7,20 %</td>
<td>6,20 %</td>
</tr>
<tr>
<td>42*</td>
<td>8,48 %</td>
<td>9,04 %</td>
<td>8,06 %</td>
<td></td>
</tr>
<tr>
<td>CO₂ savings (ton)</td>
<td>40*</td>
<td>60,43</td>
<td>65,64</td>
<td>56,53</td>
</tr>
<tr>
<td>42*</td>
<td>78,87</td>
<td>84,08</td>
<td>74,97</td>
<td></td>
</tr>
<tr>
<td>Fuel savings (€)</td>
<td>40*</td>
<td>€31.112,05</td>
<td>€33.792,90</td>
<td>€29.104,19</td>
</tr>
<tr>
<td>42*</td>
<td>€40.604,53</td>
<td>€43.285,38</td>
<td>€38.596,67</td>
<td></td>
</tr>
<tr>
<td>Payback period (months)</td>
<td>40*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Next, the fuel consumption rate for vehicles equipped with improved aerodynamics and rolling resistance in freeway traffic is raised with 5% from 29,68 L/100 km to 31,16 L/100 km. The results are shown in Table B-3. The savings for the concerned measure decrease as expected, resulting in a longer payback period.
Table B-3: Results for one year with varying fuel consumption for trucks with improved aerodynamics and rolling resistance on freeways

<table>
<thead>
<tr>
<th></th>
<th>Conventional vehicle</th>
<th>Improved driving behaviour</th>
<th>Hybrid drivetrain</th>
<th>Improved aerodynamics and rolling resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumed fuel (L)</td>
<td>29,68*</td>
<td>315.408,53</td>
<td>313.479,87</td>
<td>316.853,04</td>
</tr>
<tr>
<td></td>
<td>31,16*</td>
<td>315.408,53</td>
<td>313.479,87</td>
<td>326.001,34</td>
</tr>
<tr>
<td>Savings (%)</td>
<td>6,63 %</td>
<td>7,20 %</td>
<td>6,20 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6,63 %</td>
<td>7,20 %</td>
<td>3,49 %</td>
<td></td>
</tr>
<tr>
<td>CO2 savings (ton)</td>
<td>29,68*</td>
<td>60,43</td>
<td>65,64</td>
<td>56,53</td>
</tr>
<tr>
<td></td>
<td>31,16*</td>
<td>60,43</td>
<td>65,64</td>
<td>31,83</td>
</tr>
<tr>
<td>Fuel savings (€)</td>
<td>29,68*</td>
<td>€ 31.112,05</td>
<td>€ 33.792,90</td>
<td>€ 29.104,19</td>
</tr>
<tr>
<td></td>
<td>31,16*</td>
<td>€ 31.112,05</td>
<td>€ 33.792,90</td>
<td>€ 16.388,05</td>
</tr>
<tr>
<td>Payback period (months)</td>
<td>29,68*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>31,16*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Fuel consumption improved aerodynamics and rolling resistance on freeways (L/100 km)

The results from Table B-2 and Table B-3 do not show extreme values, thus the calculation tool is not very sensitive to the concerned fuel consumption parameters.