22-01-2020

Measures to reduce CO_2 emission of Plegt-Vos Infra&Milieu based on CO_2 performance ladder

Bachelor assignment Civil Engineering

Assignment period: 4 November 2019 - 22 January 2020

Bregje Braaksma - s1914324

PLEGT-VOS

UNIVERSITY OF TWENTE.

22-1-2020

Bachelor thesis Civil Engineering at Plegt-Vos Infra&Milieu

Measures to reduce CO2 emission of Plegt-Vos Infra&Milieu based on CO2 performance ladder

Student

Name:	B.J.J. Braaksma (Bregje)
Student number:	s1914324
E-mail address:	b.j.j.braaksma@student.utwente.nl
Telephone number:	+31658953050

Internal supervisor

Name:	Dr. S. Bhochhibhoya (Silu)
Function:	Researcher/lecturer at University of Twente
E-mail address:	s.bhochhibhoya@utwente.nl
Telephone number:	+31534893313

External supervisor

Name:	E.M. Kolkman (Marcel)
Function:	Manager Ontwerp en Ontwikkeling
E-mail address:	marcel.kolkman@plegt-vos.nl
Telephone number:	+31630030257

Educational program

Study:	BSc Civil Engineering
Institute:	University of Twente
Department:	Construction Management and Engineering
Timing:	Third year, module 12

Preface

This thesis is written as part of the third year of the bachelor program of Civil Engineering at University of Twente. In cooperation with Plegt-Vos Infra&Milieu and University of Twente, this thesis was developed.

I would like to thank Marcel Kolkman and Silu Bhochhibhoya for their supervision and feedback during the research period. Furthermore, I would like to thank the whole department of Plegt-Vos Infra&Milieu for their friendliness and interest into my thesis during the lunchbreak walk.

Abstract

This thesis focuses on the possibilities for reduction of CO_2 emissions in the construction sector with respect to the CO_2 performance ladder. The CO_2 Performance Ladder currently is broadly accepted, but some issues remain once a company has gained the CO_2 awareness certificate. These issues relate to difficulties to realize proposed CO_2 reduction goals in full. On the one hand, companies often have no concretely elaborated implementation plans for reducing CO_2 emissions. On the other hand, the CO_2 emissions which the company has to deal with are in fact caused by their partners. Therefore, it is necessary to convince these partners to reduce CO_2 emissions.

The goal of this study is to find concrete measures to reduce CO_2 emissions in scope 3 of the CO_2 Performance Ladder, by using Plegt-Vos Infra&Milieu as a case study. The following research question is stated: *"Which CO_2 reducing measures can be used to achieve the reduction goal stated by Plegt-Vos Infra&Milieu: to reduce -10.5% CO_2 emissions in scope 3 at the end of 2020?"* Scope 3 relates to the CO_2 emissions of partners, and the -10,5% is the percentage CO_2 emission reduction that Plegt-Vos Infra&Milieu wants to achieve.

The methods used to answer the main question include a literature review, field interviews with partners and CO_2 reduction calculations. The goal of the literature review was to take stock of the possible ways to reduce and/or replace diesel by alternative energy sources. Interviews with the top 10 partners of Plegt-Vos, focused on their attitude towards CO_2 reduction, CO_2 awareness and the CO_2 Performance Ladder. Then the results of literature review and interviews were combined. For each measure that partners were interested in, and for which the literature review gave good results, calculations were made to estimate possible CO_2 reduction, as well as associated investment and operational costs, to meet the reduction goal of scope 3.

The literature review indicates good short-term results for the alternatives for diesel, which are: biodiesel, electrification (hybrid machines). On the long term hydrogen may become an attractive option. Furthermore, the course 'het nieuwe draaien' leads to decent CO_2 reduction by changing behaviour of employees. From the interviews with partners was it became clear that partners were aware of their CO_2 emission, and actively wanted to reduce them. They felt limited in CO_2 reduction opportunities by costs and lack of sufficient mature effective reduction options. The combined results of the literature review and interviews with partners, resulted in a set of the best options currently available. These alternatives are biodiesel, electrification (hybrid) and the course 'het nieuwe draaien'. Therefore, in order to achieve their reduction goal in scope 3, Plegt-Vos is advised to, cooperatively with their partners, invest in biodiesel, the course 'het nieuwe draaien' and hybrid machines.

The best overall approach to achieve a substantial CO_2 emission reduction appears to consist of a combination of technical, behavioural and procedural methods. Thereby it is important to take both initial investment and operational costs into account. The environmental benefits may go hand in hand with economic benefits in the sense of a positive (financial) return on investment.

Based on the results of this thesis some further research topics are proposed. This thesis mainly focuses on diesel usage as the main emission source. Because the CO_2 emission of scope 3 does not fully depend on diesel alone, it is recommended to repeat this study for other CO_2 reducing measures that do not involve diesel usage. Additionally, it could be useful to repeat this study with other construction companies and their partners. It could also be useful to include clients and regulators; in the end, the topic of CO_2 emission reduction can only be dealt with in the whole chain. Furthermore, it can be useful to look further into the suggested measures and perform more detailed calculation to check if the assumed investment and operational cost are right, and the supposed CO_2 reduction correct.

Table of contents

1. Introduction

This thesis is written in cooperation with Plegt-Vos Infra&Milieu and the University of Twente. The topic of the report is the reduction of CO_2 emissions based on the CO_2 Performance Ladder. This chapter presents an introduction, the background of the study and the problem description.

All over the world nowadays a lot of attention is paid to climate change. During the Climate Agreement from Paris in 2015, the Member States of the United Nations agreed on minimizing the global warming of the earth to an absolute maximum of 2 degree Celsius, but strive for 1.5 degree Celsius (The Intergovernmental Panel on Climate Change (IPCC), 2018). To accomplish this, a reduction of 40% in 2030 and almost 100% in 2050 of greenhouse gases emission is required. The percentages are relative to the CO_2 emissions of 1990 (Ecovat, 2018). The Dutch government has set their reduction goals at 49% less emissions in 2030 and 95% in 2050, relative to the CO_2 emissions of 1990 (Rijksoverheid, 2019). Although the government has agreed to reduce Dutch emissions, in practice this means that all of Dutch society will have to contribute, including the construction sector. The construction sector is on a global level the most CO_2 intensive sector, about 38% of global CO_2 emissions can be traced back to this sector (Wills, 2018). It is therefore important that the construction sector reduces its CO_2 emissions, as they have a large share in the CO_2 emissions.

Initiatives are being set up to make construction companies more aware of the role they have in achieving the reduction goals stated by the Dutch government. Eventually, they have to reduce their CO_2 emissions. One initiative to achieve this goal is the **CO_2 Performance Ladder**. This initiative was developed in 2009 by ProRail, and is since 2011 accommodated by Climate Friendly Procurement and Business Foundation (In Dutch: Stichting Klimaatvriendelijk Aanbesteden en Ondernemen, (SKAO) (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2019b). When companies apply for the ladder and succeed in the requirements stated by SKAO, they will receive the CO_2 awareness certificate on a certain level (1-5) of the CO_2 Performance Ladder. How a company can apply for the certificate is explained in Appendix I.

The CO_2 Performance Ladder aims to help certified companies in reducing their CO_2 emissions more than average in the Netherlands. On average, companies with a CO_2 awareness certificate reduce their CO_2 emissions with 3,2 percent per year, which is twice the average of reduction in the Netherlands (1,6 %) (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2016). The number of companies participating in this initiative is growing, see Figure 1. At the start of 2020, there are already 949 certificate members.

Figure 1 Amount of certificate members (Stichting Klimaatvriendelijk Aanbesteden en Ondernemen, 2019d)

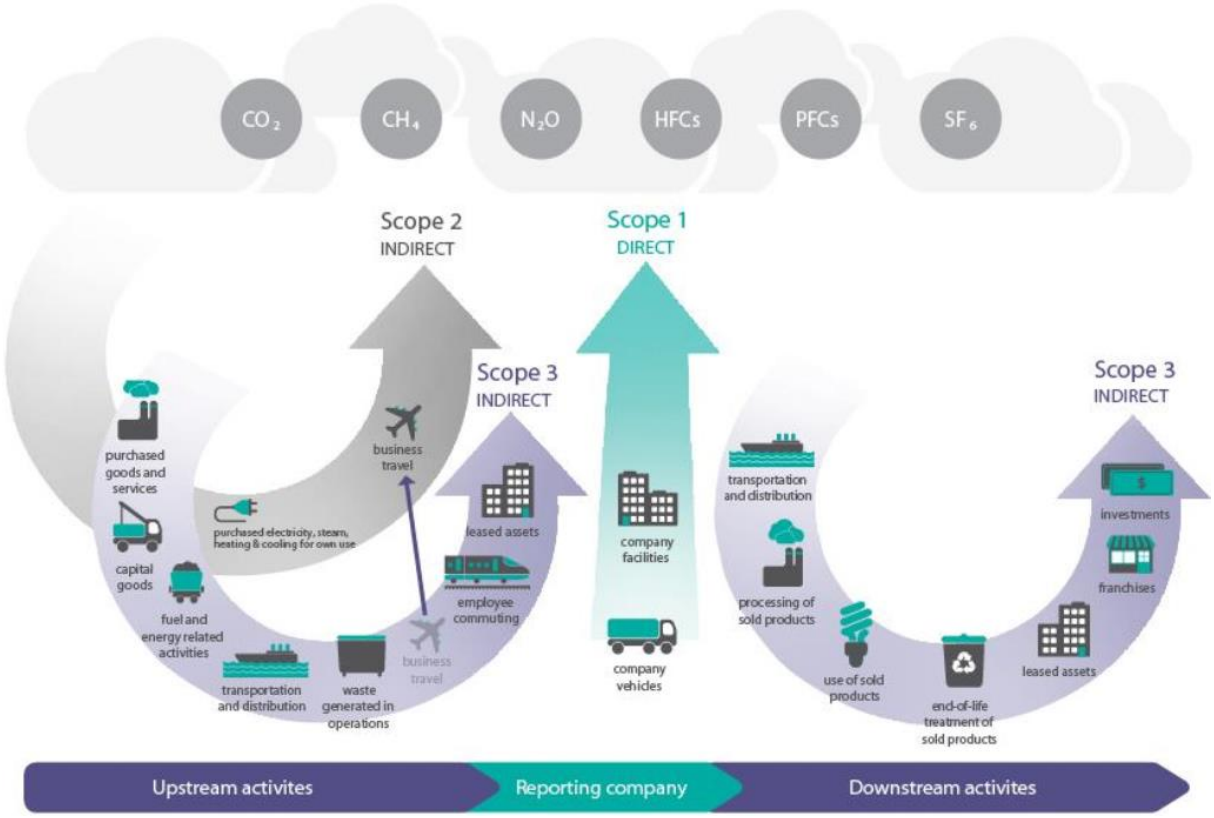

Figure 2 Activities per scope (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2015)

The Ladder consists of five levels. The first three focus on the own organizational CO_2 emissions. Level 4 and 5 take this a step further and focus on the CO_2 emissions outside the company which can be influenced by the company. The emissions are divided into three 3 different scopes: **scope 1** is the energy use which is directly related to the company, **scope 2** includes energy use which is indirectly related to the company and **scope 3** includes energy usage within the production chain, see Figure 2. It can be more difficult to reach level 4 and 5, since the company itself has no direct influence on these external CO_2 emissions. To reduce CO_2 emissions outside the company, agreements have to be made with partners to agree on certain reduction goals. Currently, SKAO doesn't have specific tools or advices on how to engage these partners. Therefore, companies have to develop their own policy for engaging partners.

1.1. Background

This section explains the background of the study. The focus lies on CO_2 Performance Ladder, why companies need a certificate and what the relation with Plegt-Vos Infra & Milieu and the ladder is.

1.1.1. What is the CO_2 Performance Ladder?

'The CO_2 Performance Ladder is the most sustainable instrument in the Netherlands that helps companies and governments on CO_2 reduction and costs, within their organisation, projects and business sector. The ladder is used as CO_2 management system, tender instrument and enforcement used by governmental bodies.' (translated) (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2019b)

The CO_2 Performance Ladder is a certificate for companies to demonstrate their efforts to reduce the CO_2 emissions. Eligibility of company for the certificate is decided by the Climate Friendly Procurement and Business Foundation (SKAO). SKAO has published a manual which companies can use to start with the CO_2 Performance Ladder (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2015). The goals SKAO wants to achieve with the CO_2 Performance Ladder are primarily a reduction of CO_2 emission, and in addition getting more awareness for CO_2 emission within the work field. So that all CO_2 emission of the whole chain are taken into account.

1.1.2. Why does company need CO_2 certificate?

Clients (mostly governmental bodies) accept construction projects which produce less CO_2 emissions, since they have goals for CO_2 reduction themselves. With the CO_2 awareness certificate, companies can get a (fictional) discount on their registration price during tender phase, see Table 1. Additionally, there are some clients that will only work with contractors that have a CO_2 awareness certificate. This may lead to more projects where CO_2 reduction is taken into account. Furthermore, SKAO aims that when a company is reducing CO_2 emission, this will lead to reducing cost on the energy bill of the company.

Table 1 Example for (fictional) discount during tender phase (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2019b)

How does fictional discount with the CO2 performance

Organization	Registration price	Step on the ladder	Fictional discount	Fictional price	Winning of tender
A	€ 9,7 million	Non	0%	€ 9,7 million	NO
B	€ 10 million	3	4%	€ 9,6 million	NO
C	€ 10,3 million	4	7%	€ 9,58 million	YES: € 10,3 million

1.1.3. Plegt-Vos and the CO_2 Performance Ladder

Plegt-Vos Infra&Milieu is part of the bigger contracting company Plegt-Vos Bouwgroep. Plegt-Vos Infra&Milieu is a design and execution company. They have a wide knowledge on redesign of the public and private space. Their work field includes: making land ready for construction, demolition of existing buildings, remediation of soil and groundwater, construction of (water) roads and advise on civil and environmental projects (Plegt-vos Infra&Milieu, 2019b). Plegt-Vos Infra&Milieu received the CO_2 awareness certificate in February 2019. They are on the highest level (5) and therefore had to define ambitious CO_2 reduction goals. The upcoming 3 years they want to reduce their CO_2 emission further, taking 2017 as a reference year. See Table 2 below for their exact reduction goals (Plegt-Vos Infra&Milieu, 2019a).

Table 2 Reduction goals per scope

Scope	Every year	Over 3 years
1	-1.5%	-4.5%
2	-1.5%	-4.5%
3	-3.5%	-10.5%

Table 3 Reduction measures per scope (Plegt-Vos Infra&Milieu, 2019a)

Scope	Measures	Reduction
1	Replacing/buying of A and B-labeled cars	Average 3,0 ton CO_2 per year per car
2	Buying green energy with a certificate NL	± 75% of total reduction needed scope 2
3	Reduction of diesel for rental and use of machines	± 80% of total reduction needed scope 3

To achieve their goals, Plegt-Vos names per scope one measure which they think can be useful to reduce CO_2 emission, Table 3 shows the measures per scope, and their expected impact.

The first two measures are easy to implement, and in fact have been implemented. The third measure is the most difficult one. To be precise, when looking at Table 4 it can be seen that they are not making progress for achieving their goal on scope 3. To make sure the goals for end 2020 are achieved, it is necessary to implement the measures for scope 3. However, this is a difficult measure to implement, since CO_2 emission is not directly related to Plegt-Vos, but to their partners. This leads to the problem that: Plegt-Vos Infra&Milieu wants to reduce CO_2 but they can only do this with cooperation of their partners.

Table 4 Total emissions per scope (2017-2019) Plegt-Vos Infra and Milieu

Discription	2019 (half year)	2018 Total Tones CO2	2017 Total Tones CO2	Percentage 2018 Compared to 2017 Percentage	Percentage 2019 Compared to 2017 Percentage
Scope 1					
Gas and diesel consumption location Hengelo					
Total CO2 emission energy consumption office Hengelo	**2,9**	**6,2**	**6,2**	**-0,1%**	**-6,8%**
Diesel en gasoline own fleet (lease cars)					
Total CO2 emission own cars	**104,1**	**222,8**	**252,3**	**-11,7%**	**-17,5%**
Scope 2					
Electricity consumption					
Total CO2 emission electricity	**5,1**	**10,2**	**35,7**	**-71,4%**	**-71,4%**
Business km					
Total CO2 emission business other employees	**1,2**	**3,1**	**5,2**	**-41,0%**	**-54,1%**
Scope 3					
Fuel en energy related activities					
Total CO2 emission fuel en energy related activities	**631**	**1.315,1**	**1.314,9**	**0,0%**	**-4,0%**
Upstream transport en distribution					
Subtotal category upstream transport en distribution	**186,2**	**296,1**	**274,0**	**8,1%**	**35,9%**
Building en demolition waste					
Total CO2 emission production waste	**39,8**	**41,4**	**45,7**	**-9,2%**	**74,3%**
Commuting					
Total CO2 emission commuting	**4,8**	**10,1**	**17,4**	**-42,0%**	**-44,8%**
Total emission PV Infra & Milieu scope 1,2 en 3	**975,1**	**1.905,0**	**1.951,3**	**-2,4%**	**2,4%**
Part scope 1	**107,0**	**229,0**	**258,5**	**-11,4%**	**-17,2%**
Part scope 2	**6,3**	**13,3**	**40,9**	**-67,5%**	**-69,2%**
Part scope 3	**861,8**	**1.662,8**	**1.651,9**	**0,7%**	**4,3%**

1.2. Problem description

The CO_2 Performance Ladder currently is broadly accepted. Over 150 clients use the certificate for selecting their contractors (Stichting Klimaatvriendelijk Aanbesteden en Ondernemen, 2019d), and good reduction results are presented: an average CO_2 reduction of 3,2% per year per participating company. Nevertheless, some issues remain once a company has gained the CO_2 awareness certificate, especially when trying to realize its CO_2 reduction goals in full. This has several causes namely:

First, the ladder mainly focuses on permitting the company to get insight in their CO_2 emissions and stating goals for reducing their CO_2 emissions. Moreover, SKAO stimulates companies to formulate ambitious reduction goals, which effectively means that without ambitious goals companies will not reach the CO_2 awareness certificate, see section 6.2.2 of the Handboek CO_2 prestatieladder 3.0 (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2015). What is not so much stimulated, however, is the development of elaborated ideas on **how** to reduce CO_2 emissions in order to achieve the reduction goals stated by the company. Although companies have to hand in a reduction plan when applying for the certificate, this plan is not very intensively assessed on implementation validity and feasibility. This may result in (too) ambitious goals and thereby the following problem:

Companies have no elaborated implementation plans for reducing CO_2 emissions, therefore their ambitious goals are difficult to achieve.

A second problem concerning the CO_2 Performance Ladder is that CO_2 emissions are divided in different scopes. When considering an upstream contracting company (with a lot of subcontractors) most of the CO_2 emissions it expels does not originate from its own assets. These CO_2 emissions are only indirectly related to their activities because they originate from their partners. Such emissions are captured in **scope 3** of the CO_2 Performance Ladder. To summarize, a difficult issue for reducing CO_2 emissions in scope 3 is that the company itself is not the 'owner' of the CO_2 emissions, see 1.1.3, which lead to the following problem:

Contractors need to reduce CO_2 emissions with the help of their partners, and therefore convince them to reduce in turn their CO_2 emissions.

The problems stated will be captured within this thesis. The related research questions are stated in section 2.4 below.

2. Research objectives

In this chapter the relevance, scope and aim of the research are named. Lastly, the main research question is stated, and some related sub questions are named.

2.1. Research relevance

As mentioned in chapter 1, reduction of CO_2 emissions by companies is an important topic nowadays. It is important that CO_2 emissions will be reduced by companies to meet the reduction goals stated by the Dutch government. The CO_2 Performance Ladder is an initiative which can be used to reduce CO_2 emissions within the construction sector, although there are some issues with the Ladder. Therefore, it is important for the whole construction sector to understand and analyse these issues, and eventually solve them. When these issues are solved more CO_2 reduction can be realized, which will eventually help to meet the goals of the UN Climate Agreement of Paris. The main goal of this research is to study the problems enumerated in section 1.2 and propose possible solutions.

Furthermore, this study will look into alternative measures to reduce CO_2 emissions, in particular measures that help reduce CO_2 emissions of partners. The measures obtained from this study could in principle be implemented by a lot of contracting companies that have issues in the reduction of CO_2 emissions located in scope 3 (caused by their partners).

2.2. Research scope

This study focusses on the CO_2 Performance Ladder for Plegt-Vos Infra&Milieu. Plegt-Vos Infra&Milieu is currently on level 5 of the CO_2 Performance Ladder, which means it is a good object to study for this research. As discussed above, the key interests and main focus of this study lie in scope 3, more specifically the diesel consumption in scope 3. The result of this study consist of measures that Plegt-Vos Infra&Milieu can implement within their company. In addition, it can be used by other companies to construct a reduction plan for their company.

2.3. Research goal

To solve the problems mentioned in the Problem description the following research goal has been formulated:

"The goal of this research is to find concrete measures to reduce CO_2 emissions in scope 3 of the CO_2 Performance Ladder, by using Plegt-Vos Infra&Milieu as a case study."

Because it is not possible to look at the whole construction sector, and this research will be done at Plegt-Vos Infra&Milieu, they are chosen to be a representative case study, see 2.2 Research scope for more information about the boundaries. Moreover, the research questions are based on the reduction goals stated by Plegt-Vos Infra&Milieu.

2.4. Research questions

This section will present the main research questions and sub questions to be considered for this study.

2.4.1. Main question

"Which CO_2 reducing measures can be used to achieve the reduction goal stated by Plegt-Vos Infra&Milieu: to reduce -10.5% CO_2 emissions in scope 3 at the end of 2020?"

2.4.2. Sub questions

To answer the main research question several sub questions are formulated.

2.4.2.1. Sub question 1

What are the options for reducing diesel in rented machines and transport?

- What are possible ways to replace diesel usage?
- What are possible ways to make diesel usage more efficient for machines and transport?

2.4.2.2. Sub question 2

What are the perceptions of partners on reduction of CO_2 emissions?

- Can partners prove that they are aware of CO_2 emissions (by a certificate)?
- Are partners willing to reduce CO_2 emissions?
- Do partners have CO_2 reduction goals for themselves?
- Do partners think about CO_2 reducing measures?

2.4.2.3. Sub question 3

What will be the reduction of CO_2 emissions when using the results of sub Q1&2?

- What can be the CO_2 reduction for replacing diesel usage?
- What can be the CO_2 reduction for making diesel usage more efficient?
- What can be the CO_2 reduction for the measures named by partners?

3. Methodology

In this chapter the research methods are explained per sub question. Furthermore, it is explained how the interviews will be conducted and how the CO_2 reduction will be calculated. Lastly, a schematic overview of the full research method is provided.

3.1. Research method per sub question

In this section, the research method per sub question is explained. Each sub question asks for a different approach.

3.1.1. Sub question 1

What are the options for reducing diesel in rented machines and transport?

A literature review was conducted to take stock of the possible ways to reduce and/or replace diesel. Several research studies are available on diesel usages and measures to reduce the usage and/or replace it. The possibility to replace diesel with alternative fuels was investigated, focusing on the alternatives of electrification, biodiesel, gasses and hydrogen. Furthermore, the efficiency of diesel usage with respect to CO_2 emissions for machines and transport was examined. Possibilities have been explored to increase the efficiency of diesel usage in machines and transport. This literature review summarizes the state of the art knowledge on diesel consumption in construction industry and result in more insight into alternatives for diesel, and fuel/diesel efficiency.

3.1.2.Sub question 2

What are the perceptions of partners on reduction of CO_2 emissions?

A desk research study was conducted, where the top 10 partners (revenue above €100.000,-), were checked on certificates and CO_2 awareness. Furthermore, more information about all top 10 partners was collected to understand the key activities of the companies, and thereby have better input for the interviews. The results of sub question 1 were used as input for the interviews. Interviews have been conducted with the top 10 partners, focusing on their attitude towards CO_2 reduction, CO_2 awareness and the CO_2 Performance Ladder. More explanation about the layout of the interview can be found in section 3.2. The results of this sub question yield better insight in the attitudes of the top 10 partners, with respect to CO_2 emissions.

3.1.3. Sub question 3

What will be the reduction of CO_2 emissions when using the results of Q1&2?

This sub question combines the results of sub question 1 and 2. All measures that are identified in Q1 & 2 were examined, and their proposed CO_2 reduction was estimated. This estimation was done with the help of the literature review. A connection was established between the opinions of the partners and the proposed alternatives for diesel reduction from sub question 1. For each measure that partners were interested in, and for which the literature review gave good results, a calculation was made. This calculation

shows the estimated investment and operational costs, to meet the reduction goal of scope 3. Furthermore, the return on investment period and the yearly (reduction) cost are calculated.

3.2. Interviews

90% of the calculated CO_2 emissions from Plegt-Vos Infra&Mileu is related to their partners, therefore the partners are important and need to be taken into account. Currently, Plegt-Vos mostly uses local partners from the regions where they work, so that not a lot of transportation is needed. Furthermore, in every region they have one main partner and several smaller partners. Because of time limitations only the bigger partners were interviewed, and not the whole top 10. Details about the partners interviewed for this study are given in Table 5.

3.2.1. Information about interviewed companies

Most of the interviewed companies have key activities in the area of heavy machine rental and earth moving. One company was a supplier of concrete materials, and one was a green facility company. The sizes of all companies were roughly comparable. The smallest has 15 to 18 employees and a middle size market share within the region. The biggest company have 450 employees, 8 locations trough the Netherlands, and is market leader. The assignments in cooperation with Plegt-Vos Infra&Milieu varied a lot, from very small to a quarter of the assignments.

Table 5 Information about interviewed partners

Company	Key activities	Location	Size of company (employees)	Size of company (market share)	Assignments in cooperation with Plegt-Vos of total (estimation)
Blokland Holding B.V.	- rental of heavy machines	Ter Aar	90	15% of sector	
Geurs Loon-Grondverzet- en Transport bedrijf B.V.	- earth moving - (re)placing of fake grass - rental of heavy machines - agriculture- and transport work	Hengevelde	32	high within sector and region	10% 1-2 employees fulltime
Groenservice Noord B.V.	- planting trees and other green - maintenance of trees/green (around 3 years)	Groningen	30	10% in province of Groningen	big projects in region of Groningen ≈€100.000 a year
Aannemings bedrijf Kramer Metslawier BV	- earth moving - rental of machines - subcontracting - placing sheet piling	Metslawier	15-18	middle size within the sector and region	25% 3 employees fulltime
Vogelzang & Zn	- earth moving - cleaning ditches	Boerakker	40	high in province of Groningen	5%
Struyk Verwo Infra	- fabrication of pavement - other concrete material for the public space	Tiel	450, at 8 locations	market leader in sector	small part

The interviews were conducted with a representative of each company, preferably an employee that knew most about the CO_2 emissions, goals for CO_2 reduction and insights of the company. Since most of the companies in the list are material rental companies, they depend very much on diesel usage. Therefore, most questions where asked about diesel usage and efficiency of/alternatives for diesel.

3.2.2. Interviews description

The summaries of the interviews are given in Appendix III. All interviews started with the same introduction about the research purposes and an explanation on the topics of the interview. The interview thereafter was divided into 6 parts:

- Part I: company characteristics;
- Part II: environmental goals and vision;
- Part III: CO_2 reducing measures;
- Part IV: alternatives for diesel;
- Part V: efficiency of diesel;
- Part VI: insight into CO_2 emissions.

All categories named above where integrated in the semi-structured interview. See the interview scheme in Appendix II for more information.

3.3. Schematic overview of research methods

In this section a schematic overview of the full research method is presented.

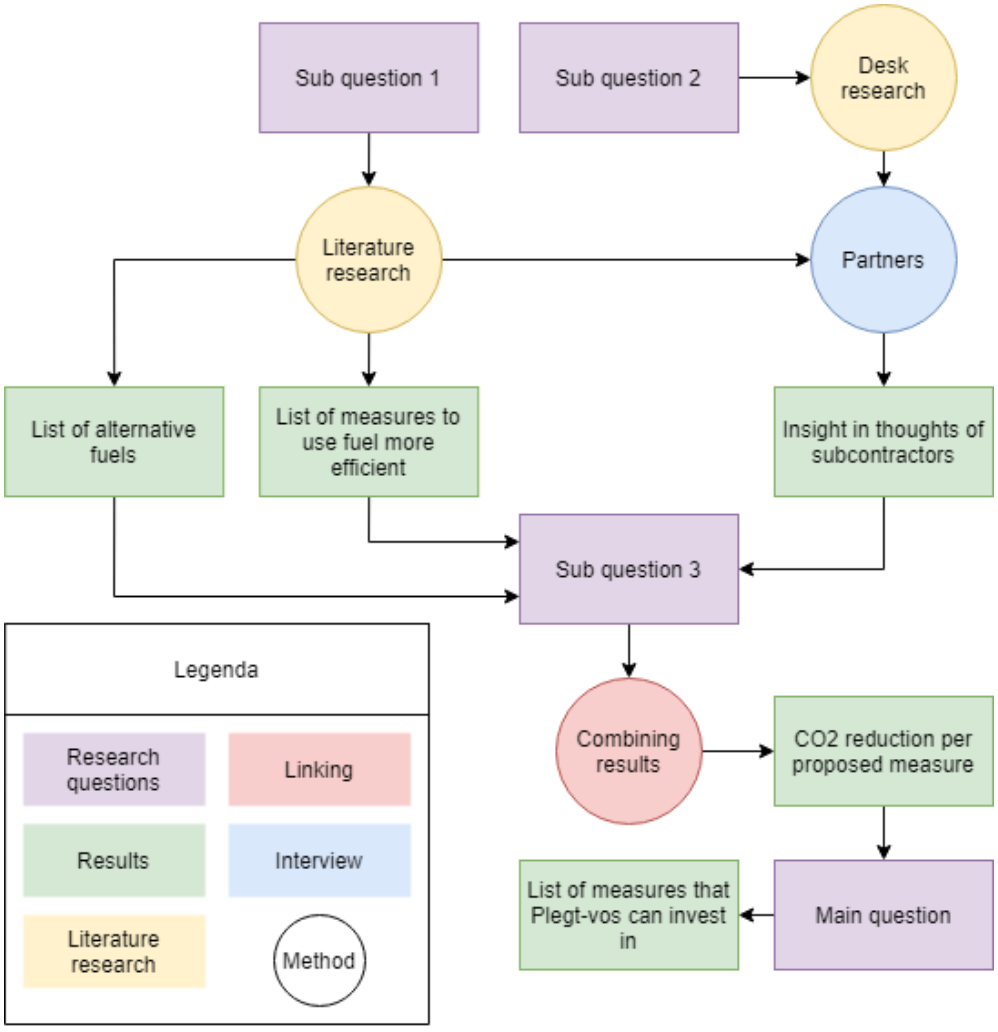

Figure 3 Schematic overview of research method

4. Literature review

In this chapter, the literature review concerning the research question is presented. First the literature review on alternatives to replace diesel usage are discussed. Then, the results of the literature review on efficient diesel usage solutions for machines and transport are shown.

4.1. Alternatives for diesel usage

Diesel fuel is by far the biggest energy producing source in the construction industry. In the US around 98% of the energy in the construction sector is produced by diesel (Diesel Technology Forum, 2019). In the Netherlands this percentage is only slightly lower. In 2014 1,7 Mton CO_2 emission, is produces by transport of building material, this is 18% of the total climate impact of the building industry. Machine use on the building sites produces 2 Mton CO_2 emission, which is 19% of the total building industry climate impact (Bijleveld M. , Bergsma, Krutwagen, & Afman, 2014b). Together this means 37% of the total CO_2 emission of the building industry can be directly related to diesel usage. Diesel when combusted, produces a lot of CO_2 emission: **3,230 Kg/L** (Greendeal, 2019), and is therefore extremely polluting for the environment. Plegt-Vos' biggest partners use a lot of diesel. Their CO_2 footprints depend for 90-99% on diesel. A good way to reduce CO_2 emission is to decrease the use of diesel. Besides, there are other disadvantages of using diesel, for example the noise pollution diesel engines causes within cities. This noise pollution and other pollutions causes that more and more municipalities want to ban diesel from their cities, which results in environmental zones where diesel cars before 2001 are not allowed (ANWB, 2019). In future these environmental zones will probably be expanded, and which can result in heavy machines and transport to be expelled from cities altogether. Consequently, several alternatives for diesel have been suggested. In this study the four main alternatives: electrification, biodiesel, hydrogen and gases are discussed. Each alternative is issued individually considered separately and it is explained how the technology works, what is currently available, what the possible benefits and difficulties are and how big the possible reduction in CO_2 emission can be.

4.1.1. Electrification

The opportunities for electrification within the infrastructure and construction sector, using electrically powered machinery during the construction phase are large (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2018). Electrification of machines can assumed various forms. The most common forms will be discussed, being full-electrical machine with a battery, hybrid machine and full-electrical machine with cable.

Electricity is formally seen as an energy carrier, which means that the energy has to be produced first. When the electricity is produced in a green way (wind-, solar- or water powered), the emissions of electrical machines can be near zero, but even 'grey' electricity emits far less CO_2 than diesel. An additional advantage of electrical energy is that is does not produce emissions locally (at the place of the machine), but only at the energy production site (Kindt & van der Meulen, 2011).

The CO_2 emission factors of electricity are: **0,649 kg/kWh** for grey electricity and **0,000 kg/kWh** for green electricity (CO_2-emissiefactoren, 2019).

4.1.1.1. Full-electrical machines with battery

Currently, there are few full-electrical heavy machines with a battery available on the market. Nevertheless, there are smaller class machines available (SGS Search Consultancy, 2017). See section 4.1.1.1.1 for examples of full-electrical machines with a battery. SGS Search did a study in 2017 into electrification of mobile machines. They investigated what the best developments where at that moment, checked the operational pros and cons, and checked what the financial aspects were for a transition to electrical mobile machines. They concluded that there are two main problems for the development of fully-electrical heavy machines. The first one is limitations in the size and weight of battery packs. For small machines it is possible to use suitable batteries, but for bigger machines more power is required, which results in bigger batteries. The volume and weight of the batteries are currently a bottleneck for this technology. Secondly, a problem is the small period of time the machine can be used before the machine has to be recharged, which usually takes

a long time. The development of batteries for electrical machines is slow, batteries keep having long charging times, and compared to a diesel tank require more space and weight within the machine.

4.1.1.1.1. Example: full-electrical machines

The concept of an electrical truck is very new: the first electrical truck in the Netherlands was developed for one and a half years and revealed at the beginning of 2019 (KWS, 2019). This truck includes a crane, and is fully-electric, with a radius of action of 150 kilometer. The truck was developed by KWS and their partners.

Figure 4 Full-electrical truck with crane (KWS, 2019)

The Volvo L25 is an excavator with a Li-ion battery pack. The machine can run up to 8 hours in its common applications, such as utility work. The machine has two different electric motors, one for drivetrain and one for hydraulics, which make it even more efficient. The machine can be recharged by a regular household plug socket, but a fast charging option with a higher power grid is also possible. The machine is very quiet and has zero local emission. The production will start mid-2020 (OEM, 2019).

Figure 5 Full-electric excavator (OEM, 2019)

4.1.1.1.2. Battery volume and weight

Figure 6 shows the different types of batteries, and their mass and volume compared to the energy density. Currently, Flooded and AGM (both lead acid batteries) are mostly used within electrical machines, which are not very efficient. Currently Li-ion batteries are more expensive than lead acid batteries. As can be seen from the figure Li-ion batteries are more efficient, and therefore will potentially replace the lead acid batteries (SGS Search Consultancy, 2017).

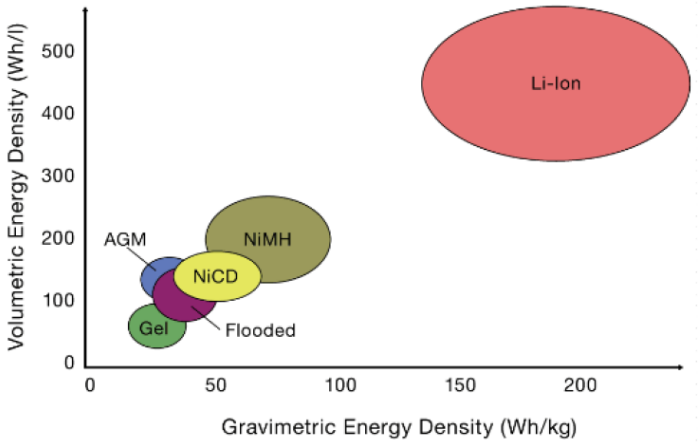

Figure 6 Comparison of battery types on energy density mass and volume (O'Connor, 2017)

Table 6 and Table 7 show the difference in volume and weight for a 23 ton excavator, when a lead acid battery, a Li-ion battery and a diesel fuel tank are used respectively. It can be seen that batteries are far more efficient (see difference in loss of return) than the diesel tank. On the other hand, the volume and weight needed for the diesel tank are much less than for both batteries.

Table 6 Comparison energy density to volume 23 tones excavator (SGS Search Consultancy, 2017)

	Unit	Lead-acid Battery	Li-ion Battery	Diesel
Energy capacity per volume	MJ / liter	0,396	1,656	35,9
Loss of return		30%[3]	20%[4]	70%
Required volume per MJ (inclusive loss of return)	Liter / MJ	3,6	0,8	0,09
Factor of volume relative to diesel		38,9	8,1	
Required space in 23 tones excavator (energy use per day)	liter	3885	813	100
Use of space in 23 tones excavator	m^3	3,9	0,82	0,3

Table 7 Comparison energy density to weight 23 tones excavator (SGS Search Consultancy, 2017)

	Unit	Lead-acid Battery	Li-ion Battery	Diesel
Energy capacity per mass	MJ / kg	0,108	0,54	29,438
Loss of return		30%	20%	70%
Required weight per MJ (inclusive loss of return)	kg / MJ	13,2	2,3	0,11
Factor of weight relative to diesel		116,8	20,4	
Required space in 23 tones excavator (energy use per day)	kg	9579	1676	82
Use of space in 23 tones excavator	ton	9,6	1,7	0,3

SGS Search Consultancy concludes that a lead acid battery can never be an option, because the volume needed is 40 times as large as a diesel tank and the weight is 120 times as heavy as a diesel tank, which will never fit in a machine. A Li-ion battery can be considered as a good option, the weight is 20 times as heavy as a diesel tank, but this may well be compensated with the removal of a heavy diesel engine (SGS Search Consultancy, 2017). Because the Li-ion battery is the only feasible solution, their study continues with only taking into account the Li-ion battery.

4.1.1.1.3. Battery recharging

Another problem that was identified earlier concerns the capacity of the battery. The problem is that batteries can only be used for a short period of time when fully charged, and require a very long loading time. A difference between a diesel tank and a Li-ion battery is that a diesel tank, when empty, can be refilled quickly and easily during the day. For a battery this is usually not the case (electricity connections are often not available at construction sites). A Li-ion battery can be partially recharged during coffee breaks and can be fully discharged in operation, in comparison to lead acid batteries (which are not able to fully discharge or partially recharge) this is a big advantage. Table 8 below shows a calculation for the needed charging time of a Li-ion battery, when using a low voltage connection (3x63A). The time needed for full recharging is around 10 hours. This suggests that a machine can only be reloaded overnight and used during the day.

Table 8 Required charging capacity and time (SGS Search Consultancy, 2017)

Energy and charging excavator 23 ton (Li-ion battery)	**Unit**	**Diesel**	**Li-ion Battery**
Energy content of the amount of diesel per net 8 hours of usage (12,5 liter/hour)	kWh	997	
Net given net energy per 8 hours (70% loss of return of diesel)	kWh	299	
Required battery capacity per 8 hour (= 299 kWh / 0,8) (starting from 20% loss of return electrical system and battery generation)	kWh		374
Loss of return conversion of AC to DC (battery charger)			10%
Required charging energy when fully discharged, taking into account loss of profit conversion (= 374 / 0,9)	kWh		416
Charging power at 3x63A low voltage connection	kWh		43
Required charging time at 3x63A low voltage connection	**uur**		**9,7**

SGS Search Consultancy concludes their study that it is possible for a 23 ton excavator to replace the diesel tank which a battery, when using a Li-ion battery. A low voltage connection is sufficient for recharging the batteries overnight, this will not lead to extra high cost, and can also be implemented on a temporarily construction site. Nevertheless, it is possible to decrease the charging time, but then a higher voltage connection is needed (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2018). This connection can for example be provided by the Dutch railway network, because that is largely powered by medium voltage power cables. Furthermore, the network for charging in the Netherlands is already quite extensive (Kindt & van der Meulen, 2011). Another solution for the long charging times can be to exchange battery packs, if contractors make use of modular battery packs (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2018). The batteries can be changed between machines the contractor needs at that moment. In this way there is always a charged battery pack available.

4.1.1.1.4. Pricing of machine

SGS Search included some pricing information in their study. They compared a diesel powered machine and a fully-electrically powered machine, both machines having a weight of 4 tones. Table 9 shows that the electrical machine has a higher purchase price, due to the battery pack. However, the yearly cost for the electrical machine is significant lower than the cost for the diesel machine. Therefore, the fully electrical machine has a payback time of around 4 years (SGS Search Consultancy, 2017), shown in Table 9.

Table 9 Financial comparison full-electrical vs diesel (SGS Search Consultancy, 2017)

Machine 35 kW	Full electrical AGM battery	Diesel
Depreciation (y)	10	7
Purchase machine and engine	€ 42.500	€ 42.500
AGM battery pack	€ 11.500	
Residual value	€ 4.250	€ 7.727
Depreciation per year	€ 5.468	€ 4.968
Maintenance costs	€ 750	€ 1.500
Costs of energy	€ 2.800	
Costs of diesel		€ 5.583
Total costs per year	**€ 9.018**	**€ 12.050**
Savings per year	€ 3.032	
Payback time AGM battery (year)	**3,8**	

Another study into the feasibility of batteries in heavy machines was conducted by McKinsey & Company (Forsgren, Östgren, & Tschiesner, 2019). They developed 48 scenarios based on a cross section of equipment type, charging technology and battery-size scenario. They tested each scenarios on capital expenditure, operating expenditure and productivity loss. See Figure 7 for the different scenarios and testing values. The total cost of ownership (TCO) is a combination of capital and operating expenditures. A positive TCO means that the TCO is lower for the electrical vehicle, than for the vehicles running on diesel.

The results are interesting: the model indicates that nowadays it is possible to have a competitive TCO for a battery-electric vehicle (BEV). For three of the four equipment types the TCO for a BEV is already 20 to 25 percent lower that the TCO of an internal combustion engine (ICE) (Forsgren, Östgren, & Tschiesner, 2019), see Figure 8. The TCO of BEV type 3 is expected to drop further around 2021.

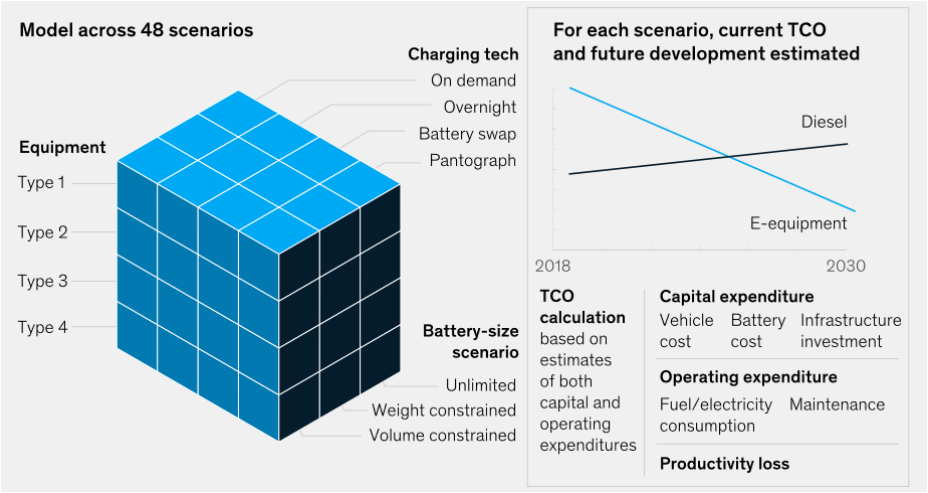

Figure 7 A granular model simulated TCO to assess when BEVs could be cost competitive with internal combustion engines (Forsgren, Östgren, & Tschiesner, 2019)

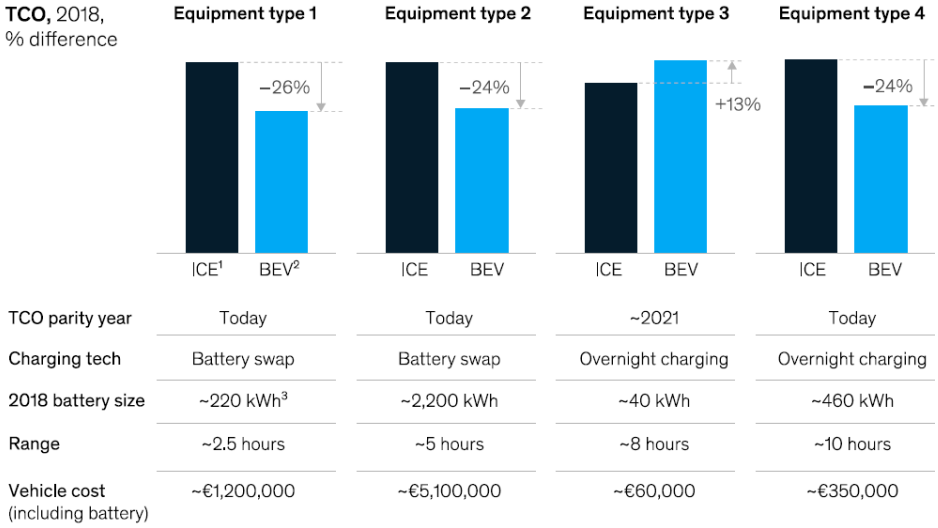

Figure 8 Analysis of operating costs and battery-charging, -size, and -range scenarios suggests there could be parity on TCO for three equipment types today (Forsgren, Östgren, & Tschiesner, 2019)

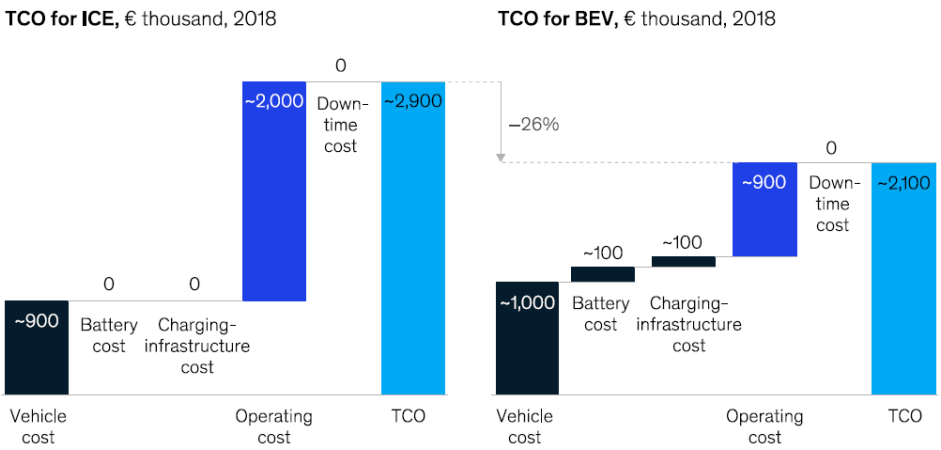

Figure 9 TCO for one BEV-equipment type is already 26 percent lower than for an ICE (Forsgren, Östgren, & Tschiesner, 2019)

The lower TCO of a BEV is mainly based on the lower operating costs, which are 40 to 60 percent lower than those of an ICE machine, see Figure 9. Forsgren, Östgren & Tschiesner (2019) mention that this is due to electric propulsion being inherently significantly more efficient than conventional engines, with 70 to 75 percent higher tank-to-wheel energy efficiency, reducing fuel consumption. Furthermore, the BEV will have lower maintenance costs, this is mainly due to the engine having fewer parts that can break down compared with ICE. A large-scale shift toward electrical machines can save up to $30 billion in operating costs, but the long-term saving needs first an investment of around $16 billion (Forsgren, Östgren, & Tschiesner, 2019).

4.1.1.2. Hybrid machines

A hybrid machine needs compared to a fully electrical machine a smaller battery, and besides that also has a fuel (diesel) tank. Compared to a conventional diesel machine, a hybrid is much more efficient, since it can switch automatically between the diesel engine and electrical engine when needed. See section 4.1.1.2.1 for examples of hybrid machines. A hybrid is a good solution for solving the limitations of the battery pack discussed before: there is no need for a big and heavy battery and if the battery is empty the diesel engine reloads it (Kindt & van der Meulen, 2011). Advantages of a hybrid machines are: reduction of fuel (diesel), higher efficiency, and machines work faster (SGS Search Consultancy, 2017). SGS Search also looked into the possibilities of hybrids. Hybrid manufacturers currently focus on making the reversible engine electrical. This has two advantages:

1. The direct electrical drive has a higher efficiency than a hydraulic drive, within a hydraulic system around 10-20% of energy is lost.
2. The regaining of kinetical energy from turning into electrical energy is easier and cheaper than regaining from a hydraulic system (SGS Search Consultancy, 2017).

Currently, hybrids are popular, mainly due to the fact that they are mentioned on the material list of the CO_2 Performance Ladder. The measure is listed as follows: 'Fuel: applying mobile machines on the basis of a fully-electrical or hybrid system'. Moreover currently a subsidy is available for electrical and hybrid machines, the MIA ('Milieu-investeringsaftrek' in Dutch).

4.1.1.2.1. Example: hybrid machines

The Hitachi ZH210LC-5B crawler excavator has a reversible motor driven both electrical and hydraulic. It weighs 22-23 tones, with 122 kW. The reversible motor generates electricity during usage of the reversible break. This energy is stored and used for acceleration of the hydraulic engine. The Hitachi excavator has a fuel reduction of around 30%.

Figure 10 Hybrid crawler excavator

The Volvo LX01 is a wheel loader of 23,5 tones. The systems for driving, turning and lifting are disconnected and individually optimized. The wheels and hydraulic pumps are powered electrically. The wheel loader can do with a diesel tank of 3,5 liter instead of 13. The fuel reduction can come up to 50%.

Figure 11 Hybrid wheel loader

4.1.1.2.2. Pricing of machine

SGS Search included pricing information of hybrid machines in their study. They compared a diesel powered machine and a hybrid machine, both machines have a weight of 23 tonnes. It can be seen in Table 10 that the hybrid machine has a higher purchase price, due to the hybrid system pack. Nevertheless, the yearly cost for the hybrid machine is significant lower, than the cost for the diesel machine. Therefore, the hybrid machine has a payback time of around 1 year if the subsidy is included and 10 year without (SGS Search Consultancy, 2017).

Table 10 Financial comparison hybrid electrical vs diesel (SGS Search Consultancy, 2017) (translated)

	Hybrid	Diesel
Purchase	€ 270.000	€ 270.000
Hybrid system	€ 30.000	
MIA subsidy	€ -27.000	
Depreciation	€ 27.300	€ 27.000
Costs of diesel (12,5 L/hour)	€ 12.500	€ 15.625
Total costs per year	**€ 39.800**	**€ 42.625**

4.1.1.3. Fully electrical machines with cable

Fully electric machines with a cable are already used on a large scale for the mining industry, and on semi stationary situational places. Nevertheless, this technology is not used widely within the construction industry, since the machines need a high amount of power, and are not easy to move (are bound to their cable). See section 4.1.1.3.1 for examples of fully-electrical machines with a cable.

4.1.1.3.1. Example: full-electrical machines with cable

The Hyundai R800LC-9 is a 60 tonnes crawler excavator. It has a 310 kW electrical engine instead of the commonly used 363 kW diesel engine.

Figure 12 Full electrical crawler excavator with cable

SENNEBOGEN transfer valves are available in different types. The picture is an example of such a type.

Figure 13 Full electrical transfer valves with cable

4.1.1.3.2. Pricing of machines

Table 11 shows the difference in pricing between a diesel machine and a full-electrical machine with cable (30 and 90 tones machine). It can be seen that the fully-electrical machine with cable has a much higher purchase price (2 times as high), but the yearly cost is significant lower, than the cost for the diesel machine.

Table 11 Financial comparison cable electric vs diesel (SGS Search Consultancy, 2017)

	30 tones excavator		90 tones excavator	
	Diesel	**Electrical**	**Diesel**	**Electrical**
Purchase	€ 275.000	€ 520.000	€ 560.000	€ 790.000
Technical life time	9	18	9	18
MIA subsidy		-€ 46.800		-€ 71.100
Residual value	€ 50.000	€ 20.000	€ 100.000	€ 50.000
Costs machine per year	€ 25.000	€ 23.853	€ 51.111	€ 37.161
Workhours per year	1100	1100	1100	1100
Maintenance costs per year	€ 11.000	€ 5.060	€ 8.250	€ 3.080
Energy costs per year	€ 26.400	€ 8.400	€ 38.720	€ 13.200
Total costs per year	**€ 62.400**	**€ 37.313**	**€ 98.081**	**€ 53.441**

4.1.1.4. Overall CO_2 reduction of electrification

SGS Search Consultancy includes the global warming potential (GWP) and CO_2 emission within their study for each of the considered alternatives, see Table 12. It can be seen that electrical has around 90% less emission compared to diesel when green electricity is used. For hybrid machines the fuel reduction can increase up until 50%, depending on type of work and machine.

Table 12 Comparison CO_2 emission (GWP) (SGS Search Consultancy, 2017)

Effect category	*Unit*	**Fuel**	**Electrical**	**Electrical**	**Electrical**	**Electrical**
Energy carrier		Diesel	Power cable	Power cable	Li-ion battery	
Electricity			Grey	Green	Grey	Green
Global warming (GWP), CO_{2eq} emission	*kg CO_{2eq}*	662	241	44	248	51
CO_2 emission reduction relative to diesel	--	0%	64%	93%	62%	92%

4.1.1.5. Development of electrification (future)

Another study into why there is currently few fully-electrical and hybrid Non-Road Mobile Machinery (NRMM) available is by Lajunen, et. all (2018). The study focuses on the development of new technologies, why this is such a slow moving process and what based on this study will be the long term scenario for electrification of NRMM. They make comparisons between the NRMM sector and on-road vehicles. They believe that electrification for NRMM will develop in the upcoming year, since more and stricter emission regulations will be introduced. New emission regulations will include both limitations for particle mass and for number of particles emitted. The conventional diesel engine cannot be adapted for these strict regulations, and therefore the authors of the study expect a speeding up for the electrification of NRMM. Nevertheless, this shift has not yet taken place. They think that this can be due to the problem that currently the vehicle operating performance and lifecycle costs are higher for electrical NRMM than for NRMM with a diesel powered engine. They say that the charging infrastructure has most effect on this price difference, but also the current high costs of electrical components affect the price of electrical machines. This problem was solved within the on-road vehicles industry by investing in mass production, unfortunately this is not possible in NRMM industry, since most machinery are so diverse and unique. They nevertheless expect that the costs for different component will drop within the upcoming years, see the Table 13.

Table 13 Hybrid and electrical powertrain component price forecast (Lajunen, Sainio, Laurila, Pippuri-Mäkeläinen, & Tammi, 2018)

Component/Year	2014	2022	2030
Controller ($/unit)	900–1000	1000–1100	1200–1300
Motor ($/kW)	25–30	23–27	20–25
Inverter ($/kW)	30–35	28–30	24–26
Battery ($/kWh)	450–500	375–425	330–380

Furthermore, they made predictions for the short- (-5 years) and medium (-10 years) term, on what will become important, and what new developments may be expected. The most-important ones are listed below:

- Air pollution regulations for all power classes in Europe
- Consumption of fossil fuel will increase, prices for fossil fuel will therefore also increase
- Development of electric components continues
- Development of electric powertrains
- Increase of renewable resources, increase of local stationary electrical energy storage

In addiction they made predictions for the long term (10-30 years), on what will become important, and what new developments may be expected. The most important ones are listed below:

- Automatization of vehicles, resulting in more accurate systems
- Autonomous machines
- Demand for energy efficiency
- Drop-in biodiesels playing a role in the fuel market
- Increasing hydrogen production
- Zero emissions legislation, within cities

They conclude that there are many external factors that can influence the implementation of alternative technologies favourably, e.g. regulations and legislations. Furthermore, they predict that the lifecycle management of powertrain electrification is the most important factor for the economic success of hybrid and electric powertrains in NRMM. They finish with the major constrains of electrification, which are high component process and system development costs. This implies that cost management of energy storage systems will be an important factor to decrease higher costs of electrification (Lajunen, Sainio, Laurila, Pippuri-Mäkeläinen, & Tammi, 2018).

4.1.2. Biodiesel

Biodiesel is a good alternative for diesel, since it is nontoxic and degradable. It releases significantly less chemicals to the atmosphere, also the CO_2 emissions is relatively lower, when the full life cycle is considered (Kindt & van der Meulen, 2011). An advantage of biodiesel is that it is a renewable resource. Biodiesel is mostly used in a blend of normal diesel (obtained from fossil fuel) and biodiesel (produced from plants and waste); the percentage of biodiesel can vary between 10 and 100%. A disadvantage of biodiesel is that a lot of resources are needed to produce it (Kindt & van der Meulen, 2011). There are different ways of producing biodiesel, one more sustainable than the other. The two that will be discussed here, are Hydro-treated vegetable oil or blue diesel (HVO) and biodiesel made from crops. Using agricultural land for the production of biodiesel or deforestation for the production is not suggested, and bad for the environment (Kindt & van der Meulen, 2011). Currently, biodiesel is widely available in the Netherlands, many power stations offer a type of biodiesel. Within the Netherlands 40% of the biodiesel originates from palm and rapeseed oil, 60% comes from oil retrieved from waste (frying oil and meat).

The CO_2 emission factors of biodiesel (B100) are: **3,154 kg/L** for biodiesel made out of crops and **0,345 kg/L** for biodiesel from waste oil (CO_2-emissiefactoren, 2019).

4.1.2.1. Biodiesel from crops

There are many crops that can be used for the production of biodiesel. Biodiesel is relatively easily produced from plants, and often a byproduct of food processing (Bachman, 2011). Nevertheless, it is not a good idea to produce biodiesel from dedicated crops (only meant for producing biodiesel), since this will impact the feedstock. Another negative side effect of biodiesel is that plantations of crops may lead to deforestation (Kumar, Sonthalia, Pali, & Sidharth, 2018).

4.1.2.2. Hydro-treated vegetable oil or blue diesel (HVO)

HVO is produced for 80% from renewable sources, and for 20% from primary sources. For research purposes it is assumed that 20% is rapeseed oil, 40% frying oil, 40% meat oil. HVO is then produced with a hydro treatment process: this process uses hydrogen to change the molecules of the oils to hydrocarbons. HVO is used in a mixture with fossil diesel; around 30% HVO can be used in a regular engine, but the engine should be tested extra for bacteria forming (Kootstra, 2018). This HVO blend results in a reduction of environmental impacts when comparing to normal diesel, see Figure 14 for the environmental cost indicator (ECI).

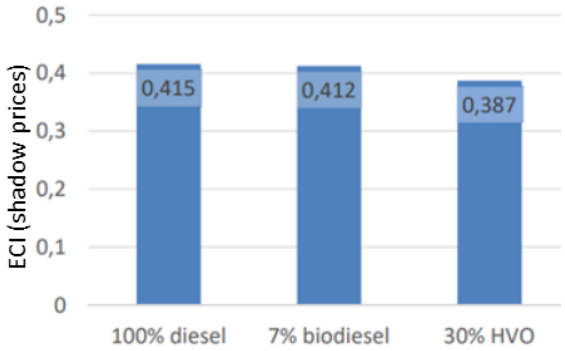

Figure 14 ECI per litre fuel for Euro 5 trucks (Kootstra, 2018) (translated)

Another study shows that use of HVO can reduce 90% of environmental impact compared to fossil diesel (Natuur & Milieu, 2018). Currently it is even possible to have 100% HVO within the diesel mixture. This amount of HVO will lead to a reduction of 89% to 100% CO_2 emission (Den Hartog bv, 2019).

4.1.3.Gasses

Using gases instead of diesel gives a potential CO_2 reduction, nevertheless the Dutch Government wants to get rid of natural gas use in the near future. Therefore, this study will not go into too much detail concerning the possibility to replaces diesel by gasses. Natural gas produces around 25 percent less CO_2 emission compared to fossil oil, and therefore is the cleanest fossil fuel known. Furthermore, it also produces less soot and particulate matter (Kindt & van der Meulen, 2011).

The CO_2 emission factors of gasses are: **1,806 kg/L** for LPG, **3,370 kg/kg** for LNG and **2,728 kg/kg** for natural gas (CO_2-emissiefactoren, 2019).

4.1.3.1. Liquefied Natural Gas (LNG)

LNG is made out of natural gas, which is being cooled to -162 degrees Celsius . The volume becomes 600 times smaller than natural gas (Kindt & van der Meulen, 2011). LNG consist for 98% of methane. It has a slightly lower energy content compared to diesel, and therefore more LNG is needed to produce the same amount of energy (Bachman, 2011). Nevertheless, it still reaches a CO_2 reduction of around 23% (Bouwmachines, 2019). Purchase costs of a LNG vehicle are higher than costs for a diesel vehicle. Prices for the LNG itself are slightly lower, compared to diesel (Kindt & van der Meulen, 2011). Another advantage of LNG vehicle is that it has a low noise level compared to a diesel vehicle (Kindt & van der Meulen, 2011).

4.1.3.2. Liquefied Petroleum Gas(LPG)

LPG is a blend of propane and butane, both byproducts of crude oil refining, and come from natural gas wells (Bachman, 2011). Most vehicles use a blend of LPG (25-40%) and diesel. LPG is cleaner than diesel, because is burns more evenly. Machines running on LPG can reduce 10% CO_2 emissions, based on the fact that it is a waste product and used in a mixture. The pricing of LPG is beneficial compared to diesel. Nevertheless, the initial cost for a vehicle powered by LPG are higher.

4.1.4.Hydrogen

Hydrogen is similar to electricity an energy carrier, and not a fuel. Nowadays around 95% of the produced hydrogen is produced from fossil fuels, only 5% is made from renewable sources. Therefore hydrogen is now a very costly and large emission producer (Kumar, Sonthalia, Pali, & Sidharth, 2018).

The CO_2 emission factors of hydrogen are: **12,00 kg/kg** for grey hydrogen and **0,840 kg/kg** for green hydrogen (CO_2-emissiefactoren, 2019).

4.1.4.1. Production and use of hydrogen

Hydrogen made out of natural gas has about 30% les CO_2 emissions compared to diesel. When hydrogen is produced by green energy, the life cycle CO_2 emission can reach zero. Hydrogen can be used in two ways for the powering of a vehicle. The first one is the same as a conventional combustion engine, the hydrogen is combusted, which causes the powering. The second method is by use of a fuel cell: within a tank the hydrogen together with oxygen is transformed into steam. This explosive reaction causes heat and energy which is used to power an electrical generator.

Hydrogen when combusted with oxygen at high pressure and temperature has a very high energy content and a low density: 120,000 kJ/kg, 0.0898 kg/m^3. Hydrogen is carbon-free and therefore does not produce any CO_2 emission nor local emissions (Natuur & Milieu, 2018). When combusted it releases only steam, furthermore it also has a low noise level (Kindt & van der Meulen, 2011).

4.1.4.2. Future developments

Currently, the government of Groningen makes use of garbage trucks powered by hydrogen, and is shifting other material to hydrogen (Bouwmachines, 2019). Additionally, they want to invest in the upscaling process of the production of hydrogen (Avebe, et al., 2019). Together with partners the governmental bodies of Groningen wrote an investment plan for the upcoming years. Their vision is to produce emission free hydrogen by using renewable energy (green H_2) and by CO_2 capture and storage (blue H_2). They see upscaling of the process as an essential element for the development of a hydrogen economy. Without upscaling the operational cost will remain to high, and hydrogen will never be attractive for consumers to use. They want to scale up the hydrogen production to 70 PJ per year, see Figure 15 below.

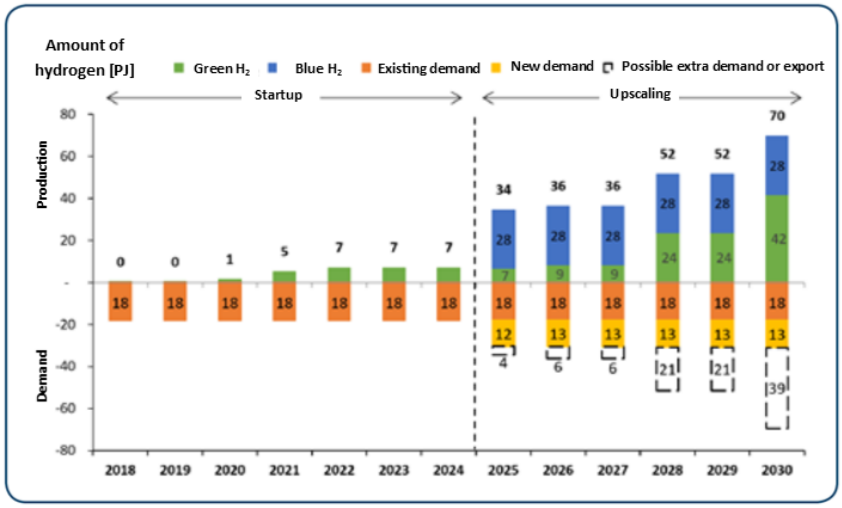

Figure 15 Hydrogen development until 2030 (Avebe, et al., 2019)(translated)

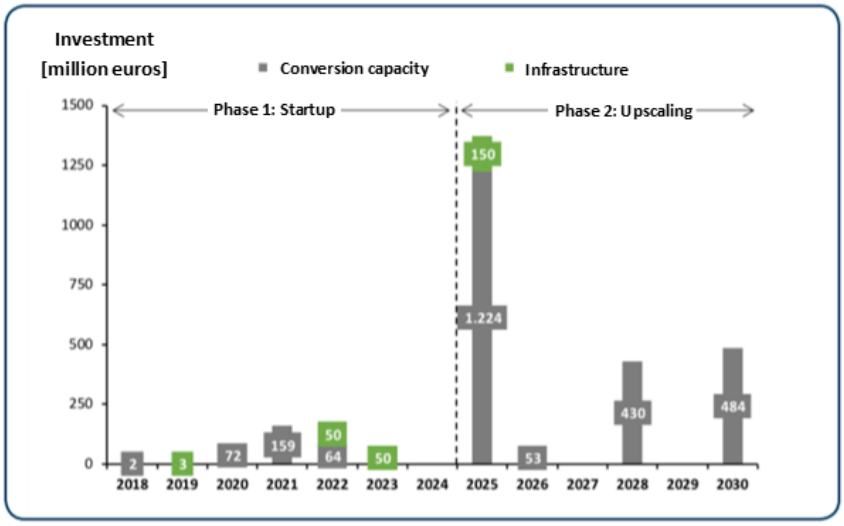

Figure 16 Needed investment per year until 2030 (Avebe, et al., 2019) (translated)

The potential CO_2 reduction when 1 billion m^3 grey hydrogen (this amount is equal to an energy capacity of 10,8 PJ) is replaced by green and blue hydrogen, will lead to a reduction of **600 kilotons of CO_2 emission** (Avebe, et al., 2019). Upscaling the process can also help to achieve the climate goals of the Dutch government, estimated is a CO_2 reduction of 49 to 55% of total. To accomplish the upscaling a total investment of 2,8 billion euros is needed, which is spread over the upcoming years, see Figure 16

The north of the Netherlands is a good place to start with hydrogen production and upscaling. The present pipelines structure for natural gas can be used to transport the hydrogen. Furthermore, the present salt

caverns can be used as storage rooms for hydrogen. They think of three phases of consumers for hydrogen (Avebe, et al., 2019):

1. First they will start with city busses and utility vehicles with long term and continued use
2. Second phase comprises light truck transport and long distance passenger transport
3. In a later phase heavy truck transport and part of the shipping and transport by train will be developed.

This will result in a transport sector with almost zero emission. Furthermore, they expect that the employment opportunities will grow, for the hydrogen economy 16500 structural new jobs in 2030 are estimated. The total production plan can be seen in Figure 17 (Avebe, et al., 2019).

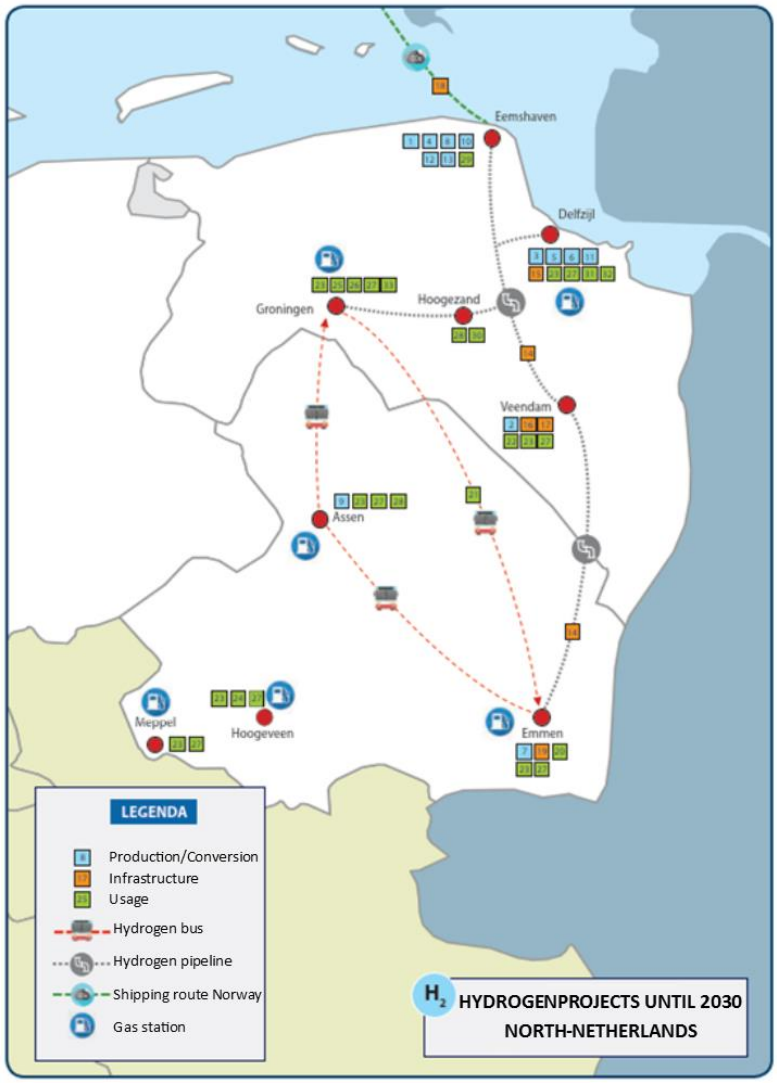

Figure 17 Overview of hydrogen projects until 2030 (Avebe, et al., 2019)

4.2. Efficient fuel usage solutions for machines and transport

The previous section considered changing the fuel. This section considerd ways of using the fuel more efficiently. Several ideas are elaborated on. Of course there are many more alternatives, but the discussion below focuses on those ideas which are already in use, or have a high potential for the construction sector.

4.2.1. Drive smarter

A way to reduce diesel is by driving more 'smart'. Planning appointments more close by or using efficient routing will help to reduce the distances that have to be travelled, and thereby reduce the fuel consumption. Furthermore, a good option to decrease travel needs is to use video conferencing for meetings with people far away. Also the course 'Het nieuwe rijden' stimulates drivers to drive more efficient and turn off their engine when possible. Here drivers are taught, similar to the course 'het nieuwe draaien', to drive in a more sustainable way, and make better choices concerning the environment.

VolkerWessels used some of these measures and experienced good results in reduction of travel kilometres. VolkerWessels monitors the driving behaviour of their drivers, and runs a competition on who is the most efficient driver of the quarter. They also purchased new software that can plan mobility movements and routes in a smarter way. Their commercial vehicles are equipped with sensors (GPS), this can help to link assignments to drivers which are already in the area. Moreover, the company invested in video conferencing, every branch has at least one screen for video calling. In 2017 they saved around 47.000 travel kilometers per month (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2019a).

4.2.2. Use of lighter machines

Heavy machines use 5 to 10 times more fuel, than lighter machines from the same type (Natuur & Milieu, 2018). Therefore it is important that no heavier machine will be used than needed for a task, see Table 14 for the results of using a heavier machine on fuel usage. It can be even better to use several smaller machines instead of one bigger machine.

Table 14 Average fuel consumption wheel loader (in litre/ hour) for different workloads (Natuur & Milieu, 2018)

	Low	Medium	High
8ton kg	4	5	6
50ton kg	26	35	50

4.2.3. Course 'Het nieuwe draaien'

'Het nieuwe draaien' is a course which drivers of all sorts of machines can take to make them more aware of how to operate their machines in an efficient way. They also learn how to reduce environmental impacts of their machines (Natuur & Milieu, 2018). 'Het Nieuwe Draaien' aims to result in a CO_2 reduction of 8 to 10%. The course should noticeably lead to reduction of fuel (8-10%), which will lead to reduction of costs. Some tips that will be taught during the course are (Duurzaam MKB, 2019):

- Work as evenly as possible, avoid sudden fastening and slowing down of the machine
- Accelerate as fast as possible, driving with a lower number of revolutions per minute is beneficial for the energy use, because of less internal friction
- When you see you have to slow down or stop, let go the gas pedal in advance, and let the machine roll out to stand still
- Turn off the engine for short breaks
- When starting, do not use the gas pedal
- Check the tire pressure monthly

The government of the Netherlands stimulates to use the course 'Het Nieuwe Draaien', because it is proven that this course is very effective, and results can be seen almost immediately (Bouwmachines, 2019).

4.2.4.Drive assistant or autonomous machines

The upcoming 5 year a copilot within machines will become more common. This will help drivers to be more efficient in their work. Currently there are a lot of contractors that already use GPS, which also improves the efficiency. Furthermore, the expectation is that in 2025 the first autonomous vehicles are operational, which again will result in a higher efficiency (Natuur & Milieu, 2018).

5. Results

In this chapter the results of the literature review are presented. Thereafter the results of the conducted interviews are presented. Lastly, the results of the CO_2 reduction calculation of different proposed measures are shown in section 5.3.

5.1. Literature review

In this section the results of both parts of the literature review are briefly presented.

5.1.1. Alternatives to replace diesel

In Table 15 the results of the literature review on alternatives for diesel are summarized.

Table 15 Brief description of the literature review on alternatives for diesel

Option	Possible reduction	Costs	Remark
Electrification	100% full electrical 10-50% hybrid	batteries are currently very expensive. hybrids increase investment cost by 10%	full electrical with cable is a bad option cost expected to drop in future
Biodiesel	90% for B100	18 cent extra per litre	only CO_2 reduction if it is made out of waste oil
Gasses	23%	roughly the same as diesel	not a good option, since Dutch government wants to get rid of natural gas
Hydrogen	100% in future	very expensive, not feasible at this moment	in future a good option, but technology has to develop

5.1.2. Increasing diesel efficiency

In Table 16Table 15 the results of the literature review on alternatives for diesel are briefly presented.

Table 16 Brief description of the literature review on efficient measures for diesel

Option	Possible reduction	Costs	Remark
Drive smarter	an amount of travel kilometre	extra cost for planning employee, but cost saving for travel kilometre reduction	based on efficient planning
Use of lighter machines	effect not known	-	use of lighter machines can be an option to reduce CO_2
Course 'het nieuwe draaien'	8-10% fuel reduction	initial cost for course, thereafter reduction of fuel.	course will only help if drivers are willing to reduce CO_2
Drive assistant or autonomous vehicles	effect not know, but increases efficiency of work	-	future will learn how autonomous vehicles can be used in the construction industry

5.2. Interview partners

In this section the results of the interviews with partners of Plegt-Vos Infra&Milieu are provided. The results are grouped by per question, so that similarities and differences between partners can be seen easily. For the different categories of the interview tables are provided to show the answers given by the interviewees.

**When employees are named, it is referred to the drivers of the machines.*

5.2.1. Category I: environmental goals and vision

Most partners are certified with the CO_2 aware certificate, some partners are currently busy with the certification procedure. Most of the partners have a vision on sustainability and CO_2 reduction. Furthermore, all which have the certificate, made CO_2 reduction goals, those with no certificate also have no CO_2 reduction for themselves. Their opinion on CO_2 neutral possibilities vary, some say it will never happen, while other are more positive. The exact numbers for scope 1 and 2 (direct emissions) are normal, compared to the sizes of the companies.

Table 17 Category I vision, goals and information on CO_2

Company	CO_2 aware certificate available, and on which level	Vision on sustainability and CO_2 reduction	CO_2 reduction goals	CO_2 neutral possible?	CO_2 quantity (scope 1+2, tonnes/year for 2018)
Blokland Holding B.V.	yes, level 3	reduce CO_2 emission and cost	Scope 1: 1% per year Scope 2: 1% per year	no, too much depending on diesel usage	2046
Geurs Loon-Grondverzet- en Transportbedrijf B.V.	in progress, level 3 (January 2020)	help the environment and stay interesting for clients	not jet developed	yes, when compensation is possible	1631
Groenservice Noord B.V.	yes, level 5	zero emission, being the most sustainable company within the sector and region	scope 1: 30% in 2025 scope 2: 30% in 2025 scope 3: 40% in 2025	no, maybe when compensation is possible	210
Aannemingsbedrijf Kramer Metslawier BV	yes, level 3	reduce an amount CO_2 over a period of 30 years	scope 1: 7% in 2023 Scope 2: zero emission	no, too much depending on diesel usage	731
Vogelzang & Zn	in progress, level 3 (January 2020)	improve on the area of CO_2 emission reduction.	not jet developed	yes, with biodiesel	1596
Struyk Verwo Infra	yes, level 3 and MVO level 4	having the lowest MKI score in the whole sector, in 2023	not developed	no, depend too much on cement, willing to improve their reduction on CO_2	6150

5.2.2. Category II: CO_2 reducing measures #1

Partners that have the certificate already implemented some measures, these are measures with respect to reduction of diesel and others that do not relate to diesel. They mention mostly practical measures, like checking tire pressure regularly, updating the office building (LED-light) and buying new cars and machines. Measures that are mentioned as having the highest (potential) effect are measures that change the behaviour

of employees (in ways of efficient driving and the course 'het nieuwe draaien', and buying new cars and machines (hybrid, euro6=the most clean engine at this moment). Additional measures that they are considering for implementation are mainly buying new machines, using biodiesel, improve office building in terms of energy efficiency, make employees more aware of CO_2 emissions.

Table 18 Category II: CO_2 reducing measures #1

Company	Measures already implemented	Measures with highest effect	Additional measures considered
Blokland Holding B.V.		not yet available	- hybrid machines
Geurs Loon-Grondverzet- en Transportbedrijf B.V.	- efficient planning - checking tires pressure (4x a year) - buying new machines (add blue and euro 6) - working efficiently with GPS (2D/3D technology) - using soot filters	not yet available	- GPS total station (laser guided) - planting trees to compensate for CO_2 emissions - hydrogen initiative project
Groenservice Noord B.V.		- changing behavior of employees - reducing fuel - buying new cars - recycling waste - checking tires pressure	
Aannemingsbedrijf Kramer Metslawier BV		- course 'Het Nieuwe Draaien'	- Black Box machines (tracking of drivers) - course 'Het Nieuwe Draaien' - checking tires pressure - campaign consciousness of CO_2 emissions employees
Vogelzang & Zn	- LED lights office - 2 hybrid cranes - buying new cars	- buying hybrid cranes - buying new cars	- buying solar panels - buying hybrid machines - use biodiesel B50/B100 - participation in initiatives - planting trees - improving energy label of office building
Struyk Verwo Infra	- green electricity - early start sustainability - exchange knowledge with partners	- geopolymeers	- geopolymeers - LED light - update office building - developing new products - innovation tracks - working together to exchange knowledge

5.2.3. Category III: CO_2 reducing measures #2

Measures which partners mention as easy to implement are efficient planning, checking tire pressure regularly, upgrading the office building and changing the behaviour of employees. The measures that they consider difficult to implement mainly consist of investments in electrical machines and alternative fuels (biodiesel). The question of how Plegt-Vos Infra&Milieu can help them to reduce CO_2 emission is answered by all partners by: extra financial contribution, support paying electrical machines or biodiesel.

Table 19 Category II: CO_2 reducing measures #2

Company	Measures easy to implement	Measures difficult to implement	How can Plegt-Vos help
Blokland Holding B.V.	- upgrade the office building - isolation and - solar panels	- electrical material	- providing charging facilities on building site - understanding of electrical machines from implementers
Geurs Loon-Grondverzet- en Transportbedrijf B.V.	- NEOX compensate emission - efficient planning - check tire pressure	- changing to alternative fuel (hydrogen and electrical)	- pay for alternative fuel - compensate emissions (planting trees or NEOX)
Groenservice Noord B.V.	- change the behavior of employees - carpooling - efficient planning	- electrical vehicles	- change designed: planting more green that extract CO_2 and sustainable material - talk and learn from each other
Aannemingsbedrijf Kramer Metslawier BV		- biodiesel	- splitting costs for biodiesel or higher hourly rate
Vogelzang & Zn	- place solar panels - plant trees - course 'Het Nieuwe Draaien'	- participation in initiatives - changing to alternative fuel - changing energy label of the office	- better price for sustainable choices - design in a more sustainable way
Struyk Verwo Infra	- upgrade the office building - invest in electrical transport	- develop geopolymeers - exchange knowledge	Not applicable

5.2.4. Category IV: alternative for diesel

Half of the partners currently use a blend of biodiesel in all their machines, and see potential to increase the percentage of biodiesel in the blend. All partners see potential to invest in electrification, but only in hybrids and small fully-electric machines. Nevertheless, those measures are not implemented yet because of the poor availability of hybrid machines and the higher purchasing prices. For hydrogen they are also positive, but not for now: in the future they want to invest in it. Overall they see biodiesel and electrification (hybrid) as most promising in the short term. And if available hydrogen in the future.

Table 20 Category IV: alternative for diesel

Company	Biodiesel	Electrical	Hydrogen	Best option
Blokland Holding B.V.		- invest in hybrid cranes		- electrical
Geurs Loon- Grondverzet- en Transportbedrijf B.V.	- standard biodiesel use - more expensive than normal diesel - the price can vary per day with 10-20 cents - can be an option, if prices will be payed or prices will be lower	- smaller vehicles - batteries need to charge, some projects no power available - batteries, big and heavy, do not fit machines - hybrid limited available	- prices of machines are 4x more - fuel is more expensive - not yet good technologies available	- hydrogen, long term - biodiesel if pricing is good, short term
Groenservice Noord B.V.	- standard aspen fuel, better for environment - disadvantage: few fuel stations	- use small electrical machines - hybrid cranes, within short period of time - electric vehicles move employees within short period of time	- future for hydrogen in cars, not for machines	- electrification, short + long term
Aannemingsbedrijf Kramer Metslawier BV	- is feasible, but more expensive	- hybrid, full electric not - short term they thinking of a hybrid crane - when old machine to be replaced, look for benefits of a hybrid	- currently not realistic	- most potential in hybrid - hydrogen not so much
Vogelzang & Zn	- standard B20 use - positive about the blue diesel - machines perform better, less bacteria formation than before - improve the blend to B50/B80/B100, now too expensive (+30 cent/L)	- two hybrids cranes - when old machine to be replaced, look for benefits of a hybrid	- good alternative in the future - now to less available on the larger scale	- hydrogen, long term - biodiesel and hybrid, short term
Struyk Verwo Infra	not applicable	not applicable - check possibilities for electrification	not applicable - see hydrogen more for the future	- use app for transport

5.2.5.Category V: efficiency of diesel

The opinions on autonomous machines are divided, some partners see it never happen, while other think it will be very much used in future, if technologies are well developed. The course 'het nieuwe draaien' is seen by all as a great aid to reduce CO_2 emission in a fast way. Some of the employees of partners already took the course, and achieved good results. For some partners clients choose which machines they need, other choose the machines themselves and make an efficient planning. It sometimes happens that a heavier machine is used than needed, but mostly not, since those machines are also more expensive.

Table 21 Category V: efficiency of diesel

Company	Autonomous machines	Course 'Nieuwe Draaien'	Machine use and planning
Blokland Holding B.V.	yes, for potentially high risk work	- implemented - noticed that was more efficient	- client choses machine - heavy machine cost more than smaller
Geurs Loon-Grondverzet- en Transportbedrijf B.V.	yes, in the future for digging slots, possibly only parts of tasks - first autonomous cars	- establish sustainable consciousness for drivers - similar course on efficient use of machines from CODE 95 - use stop and go system	- efficient planning - if needed renting - client can chose machine and size - sometimes bigger machine, planning wise better - lighter work with the eco stand - smaller work with mini cranes
Groenservice Noord B.V.	no, way too dangerous	no, have no heavy machines	- select machines based on availability - if needed renting - choose most light machines, cost less - client can choose machines, never occurs
Aannemingsbedrijf Kramer Metslawier BV	yes, currently use of GPS is a start - future full autonomous cranes, on a fenced building site	- implement January 2020 - check for which drivers course is beneficial	- sometimes larger or smaller machines are used, smaller take more time - a lighter rented machine costs more than own heavier type - use GPS, efficient driving - client can choose driver, comes with fixed machine
Vogelzang & Zn	no, questions possibility within construction	- added in long term reduction plan - check if costs weigh up to benefits - already check their tire pressure regularly	- select machines based on availability - client sometimes askes for a specific machine, mostly not - use bigger machine than needed sometimes occurs
Struyk Verwo Infra	- most machines autonomous - some processes not possible	*CO_2 storage?* - no experience - recycling waste water	not applicable

5.3. Proposed measures for CO_2 reduction

In this section the proposed alternatives for diesel and measures to use fuel more efficiently will be linked to the opinions of partners. Furthermore, an estimation is made how many CO_2 emission can be reduced and what the cost of the measures will be. The measures discussed below, are the measures which all partners mentioned as most realistic or promising.

5.3.1. CO_2 aware certificate

Most partners have the certificate, or are trying to be certified. Because the certificate focusses on insight in CO_2 emissions and defining CO_2 reduction goals it can be a criterion for Plegt-Vos when selecting their partners. Companies with a certificate commit to a 3,2 percent reduction of CO_2 emission each year. If Plegt-Vos should decide it will only work with partners that have the certificate, this implies that their scope 3 emission will decrease around 3,2 percent each year. Furthermore, if partners are aware of CO_2 emission and see the need to reduce CO_2 emission Plegt-Vos can create initiatives together with their partners to discuss possible new ideas and solution to reduce CO_2 emission.

5.3.2. Hydrogen

Hydrogen is at this moment in time not a realistic option, but if technology continues and the plans of the North of the Netherlands are executed, it will become a good option to reduce CO_2 emission. If hydrogen can be produced in a blue or green way, the emissions produced will be zero. For now the amount of hydrogen available is minimal, and machines running on hydrogen are 4 times more expensive than a machine running on diesel.

5.3.3. Hybrid machines

All partners agree that changing their machines to hybrids is a good option to reduce CO_2 emission. Section 4.1.1.2 shows that hybrids can reduce around 10 to 50%, for a 23 tonnes crane and excavator, as shown as example in section 4.1.1.2. In the literature review it is shown that a hybrid system is currently 10% more expensive than a traditional diesel-based system. The operational costs of hybrids lay 25% lower (depending on machine type), due to less diesel needed. An option might be that Plegt-Vos pays half of the extra costs for the hybrid system, and thereby becomes co-owner of the machine. In that scenario, Plegt-Vos may use this machine for all its projects within the region. In this way the projects that make use of hybrid material produce fewer CO_2 emission, and the costs for reduction are split between Plegt-Vos and their partners. After some years the machine is paid off, thereafter the machine will run cheaper, and this profit can also be split between Plegt-Vos and its partner.

This option is particularly interested for Geurs Loon- Grondverzet- en Transport bedrijf B.V. and Aannemings bedrijf Kramer Metslawier BV, since they rent employees + machine to Plegt-Vos fulltime. If all these fulltime employees would be using a hybrid machine, the reduction become beneficial for the CO_2 reduction in scope 3 of Plegt-Vos.

5.3.4. Biodiesel

Partners are willing to use biodiesel, but are reluctant due to the high costs. If the additional costs can be split between Plegt-Vos and its partner biodiesel will be a good CO_2 reducing measure. If a blend of B100 is used and this blend is only made out of waste oil the emission factor is **0,345 kg/L**. The emission factor for diesel is **3,230 Kg/L.** This means that biodiesel can cause a reduction of almost 90%. The costs for this Blue diesel are 18 cent higher than conventional diesel (NOS nieuws, 2018). It is also possible that an agreement is made for a blend that is cheaper, but produces more CO_2 emission, for example a B20-B50 blend.

5.3.5. Course 'het nieuwe draaien'

All partners saw high potential in the training course 'het nieuwe draaien'. The course is expected to result in a reduction of CO_2 emission between 8 and 10 percent. This CO_2 reduction is cause by a reduction in fuel usage, and increase in fuel efficiency. Hence, partners will reduce costs. If partners make sure all their employees take the course, and can show this by a certificate, Plegt-Vos will indirectly reduce 8-10% CO_2 emission. If Plegt-Vos demands from all their partners they take the course, and in return pay the same

hourly rate for the machines, partners can earn back the money they paid for the course (because they save on fuel cost, but are still paid for it).

5.3.6. Costs and CO_2 reduction

For each potential alternative named in the sections 5.3.3 until 5.3.5 the investment cost, yearly cost and amount needed to achieve the reduction goals of scope 3 (reduce -10,5% CO_2 emission) are calculated. See Appendix IV for a detailed calculation, the results of this calculations are summarized in Table 22. For both biodiesel no investment costs are needed, only yearly costs apply. For both hybrids and the course 'het nieuwe draaien' first an investments has to be made, before yearly cost reduction will be applicable. This yearly cost reduction arises due to the fact that the operation costs are lower, since diesel is used more efficient. From Table 22 is can be noticed that the payback time for the course 'het nieuwe draaien' is very small, and that the payback time for hybrid, is only 3 to 6 years.

Table 22 Investment and yearly cost per proposed measure

Measure	Investment cost (euro)	Yearly cost (euro)	Payback (time)	Amount needed (…)	Reduction per (kg CO_2 …)
B100	none	€5.411	none	60.122 litre	2,885 per litre
B20	none	€13.676	none	358.001 litre	0,4845 per litre
Hybrid (15%)	€240.000	-€5.413	6 year	16 machines	11.442 per vehicle
Hybrid (30%)	€120.000	-€10.826	3 year	8 machines	22.884 per vehicle
Het nieuwe draaien	€3.625	-€2.887	1 month	29 drivers	6.102 per driver

6. Conclusion

In this chapter conclusions are drawn from the results presented in chapters 5.

6.1. Alternatives for diesel usage

In the following sections conclusions are shown for each diesel alternative. Thereafter an overall conclusion is drawn to answer sub question 1.1: 'What are possible ways to replace diesel usage?'

6.1.1. Electrification

Electrification of machines can lead to a maximum of 92% of CO_2 reduction. Furthermore, electrical machines do not produce emissions locally (where machine is used). Currently, the prices of both electrical and hybrid machines are higher than the same machine with a diesel engine. Nevertheless, the operational cost are lower, electrical machines are more efficient and need less or no diesel. Furthermore, electrical power is less expensive than diesel. Nowadays, there are good alternatives available to replace traditional diesel powered machines by hybrid machines. For heavy machines there are currently less options available for going fully-electrical, mainly due to limitations (weight and volume) of battery packs. Within the near future the situation is expected to improve, and new electrical machinery types will become available. If the development continues, the focus should be on lowering the system development costs, so that the machines will become more attractive.

6.1.2. Biodiesel

Biodiesel is only better for the environment than diesel if it is produced out of waste material and byproducts. Currently, the production of environmentally friendly biodiesel is limited, since there is no unlimited supply of waste material and byproducts. If biodiesel is made out of crops, which are especially planted for the production of biodiesel, it is not better for the environment. The reason for this is that it competes with the feedstock and can lead to deforestation. Another disadvantage of biodiesel is that it produces emissions locally.

6.1.3. Gases

Gases can be a solution in the short term to reduce CO_2 emission. Nevertheless, for the long term it will be a poor choice, since it is still a fossil fuel and produces CO_2 emission locally. Additionally, the Dutch government wants to get rid of natural gas use in the near future, therefore it is not recommended to invest in gas, since this investment may not be paid back in time.

6.1.4. Hydrogen

In the short term hydrogen use in the construction sector will be limited. The technologies for using hydrogen in machines are currently not mature and there is no operational network available yet for production and powering. Nevertheless, when looking at the plans for the north of the Netherlands, hydrogen can become a solution of the future (2030). Taking into account that in the upcoming years also the technology for machines powered by hydrogen will be improved, hydrogen will certainly become a viable option for the future. An advantage of hydrogen powered machines is that they will not produce CO_2 emissions locally, only steam. If all hydrogen can be produced emission free, the shift to hydrogen powered machines will result in zero emission.

6.1.5. Best alternative for diesel

All alternatives for diesel have their pros and cons. It can be expected that electrification and biodiesel will be implemented within a short period of time, from now on. In the long term, hydrogen could very well become the best option. Furthermore, it seems unlikely that natural gas is a useful option to invest in, due to the plans of the Dutch government to cut the Netherlands off the gas. Currently, biodiesel is available on a small scale, there are few fuel station where biodiesel can be tapped. When more companies are willing to use biodiesel, it is likely that the prices for the fuel will raise unless a way is found to increase the production, but that seems unlikely. This results in increased prices for machine rental and transport. Electrification is only available on a small scale and only for small machines. It is assumed that in the future more machine types will become available in a fully-electrical version, in particular small machines. Heavy

machines cannot be produced fully-electrical yet, but hybrid versions are becoming more wide-spread. A problem of electrification is that a higher investment is needed when buying a new machine than when buying a traditional diesel powered machine. These extra investment costs, however can be earned back over a reasonable period, because of the lower operational costs.

Based on the literature review the alternatives are ranked from most potential to least potential (on the short term):

1. Biodiesel *2. Electrification* *3. Hydrogen* *4. Gas*

Most likely not a single one of these alternatives will solve the whole CO_2 problem, probably a combination will be needed.

6.2. Efficient fuel usage solutions for machines and transport

In the following section, the answer is given to sub question 1.2: 'What are possible ways to make diesel usage more efficient for machines and transport?'

Driving smarter is a good way to reduce fuel. By planning more efficiently, making use of digital technologies to help drives work more efficiently and using of video conferencing CO_2 emissions can be reduced. Another measure to reduce CO_2 emissions is to **use lighter machines**. If for each project and task a balance can be found between the lightest machine (which can handle the job) and the location where the machines has to come from, this will save fuel, and thereby reduce CO_2 emission. The **course 'het nieuwe draaien'** makes drives more aware of their behaviour when operating a machine. They learn what the impact of their behaviour is on the efficiency of fuel usage. It is proven that drivers who have taken the course reduce 8 to 10% of fuel, and thereby around 8 to 10% of CO_2 emissions from their machine. Computers can be programmed to perform a routine task more efficiently than humans. With the help of a **driving assistant** machines work more efficiently, and can reduce fuel usage. In future, **autonomous machine** may become available which are even more efficient, because they are fully computer programmed.

All measures mentioned help to reduce CO_2 emissions. The most effortless way to increase fuel efficiency is with the course 'het nieuwe draaien' and by driving smarter. These are simple, but effective options to reduce fuel immediately by nudging behaviour. The use of lighter machines should be taken into account, but in some cases it is not possible to go for a lighter machine, due to stock limitations. There should always be a balance between using a lighter machine, and where it has to come from. In the future the construction sector may become more dependent on driving assistants and autonomous machines, which will result in higher fuel efficiencies, and therefore lower CO_2 emissions.

6.3. Interview partners

In this section conclusions are draw from the results of the interviews, which were presented in section 5.2. Furthermore, sub question 2: 'What are the perceptions of partners on reduction of CO_2 emissions?' is answered.

6.3.1. Best measures

Most of the interviewed partners own heavy machines and their CO_2 footprint depends for 99% on emission caused by diesel. What is positive is that most of the interviewed partners have a CO_2 aware certificate or are working on obtaining the certification. The reduction goals were similar, most have goals of a reduction around 1 to 2 percent CO_2 emission per year. All partners are positive about the course 'het nieuwe draaien', since this course changes the behaviour of employees, and reduces fuel immediately. They also mention that an efficient planning method helps to reduce CO_2 emission. Also technical upgrades for the machines make them more efficient (GPS and Black Boxes). Some see potential for autonomous machines in the future. Finally they recommended cooperation between partners to exchange knowledge. It must be noted, that some partners were sceptical about the possibilities of direct reduction methods and advocated indirect (compensation) methods.

6.3.2. Alternative fuels

Most partners see biodiesel as a feasible alternative to reduce CO_2 emission, nevertheless all say that it is currently very expensive and it is less available at fuel stations. All partners mention that currently there are not enough electrical options for machines, and they hope this will increase in future. They see more potential in hybrid than in fully-electrical machines, due to volume, load times and weight constraints of bateries. All are willing to invest in hybrid machines at this point (mainly cranes). The partners believe that there is currently no potential for hydrogen powered machines. The machines and fuel are too expensive to be attractive. Some partners see potential in hydrogen in the future and they hope that more mature technologies will become available, so they can invest in machines powered by hydrogen. To summarize: all partners see potential in the short term for electrical machines, especially hybrid. Biodiesel is considered an intermediate step, which will however not become sufficiently widely available as a lasting solution the long run, most see hydrogen as a potential fuel.

Based on the interviews the alternatives are ranked from most potential to least potential (in the short term):

1. Electrification (hybrid) *2. Biodiesel* *3. Hydrogen*

6.3.3. Recommendations to Plegt-Vos

Most partners where concerned with the higher cost for biodiesel and hybrid machines, which they do not want to pay all by themselves. Co-ownership of machines could be an option to reduce investment risks. Moreover, Plegt-Vos could consider to reward partners that are actively working towards reduction in CO_2 emission, for example by allowing them a slightly higher price as an incentive for efficiency gains. In addition, employees of Plegt-Vos might try to design and plan in a more sustainable way, for example by including charging times for electrical machines in the project planning or apply methods that allow the use of lighter machines and adopt knowledge about alternative machines and operating methods. Lastly, partners would like to see that Plegt-Vos facilitates the exchange of knowledge on possible ways of emission reduction.

In short, the best approach to achieve substantial a CO_2 emission reduction appears to consist of a combination of technical, behavioural and procedural methods. Thereby it is important to take both initial investment and operational costs into account. As argued above, the environmental benefits may go hand in hand with economic benefits in the sense of a positive (financial) return on investment.

6.4. CO_2 reduction

In this section the conclusion is drawn of section 5.3. and the answer is given to sub question 3: 'What will be the reduction of CO_2 emissions when using the results of Q1&2?'

If Plegt-Vos uses the CO_2 aware certificate as a criterion for selecting their partners, they should be able to reduce around 3,2 percent CO_2 emission in scope 3 each year. Furthermore, it appears useful to discuss possible new ideas and solution for CO_2 reduction with key partners. If Plegt-Vos helps by co-financing hybrid machines, they may potentially save 10 to 50% CO_2 emission per project run with hybrid machines. Financing hybrid machines seems most optimal when it comes to machines that operate full-time for Plegt-Vos. If Plegt-Vos is able to make agreements with partners to use a B100 biodiesel in their machines this can reduce CO_2 emission by 90%, however, this comes at a cost: this blend costs 18 cent/L extra. A B20-B50 blend will reduce CO_2 emission less, but this blend is cheaper than the B100. Hydrogen will potentially be a good option in the future (ten years from now), but the technology currently is not developed enough, too costly, and not sufficiently widely available. Nevertheless, this alternative can potentially reach zero CO_2 emission. The training course 'het nieuwe draaien' has most potential in the short term. It can help to save 8-10% fuel, that ultimately reduces CO_2 emission with a similar percentage. The pay back time is very short, which makes it an attractive measure for partners to invest in. If Plegt-Vos makes sure that all the employees of their partners have taken the course, that may yield 8-10% CO_2 emission reduction per project.

All in all this thesis answers the research question:

"Which CO_2 reducing measures can be used to achieve the reduction goal stated by Plegt-Vos Infra&Milieu: to reduce -10.5% CO_2 emissions in scope 3 at the end of 2020?"

The best measures to take to achieve the goal stated by Plegt-Vos is supporting the financing of biodiesel (B100), the course 'het nieuwe draaien' and hybrid machines. Investing in biodiesel means that every year the same yearly costs have to be paid. Investing in hybrids means that first an up-front investment has to be made, and that this investment will be earned back over a period of time. The course 'het nieuwe draaien' is the best short-term measure to implement, and will be earned back almost immediately.

7. Discussion

This study looked primarily into diesel usage in heavy machines, but the CO_2 emissions in scope 3 do not only relate to diesel usage. The CO_2 emission of scope 3 also includes the downstream activities related to, for example, building materials and recycling of materials.

The literature review is based on literature that was written or published some years ago. Since the technology is rapidly evolving, practical limitations discussed in the literature may become less relevant or vanish altogether. However, the diesel alternatives considered remain the main options. In fact, their possibilities have only increased since the literature has been written, due to the rapid developments.

The calculations that were provided in section 5.3.6 are mainly based on studies of a few years ago. Furthermore, the numbers that were used for the calculations are rough estimations. The exact numbers depend on a lot of different variables, e.g. machine type, machine size, time the machine is used, the work the machine is doing, energy prices, and weather conditions. Many of these variables are hard to control or measure so in practice the estimates will need to be combined with expert judgments.

Furthermore, the calculation method used for estimating the total CO_2 emission of scope 3 by Plegt-Vos is based on a lot of assumptions. The emissions are based on the average price which was paid for machines per hour, with the assumption that they use 12 liter diesel per hour for machines and 20 liter per hour for transport. Incidentally, it is not known if the machines are running all the time, and if they actually use 12 or 20 liter per hour (this depends on machine type). It is possible that the CO_2 emission is much higher than the actual emission (lower is also possible). If the CO_2 emission are higher than calculated for, also the total amount of reduction will become higher, which means that extra measures have to be taken to reduce more CO_2 emission.

8. Recommendation for further research

In chapter 0 it was stated that the research in this thesis has been limited by several issues, and that scope 3 of the CO_2 Performance Ladder includes more than only diesel usage. Therefore, it is recommended that a follow-up study into CO_2 reduction measures of scope 3 also considers measures that go beyond alternatives for diesel only, e.g. sustainable (concrete) material usage.

This thesis only considers one construction company and some of its key partners. Although the main conclusions and recommendations appear more broadly applicable, it could be useful to repeat the study with other construction companies and their partners to check if this is indeed the case. It could also be useful to include clients and regulators; in the end, the topic of CO_2 emission reduction can only be dealt with in the whole chain.

It is recommended that for the proposed measures a more detailed calculation is made to check if the assumed investment and operational cost are right, and the supposed CO_2 reduction correct. In particular, it might be useful to develop a model that incorporates sensitivities for values of key variables. That may yield a better insight in cost-benefit considerations.

In chapter 7 it is mentioned that the total reduction needed for scope 3 could be calculated wrongly. Therefore, it would be useful to get a better insight in the CO_2 emission of the suppliers. It is advised to invest in further research to get a better insight into the CO_2 emission of scope 3, preferably up to the level of knowing the emissions per machine. This may help in deciding which machines to replace first with hybrid or biodiesel equivalent.

9. References

ANWB. (2019). *milieuzones-steden-nederland.* Retrieved from www.anwb.nl: https://www.anwb.nl/belangenbehartiging/verkeer/milieuzones-steden-nederland

Avebe, BioMCN, EMMTEC services, Eneco, Engie, Equinor, . . . Waterbedrijf Groningen. (2019). *Investeringsagenda waterstof Noord-Nederland.* Groningen: Noord-Nederland.

Bachman, K. (2011, April 12). *6-alternatives-diesel-freight-transport.* Retrieved from /www.fmanet.org: https://www.fmanet.org/blog/2011/04/12/6-alternatives-diesel-freight-transport

Bakhiet, O. (2017). *Data collection for management of fuel consumption in vehicles and machinery.* Stokholm: KTH royal institute of technology school of architecture and the built environment . Retrieved from https://www.diva-portal.org/smash/get/diva2:1119056/FULLTEXT01.pdf

Bijleveld , M., Bergsma, G., Krutwagen, B., & Afman, M. (2014a). *Meten is weten in de Nederlandse bouw.* Delft: CE Delft.

Bijleveld, M., Bergsma, G., Krutwagen, B., & Afman, M. (2014b). *Milieu-impacts van Nederlandse bouw- en sloopactiviteiten in 2010.* Delft: CE Delft.

Bouwmachines. (2019, September 27). Uitstoot van bouwmaterieel beperken: waarom, en wat zijn de oplossingen? *Bouwmachines.* Retrieved from https://www.bouwmachines.nl/ondernemen/artikel/2019/09/uitstoot-van-bouwmaterieel-beperken-waarom-en-wat-zijn-de-oplossingen-10144485?vakmedianet-approve-cookies=1&_ga=2.50520809.1709983338.1573035360-1136843279.1573035360

brandstofprijzen.info. (2020, January 14). *http://www.brandstofprijzen.info/.* Retrieved from http://www.brandstofprijzen.info/: http://www.brandstofprijzen.info/

CO_2-emissiefactoren. (2019). *lijst-emissiefactoren/#brandstoffen_voertuigen.* Retrieved from www.co2emissiefactoren.nl: https://www.co2emissiefactoren.nl/lijst-emissiefactoren/#brandstoffen_voertuigen

Den Hartog bv. (2019). *brandstoffen/co2-saving-diesel.* Retrieved from www.denhartogbv.com: https://www.denhartogbv.com/brandstoffen/co2-saving-diesel/

Diesel Technology Forum. (2019). *about-clean-diesel/construction.* Retrieved from https://www.dieselforum.org: https://www.dieselforum.org/about-clean-diesel/construction

Duurzaam MKB. (2019). Efficiënt gebruik van mobiele werktuigen (Het Nieuwe Draaien). *Duurzaam MKB.* Retrieved from http://www.duurzaammkb.nl/tips/tip/592/efficient-gebruik-van-mobiele-werktuigen/

Ecovat. (2018). *energietransitie/klimaatakkoord-parijs-2020-2050.* Retrieved from www.ecovat.eu: https://www.ecovat.eu/energietransitie/klimaatakkoord-parijs-2020-2050/

Emissie autoriteit. (2019). *klimaatakkoord-van-parijs.* Retrieved from www.emissieautoriteit.nl: https://www.emissieautoriteit.nl/onderwerpen/klimaatakkoord-van-parijs

Forsgren, M., Östgren, E., & Tschiesner, A. (2019). *Harnessing momentum for electrification in heavy machinery and equipment.* Stokholm: McKinsey & Company. Retrieved from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/harnessing-momentum-for-electrification-in-heavy-machinery-and-equipment#

Greendeal. (2019). *lijst-emissiefactoren/#brandstoffen_voertuigen.* Retrieved from www.co2emissiefactoren.nl: https://www.co2emissiefactoren.nl/lijst-emissiefactoren/#brandstoffen_voertuigen

KEMP. (2019). */collecties/cursussen/cursus-het-nieuwe-draaien-1*. Retrieved from https://kemp-groep.nl: https://kemp-groep.nl/collecties/cursussen/cursus-het-nieuwe-draaien-1

Kindt, M., & van der Meulen, S. (2011). *Alternatieven brandstoffen Gat in de markt of verre toekomstmuziek?* ING Sectormanagement Transport & Logistiek.

Kootstra, L. (2018). *20 LCA's voor brandstof-machinecombinaties*. Utrecht: TNO. Retrieved from https://waterbouwers.s3.amazonaws.com/uploads/upload/image/289/TNO_2018_R10658_Rijkswaterstaat_GPO.PDF

Kumar, N., Sonthalia, A., Pali, H. S., & Sidharth. (2018). *Alternative Fuels for Diesel Engines: New Frontiers*. Intechopen. Retrieved from https://www.intechopen.com/online-first/alternative-fuels-for-diesel-engines-new-frontiers

KWS. (2019, January 14). */elektrische-vrachtwagen-kws*. Retrieved from www.kws.nl: https://www.kws.nl/nl/nieuws/detail/elektrische-vrachtwagen-kws

Lajunen, A., Sainio, P., Laurila, L., Pippuri-Mäkeläinen, J., & Tammi, K. (2018). *Overview of Powertrain Electrification and Future Scenarios for Non-Road Mobile Machinery*. MDPI. Retrieved from http://www.mdpi.com/1996-1073/11/5/1184/pdf

Natuur & Milieu. (2018). *Milieu impact mobiele werktuigen*. Natuur & Milieu. Retrieved from https://www.natuurenmilieu.nl/wp-content/uploads/2018/12/Factsheet-Impact-mobiele-werktuigen-2018.pdf

NOS nieuws. (2018, April 26). Milieuvriendelijke diesel in opkomst (maar wel 18 cent duurder).

O'Connor, J. (2017, January 23). *battery-showdown-lead-acid-vs-lithium-ion*. Retrieved from medium.com: https://medium.com/solar-microgrid/battery-showdown-lead-acid-vs-lithium-ion-1d37a1998287

OEM. (2019, April 10). *volvo-construction-equipment-volvo-ce-unveils-electric-compact-excavator-and-wheel-loader-at-bauma*. Retrieved from www.oemoffhighway.com: https://www.oemoffhighway.com/trends/electrification/press-release/21063694/volvo-construction-equipment-volvo-ce-unveils-electric-compact-excavator-and-wheel-loader-at-bauma

Plegt-Vos Infra&Milieu. (2017). *CO2-emissie inventaris 2017*. Hengelo: Plegt-Vos Infra&Milieu.

Plegt-Vos Infra&Milieu. (2019a). *CO2-reductieplan*. Hengelo: Plegt-Vos Infra&Milieu.

Plegt-vos Infra&Milieu. (2019b). *Organisatiebeschrijving CO2-prestatieladder*. Hengelo: Plegt-vos Infra&Milieu.

Plegt-Vos Infra&Milieu. (2019c). *Ketenanalyse CO2-reductie inhuur materieel (excl. transport)*. Hengelo: CO2-prestatieladder.

Rijksoverheid. (2019). *klimaatverandering/klimaatbeleid*. Retrieved from www.rijksoverheid.nl: https://www.rijksoverheid.nl/onderwerpen/klimaatverandering/klimaatbeleid

SGS Search Consultancy. (2017). *Elektrificatie van mobiele werktuigen, waar blijft de tesla graafmachine?* Amsterdam: SGS Search Consultancy. Retrieved from https://www.sgssearch.nl/static/default/files/documents/pdf/171220%20SGS%20rapport%20RWS%20Elektrische%20werktuigen.pdf

Stichting Klimaatvriendelijk Aanbesteden & Ondernemen. (2015). *Handboek CO2-prestatieladder 3.0*. Utrecht: Stichting Klimaatvriendelijk Aanbesteden & Ondernemen.

Stichting Klimaatvriendelijk Aanbesteden & Ondernemen. (2016, May 11). *Wat je er ook van vindt, die ladder werkt*. Retrieved from www.skao.nl: https://www.skao.nl/news/Wat_je_er_ook_van_vindt,_die_ladder_werkt-497

Stichting Klimaatvriendelijk Aanbesteden & Ondernemen. (2018, Augustus 13). *Longread:-Why-the-construction-sector-could-benefit-from-electrification-6650*. Retrieved from www.skao.nl: https://www.skao.nl/news_en/Longread:-Why-the-construction-sector-could-benefit-from-electrification-6650

Stichting Klimaatvriendelijk Aanbesteden & Ondernemen. (2019a, May 10). VolkerWessels Telecom is becoming more sustainable by using fuel more efficient and more efficiently. Retrieved from https://www.skao.nl/news_en/VolkerWessels-Telecom-is-becoming-more-sustainable-by-using-fuel-more-efficient-and-more-efficiently-6703

Stichting Klimaatvriendelijk Aanbesteden & Ondernemen. (2019b, Oktober 4). *wat-is-de-ladder*. Retrieved from www.skao.nl: https://www.skao.nl/

Stichting Klimaatvriendelijk Aanbesteden en Ondernemen. (2019c). *Maatregellijst CO2 prestatieladder 2019*. Utrecht: Stichting Klimaatvriendelijk Aanbesteden en Ondernemen.

Stichting Klimaatvriendelijk Aanbesteden en Ondernemen. (2019d, October 16). *facts and figures*. Retrieved from www.skao.nl: https://www.skao.nl/facts-and-figures

Stimular. (2019). *maatregelen/biobrandstoffen-biodiesel-en-bio-ethanol/*. Retrieved from https://www.stimular.nl: https://www.stimular.nl/maatregelen/biobrandstoffen-biodiesel-en-bio-ethanol/

The Intergovernmental Panel on Climate Change (IPCC). (2018). *Annex IV: Expert Reviewers of the IPCC Special Report on Global Warming of 1.5°C. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse g*. IPCC.

TNO. (2019). CO2-UITSTOOT TERUGDRINGEN DOOR AFVANG, GEBRUIK EN OPSLAG. *TNO*. Retrieved from https://www.tno.nl/nl/aandachtsgebieden/ecn-part-of-tno/roadmaps/naar-een-co2-neutrale-industrie/co2-uitstoot-terugdringen-door-afvang-gebruik-en-opslag/

van Capelleveen, D. (2019, March 28). Meer houtbouw nodig om CO2-uitstoot te reduceren. *Bouwwereld*. Retrieved from https://www.bouwwereld.nl/duurzaamheid/meer-houtbouw-nodig-co2-uitstoot-te-reduceren/

Wills, T. (2018, September 24). *construction-sector-must-reduce-carbon-emissions-soon/*. Retrieved from constructionclimatechallenge.com: https://constructionclimatechallenge.com/2018/09/24/construction-sector-must-reduce-carbon-emissions-soon/

10. Appendices

Appendix I: Procedure for applying the CO_2 Performance Ladder

The CO_2 Performance Ladder currently has 5 levels to reduce CO_2, level 5 is the highest. Furthermore, there are several aspects which the company has to take into account when applying for each level. Figure 18 shows that for every extra level on the ladder more aspects have to be taken into account. Aspect A describes that the company has insights in their CO_2 emissions, B describes that a company needs to reduces their CO_2 emissions, C is about transparency to external partners and D is about active participation in initiatives for reducing CO_2 emissions.

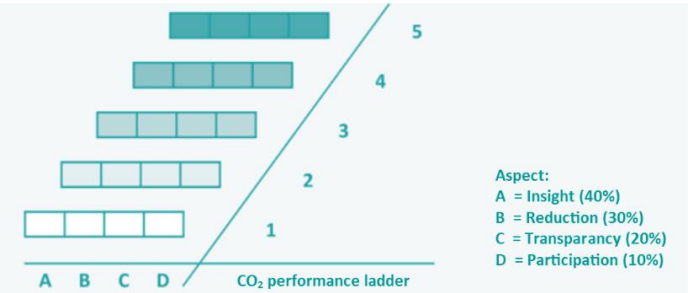

Figure 18 The different levels and aspects of the CO_2 Performance Ladder (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2015)

Also, every level has its own goals to achieve

- Level 1: Insight in most important energy streams of the company.
- Level 2: Insight in own CO_2 emissions, and try to reduce CO_2 emissions.
- Level 3: Make a CO_2 footprint conform norms of SKAO + quantitative reduction goals.
- Level 4: CO_2 consciously acting and initialize reduction in cooperation with the chain
- Level 5: Suppliers questioning and achievement of CO_2 reduction goals

In order to get the certificate, a procedure has to be followed to prove that all requirements are met. First of all, the organizational boundaries of the company have to be stated. A division has to be made between A and C suppliers. These depend on the purchasing revenues of the suppliers: the top 80% revenue are the A suppliers, the rest are the C suppliers, see Figure 19 for an example.

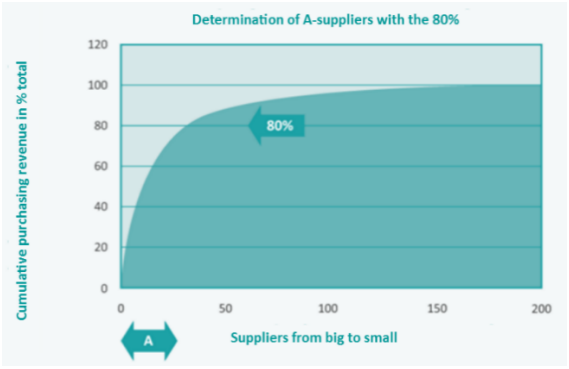

Figure 19 Cumulative purchasing revenue of suppliers in % of total (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2015)

Furthermore, the size of the company has to be determined. This is dependent on its CO_2 emissions per year, see Table 23. For a small company this means the total CO_2 emissions should not exceed 500 ton per year for services, should be less than 500 ton per year for offices and less than 2000 ton per year for building sites and production locations.

Table 23 Size categories dependent on CO_2 emissions (translation)
(Stichting Klimaatvriendelijk Aanbesteden & Ondernemen, 2015)

	Services	Work/supply
Small company (K)	Total CO_2-emission is maximum (≤) 500 ton a year.	Total CO_2-emission of offices and business space is maximum (≤) 500 ton a year, and the total CO_2-emission of all construction site and production locations is maximum (≤) 2.000 ton a year.
Middle size company (M)	Total CO_2-emission is maximum (≤) 2.500 ton a year.	Total CO_2-emission of offices and business space is maximum (≤) 2500 ton a year, and the total CO_2-emission of all construction site and production locations is maximum (≤) 10.000 ton a year.
Big Company (G)	Total CO_2-emission is maximum (>) 2.500 ton a year.	Other

To continue they have to monitor all CO_2 emissions which are related to their company, for scope 1, 2 and 3. Furthermore, a company should formulate ambitious goals for CO_2 reduction and these goals should be stated in a reduction plan. In addition, a communication plan should be written, to meet the aspect C (transparency). Both plans need to be evaluated for which a self-evaluation plan has to be written. To wrap up: all CO_2 emissions are mapped, goals are stated for reduction of CO_2, a communication plan and a self-evaluation plan are written. When all points are established, these need to be checked by an independent company (not SKAO) to make sure everything is done right.

All documents have to be handed in to SKAO to be checked. This is done via an audit, where all documents are discussed. When all documents are well established the certificate: 'CO_2 awareness certificate' is granted.

Appendix II: Interview scheme (translated version)

At the dots (…) the company name of the interviewee is used. Questions can depend on type of company, and if a company is already certified for the ladder.

1. *Before we start with the interview, do you have at this moment any questions about the interview, research or me?*

Questions about the company

2. *Could you describe what the key activities of … concern?*
3. *What is at this moment the size of …?*
    a. *How many employees does … have?*
    b. *How big is the market share of … with respect to other companies with the same key activities in the sector?*
    c. *What is the structure of … (like holding, subsidiaries)*
4. *What is the share of assignment that … does in cooperation with Plegt-Vos Infra&Milieu (revenue share)?*

Questions on the CO_2 Performance Ladder and goals

5. *Does … know the CO_2 performance ladder?*

⇨ ***When yes=> question 6***

Explain what the CO_2 Performance Ladder is

6. *Does … have a vision in sustainability and/or CO_2 reduction?*
7. *Does … have goals in sustainability and/or CO_2 reduction?*
    a. *Within how many years does … think that … can achieve the goals in sustainability and/or CO_2 reduction?*
    b. *Within how many years does … think that … can be CO_2 neutral?*
6. *What are measures that … will implement to achieve the goals?*

Questions about CO_2 reducing measures

7. *To what extend does … see potential in the named alternatives for diesel:*
    a. *Biodiesel*
    b. *Electrification*
    c. *Hydrogen*
    d. *Gases*
8. *Which alternative does … see most potential for, comparing these four alternatives?*
9. *Does … know the course 'Het Nieuwe Draaien'?*

⇨ ***When yes => question 10***

Explain what the course 'het nieuwe draaien' is

10. *Did … execute the course 'Het Nieuwe Draaien' or is … will to do that?*
    a. *When yes, what has been the effect on diesel reduction?*
    b. *When no, why do you see no potential in the course?*
11. *On which basis/criteria does … select which machine is used for which project?*
    a. *To what extend is the client responsible for these choices?*
    b. *Does … see in practice that heavier machines are used than necessary?*
    c. *Did … know that heavier machines are more polluting to ratio, than smaller ones?*
12. *Does … think that using lighter machines will be possible is certain projects?*
    a. *For what kind of project can this be feasible?*
13. *Does … think that there is room for autonomous vehicles and/or machines?*
    a. *When no, why not?*
    b. *When yes, for which applications could this be an option?*
8. *Does … think that CO_2 capturing and storage can fit in the processes of …?*
    a. *Does … have experience with capturing and storage?*
    b. *Does … see possibilities in the future for capturing and storage?*
    c. *At which places within the process would capturing and storage be an option?*

Questions about CO_2 insight

14. *Does .. have insight into their CO_2 emissions of …?*
15. *Do you have any questions or remarks concerning the interview?*

Appendix III: Summary of the interviews

In this section for each interview conducted a summary is provided.

Interview 1: Blokland B.V.

The interview with Blokland was not conducted in person, but answers to the questions where send digitally, Samir Mbarki was the interviewee.

Information about the company

The key activities of Blokland BV exist of rental of machines. They have around 90 employees, within their sector they have around 15% of the market share. The structure of the company is as following: there is one holding: Blokland Holding B.V. which covers: Blokland B.V., Blokland Handel en Transport B.V. en Blokland Milieu- en Zuigtechniek B.V.

Information about the reduction goals and measures

Their vision with respect to sustainability is to reduce CO_2 emission and cost. For the period 2011-2016 they did not reached their goal stated for the CO_2 aware certificate, due to more projects and more hours made. The goals that they have stated for the CO_2 Performance Ladder are:

- Total reduction of 5% in 2021 compared to 2016.
- Scope 1: 1% per year (related to diesel usage)
- Scope 2: 1% per year (related to electricity usage)

They think that zero emission will not be feasible within the future, the company depends too much on diesel usage, and measures to reduce via electrification stay behind.

Measures that they will implement to achieve their goals are: hybrid machines, with electrical driving and reversible systems. A difficult measure to implement is the buying of electrical material. An easy measure will be to upgrade the office building (e.g. isolation and solar panels). They did not implemented measures jet. How can Plegt-Vos help them to reduce CO_2? They think of making electrical machines available on the building site, by more charging facilities and understanding from implementers.

Opinions on alternatives for diesel

They see no potential in biodiesel, hydrogen or gas. They want to invest in electrical cranes, but those are currently quite expensive.

Opinions on other alternatives

They did both courses 'het nieuwe draaien' and 'het nieuwe rijden', the effect they noticed was that their drivers used the machines more efficiently. The client chooses which machine they want to use for 99% of the cases. Sometimes to heavy machines are used, but this is not beneficial since the costs of those are mostly higher. They think that autonomous vehicles and machine will be available in the future to do potentially high risk work.

Because they have the CO_2 aware certificate they have insight into their emission.

Interview 2: Geurs Loon- Grondverzet- en Transportbedrijf B.V.

The interview with Geurs was conducted on the 2nd of December, Johan Vogt was the interviewee.

Information about the company

The key activities of Geurs exist of earth moving and (re)placing of fake grass, they have a lot of heavy machines like cranes and dumpers. They also do some agriculture- and transport work. They have around 32 employees: 5 for agricultural work, 20-25 earth moving and 7 for transportation work. In the region East they are a bigger actor within their work field. The structure of the company is as following: there is one holding Geurs Holding BV, this holding covers Geurs Onroerend Goedmaatschappij BV, which covers Geurs Machines BV, which covers Geurs Loon-Grondverzet- en Transportbedrijf B.V. The cooperation

with Plegt-Vos is around 10%, average 1-2 employees working fulltime for Plegt-Vos. Currently Geurs is trying to get the CO_2 aware certificate level 3. They are quite far with this and will have their audit upcoming year in January.

Information about the reduction goals and measures

Their vision with respect to sustainability is based on staying interesting for clients, by offering more sustainable solutions and thereby help the environment. They have not yet developed CO_2 reduction goals, but the goals will be for the upcoming years. They think that zero emission will probably be possible within the future, but only if emissions can be compensated for example by planting extra trees.

Measures they currently think of are GPS total station (laser guided), NEOX (planting trees to compensate for CO_2 emissions), buying new machines (add blue and euro6), efficient planning, checking tires pressure (4x a year), hydrogen initiative project, establish sustainable consciousness for drivers and using soot filters. Measures which are difficult to implement are changing to alternative fuels, like hydrogen and electrical. Measures easy to implement are compensation of emissions, making planning more efficient, and checking tires pressure. How can Plegt-Vos help them to reduce CO_2? By paying more for an alternative fuel, or to compensate for CO_2 emission by planting extra trees on a building sight or to pay for NEOX certificate. They already implemented efficient planning, checking tires pressure, buying new machines and working efficiently with GPS (2D/3D technology). There are currently no numbers available to see which measure was most effective.

Opinions on alternatives for diesel

Geurs uses as a standard biodiesel in their machines, which is a bit more expensive than normal diesel. A higher percentage of biodiesel is not an option. The prices of biodiesel can vary per day with 10/20 cents, because the supply is not very big, and the demand is high, which causes high pricing. Biodiesel can be an option, but not for now, only if prices will be payed or prices will become lower. Electric can be a possibility for smaller vehicles (e.g. shovel or mini crane), currently available. The biggest problem is when the batteries need to charge, there are projects where no power is available, so it will not be possible to charge the batteries. Furthermore, it will probably never work for bigger machines, batteries are too big and heavy, and therefore they will not fit into the machines. Hybrid can be an option, but now it is now limited available. Hydrogen can be an option, currently prices of machines are 4x more than a regular machine, and fuel is also more expensive. So, not yet good technologies available, if available they want to look into it. Natural gasses is only used for heating. Most potential now will be a crane on top of a truck, which is electric, it can run for 3 to 4 hours. Furthermore potential interest in hydrogen on long term, and biodiesel if pricing is good on the short term.

Opinions on other alternatives

They are familiar with a course that has the same purpose as 'Het Nieuwe Draaien'. There drivers did a course on efficient use of machines from CODE 95. Furthermore, they use machines which have a stop and go system (stop after 1 minute not being used), also they learn their drivers to not pre-heat there machines, and make them more conscious on the environmental impacts of their machines. They choose their machines based on planning and sometimes they rent machines. The client can chose which machine they need, and can chose size. Sometimes it happens that a bigger machine than needed is used, because this is sometimes planning wise better. Lighter work is done with the eco stand of the machines. Smaller work can be done with mini cranes, depending on the work. They do see autonomous vehicles in the future, maybe for digging slots, possibly only parts. But probably first autonomous cars, thereafter machines for construction.

There main emissions are based on diesel usage 500.000 L/year which is 99% of the total emission.

Interview 3: Groenservice Noord

The interview with Groenservice Noord was conducted on the 28nd of November, Evert Johan van der Meulen was the interviewee.

Information about the company

The key activities of Groenservice Noord exist of planting trees and other plants, furthermore they do the maintenance of those (mostly for around 3 years). They have around 30 employees, and within their sector they have around 10% of the total market share in the province of Groningen. The structure of the company is as following: there is one holding Safeni Beheer, this holding covers Tiedema Beheer and Ginko Beheer, under these two bodies fall Frisia Bergum BV and Groenservice Noord BV. The last two mentioned, together have the CO_2 performance certificate level 5. Frisia Bergum BV is not a partner of Plegt-Vos, there will be only focused on Groenservice Noord. Frisia Bergum BV is a bit bigger than Groenservice Noord, the percentage of CO_2 emissions of Groenservice Noord is around 25%. The relationship of Plegt-Vos and Groenservice Noord is mainly based on big projects (around 100.000,- revenue). As mentioned Groenservice Noord is bases in the province of Groningen, but they mainly work in and around the city of Groningen.

Information about the reduction goals and measures

Their vision with respect to sustainability is zero emission, furthermore they want to be the most sustainable company of Groningen within their work field. The goals that they have stated for the CO_2 Performance Ladder are:

- Scope 1: 30% reduction in 2025 compared to 2014
- Scope 2: 30% reduction in 2025 compared to 2014
- Scope 3: 40% reduction in 2025 compared to chain

They think that zero emission will not be feasible within the future (15 years). Perhaps achievable on paper by integrating within the calculations that plants take CO_2 from air and solar panels give back energy.

Measures that had the most effect to achieve their goals are related to changing behavior of employees, reducing fuel, buying new cars, recycling waste, and keeping tires under pressure. The most difficult measure to implement they named is moving on to electrical vehicles, because they are not jet convinced of this new technology. The easiest measure to implement they name is changing the behavior of employees, for example: encouraging to carpool and planning work more efficient. How can Plegt-Vos help them to reduce CO_2? They say that maybe there can be designed for placing more plants that can extract CO_2 (maybe plants that extract more CO_2 than others) or design with more sustainable material. Furthermore they think that talk to each other and learn from each other can be very useful.

Opinions on alternatives for diesel

On the short term they see most potential in electrification to replace diesel, also on the long term electrical machines and vehicles will remain. On the long term also hydrogen can be used to replace diesel. Currently, the municipality of Groningen is experimenting with garbage trucks on hydrogen. Groenservice Noord only sees a future for hydrogen in cars, not for machines. Currently, they use electrical machines, but only small ones (e.g. chainsaw and leaf blower). In a short period of time they want to use hybrid cranes during their projects. The biggest problem for electrical vehicles will be the battery, they think. They think that on the long term they will use electric vehicles to move their employees around. The fuel they currently use in their machines is Aspen, which is better for the environment than conventional diesel. This type of diesel is only available in few fuel stations, therefor only possible when working within the city. They use gases for very little work, and do not see potential to invest in it.

Opinions on other alternatives

They see no potential in the course 'Het Nieuwe Draaien', since they do not own heavy machines. They select their machines based on availability, only if necessary they rent them. They choose the most light

machines, since those cost less. Client can have a say when choosing machines, but this never occurs. They do not see autonomous vehicles in the future, they think that will be way to dangerous.

Interview 4: Kramer Metslawier BV

The interview with Kramer Metslawier BV was conducted on the 28nd of November, Gerard Pel was the interviewee.

Information about the company

The key activities of Kramer Metslawier exist of earth moving, rental of machines, subcontracting and placing sheet pilings. They have around 15-18 employees, within their sector they are middle size (8 cranes, 4 tractor and 1 shovel). The structure of the company is as following: there is one holding G.A. Pel Holding B.V. and this holding covers different parts of the company. Aannemingsbedrijf Kramer Metslawier BV. is one of them. The collaboration of Kramer and Plegt-Vos is broad, Plegt-Vos has 3 cranes + drivers permanently in use, which is around 25% of the work Kramer does.

Information about the reduction goals and measures

Their vision with respect to sustainability is to reduce a certain amount of CO_2 emission, within a period of 30 years. The goals that they have stated for the CO_2 Performance Ladder are:

- Total reduction of 7% in 2023 compared to 2018.
- Scope 1: 7% per euro revenue tons CO_2 reduction in 2023 compared to 2018
- Scope 2: keeping the green power, which results in zero emission.

They think that zero emission will not be feasible within the future, the company depends too much on diesel usage.

Measures that they will implement to achieve their goals are: usage of black box in machines (tracking of drivers), directing on sustainable driving, course 'Het Nieuwe Draaien' (next year), checking tires pressure, and a campaign for consciousness of CO_2 emissions for employees. A measure that will probably have the most effect on CO_2 reduction is the course 'Het Nieuwe Draaien', but Kramer will first check for which drivers this is course is beneficial and for which it is not. Nevertheless, this will be an easy way to reduce CO_2 emissions. A difficult measure to implement is the biodiesel, it is far more expensive (B20 $\approx$ +10 cent/L) than conventional diesel. How can Plegt-Vos help them to reduce CO_2? They think of splitting costs for biodiesel, or except a higher hourly rate for the machines rented.

Opinions on alternatives for diesel

They think that biodiesel is feasible, but it will be more expensive. Electrical will be partly feasible, they think hybrid can work, but full electric not. On short term they think of a hybrid crane to add to their stock. When an old machine has to be replaced, they will look into the benefits of a hybrid crane. Hydrogen is currently not realistic. Natural gases is possibly an option, they drive quit far, so can be useful in their cars. They think the most potential is in hybrid, hydrogen not so much.

Opinions on other alternatives

At the start of 2020 they will start with the course 'Het Nieuwe Draaien'. Sometimes it happens that larger machines are used, that depends on availability, hiring is not optimal compared to using your own machines. Currently, they make use of GPS, which results in more efficient driving. The client can choose a specific driver, and every driver has a fixed machine. Sometimes we use a smaller crane, but than it takes more time to get the job done. Financially it is not doable to use a lighter machine, if it is not available. They see a future for autonomous vehicles, currently use of GPS is a start. In future maybe full autonomous cranes, on a fenced building sight.

Because they have the CO_2 aware certificate they have insight into their emission, I can have a list of projects they did together with Plegt-Vos to see the emission there.

Interview 5: S. Vogelzang & Zn

The interview with S. Vogelzang & Zn was conducted on the 28nd of November, Jessica Geertsema was the interviewee.

Information about the company

The key activities of S. Vogelzang & Zn. exist of earth movement, cleaning ditches. They have around 40 employees (depending on the projects they have), not all fulltime. Their market share within their sector is quite big, they do many project in the province and municipality of Groningen and for the water board Noorderzijlvest. The structure of the company is as following: there is one holding, this holding covers Verhuur, Beheer and MZW. They work together with Grondstoffen Noord Nederland. Currently, Vogelzang is trying to get the CO_2 aware certificate level 3. They are almost done with the certification process and will have their audit upcoming year, on the 3th of January.

Information about the reduction goals and measures

Their vision with respect to sustainability is to improve on the area of CO_2 emission reduction. They have made short and long term goals for reducing CO_2. They think that zero emission will probably be possible within the future, with the use of biodiesel (B100), but this fuel is currently too expensive (+30 cent/L).

Measures they want to implement and are included within their reduction plans are: putting solar panels on the roof of the office, buying new cars, installing LED-lights, buy more hybrid machines, use of biodiesel B50/B100, participation in initiatives, planting trees and improving energy label of the office building. The most difficult measure to implement is the participation in initiatives, it takes a lot of time to find good initiatives, but when found is will become less time consuming. Furthermore, changing of fuel type is difficult, it costs a lot of money per liter extra. Changing the energy label of the office is also not cheap, e.g. extra isolation is needed. Easier measures they think to implement are, placing solar panels on the roof, planting trees and let employees take the course 'Het Nieuwe Draaien'. The measures they already implemented are: LED lights, hybrid cranes and new cars. The measures that they think had most effect in reduction of CO_2 are the hybrid cranes and new cars. How can Plegt-Vos help them to reduce CO_2? They think of getting a better price for more sustainable choices and design in a more sustainable way.

Opinions on alternatives for diesel

Vogelzang is willing to improve their CO_2 emission reduction. Currently, they use B20 in all their machines and they have 2 hybrid cranes available. They are very positive about the blue diesel, there machines perform better, and there is less bacteria formation than before. They are willing to improve the blend to B50/B80 or even B100, but that is currently too expensive (+30 cent/L). They have 25 cranes and two hybrids available, when they need to replace an old crane, they will investigate if a new hybrid is a good options. They think that hydrogen will be a good alternative in the future, but it is now to less available on the larger scale. They only use gases for heating. They think that on the long term hydrogen will be a good alternative for diesel, and on the short term hybrid machines and biodiesels.

Opinions on other alternatives

They have integrated the course 'Het Nieuwe Draaien' in their long term reduction plan. They first want to check if the costs of the course weigh up to the benefits of it. They already check there tire pressure regularly, to save diesel. They choose their machines based on availability, or preference of clients. The client sometimes askes for a specific machine, but mostly not. Using a bigger machine than needed sometimes occurs, depending on availability. They do not see autonomous vehicles in the future, they question is this even possible within construction?

Globally they have around 600.000 litters of diesel usage.

Interview 6: Struyk Verwo Infra

The interview with Struyk Verwo Infra was conducted on the 12nd of December, Edwin de Bruin was the interviewee.

Information about the company

The key activities of Struyk Verwo Infra are the fabrication of pavement and other concrete material for the public space. They have around 450 employees, 8 production location in the Netherlands and therefor are a very big company. Within the sector they are market leader. Struyk Verwo belongs to CRH, a very big company worldwide (77600 employees). Plegt-Vos is one of the smaller client for Struyk Verwo. Struyk Verwo currently is very busy with sustainability and CO_2 reduction, they have the MVO level 4 certificate, which is the highest level, and no other company has reached this level so far, they cannot continue to level 5 since there is no competition presented.

Information about the reduction goals and measures

Their vision with respect to sustainability is for 2023, having the lowest MKI score for the whole sector. For specifically CO_2 reduction they have no goals, but they already have done a lot to reduce CO_2. Their CO_2 footprint is reduced by 63%. They think that it will be very difficult to have a CO_2 neutral company, since their production depend much on cement, nevertheless they are willing to improve on CO_2 reduction.

Measures that they think of when reducing CO_2 are:

- Geopolymeers that will replace cement
- LED light
- Updating the office building
- New developed products will only be used if they help in achieving the sustainable goals, so if they are more sustainable than older products.
- Innovation tracks, exploring new products (an example: generating electricity within pavement)
- Working together to exchange knowledge (e.g. with municipalities and universities)

Measures that will be difficult to implement are using and developing geopolymeers, first experience needs to be developed. Another difficult thing is how to exchange knowledge between partners, people do not listen to each other, or do not understand each other, which causes problems. Measures that are easy to implement are upgrading the office building, and investing in electrical transport. Measures they already implemented are using green electricity and exchanging knowledge with partners. Furthermore, they started very early with the topic of sustainability, therefore they have done innovated a lot in the previous year, and already reduced a lot of CO_2.

Opinions on alternatives for diesel

For material transport of Struyk Verwo external parties are used. Nevertheless, Struyk Verwo has a lot of influence on these parties. Currently, they make use of an app which helps the transporters to know where at the storage terrain they can find the delivery, which they have to pick up. The app improves the efficiency on the terrain, so that the transporters can reduce around 20 minutes during pick up. They are currently checking on possibilities for electrification and see hydrogen more for the future. They only use gas for heating.

Opinions on other alternatives

They currently have no experience with storage of CO_2, but they do recycling of water (filter and reuse it). They cannot say if storage is a possibility within their processes, because not much is known about it. When it comes to autonomous machines, if possible they will make machines autonomous, but for some processes it is not possible. When buying a new machine, they always check the availabilities.

Scope 1: 3267 ton.

Scope 2: 2883 ton.

Appendix IV: Calculation CO_2 reduction per proposed measure

In this section the reduction calculations per measure are elaborated. It is assumed that Plegt-Vos will pay half of the total costs, and the other half will be paid by the partner, and/or client.

Table 24 Factors used for calculation

Item	Factor	Source
Total CO_2 footprint scope 3	1651917 kg CO_2	(Plegt-Vos Infra&Milieu, 2019c)
Reduction goal scope 3	10,5 percent of total	(Plegt-Vos Infra&Milieu, 2019a)
CO_2 factor diesel	3,23 kg CO_2/litre	(CO_2-emissiefactoren, 2019)
CO_2 factor biodiesel	0,345 kg CO_2/litre	(CO_2-emissiefactoren, 2019)
Diesel price	1,528 euro	(brandstofprijzen.info, 2020)
Investment cost hybrid	30.000 euro	Section 4.1.1.2.2
Extra cost B100	0,18 euro	Section 0
Extra cost B20	5% more than diesel price (0,0764 euro)	(Stimular, 2019)
Investment cost 'het nieuwe draaien'	250 euro	(KEMP, 2019)
Work days in 2020	256-10 (bouwvak) = 246 days	none
Common work day	8 hour	none
Diesel use machines	12 litre/hour	(Plegt-Vos Infra&Milieu, 2017)
Hybrid CO_2 reduction	15-30%	Section 4.1.1.2
Biodiesel (B20) CO_2 reduction	15%	(Stimular, 2019)
Het nieuwe draaien CO_2 reduction	8%	Section 4.2.3

Total reduction

First the total reduction is calculated

$$total\ CO2\ footprint\ scope\ 3 * reduction\ percentage = total\ reduction$$

$$1651917 * 0{,}105 = 173451\ kg\ CO2$$

Hybrid

The amount of hybrid machines is calculated to meet the CO_2 reduction goals. A hybrid has a reduction between 15 and 30% therefor both are calculated.

CO_2 emission per machine

$$workdays * hours\ a\ day * diesel\ per\ hour * emission\ factor = CO2\ emission$$

$$246 * 8 * 12 * 3{,}23 = 76280\ kg\ CO2$$

CO_2 reduction per machine

$$CO2\ emission * perecentage\ reduction = CO2\ reduction\ per\ machine$$

$$76280 * 0{,}15 = 11442\ kg\ CO2$$

$$76280 * 0{,}3 = 22884\ kg\ CO2$$

Amount of machines needed

$$\frac{total\ reduction}{reduction\ per\ machine} = amount\ of\ machines$$

$$\frac{173451}{11442} = 16\ machines$$

$$\frac{173451}{22884} = 8\ machines$$

Total investment cost

$$\frac{amount\ of\ machines * investment\ costs}{2} = total\ investment$$

$$\frac{16 * 30.000}{2} = €240000$$

$$\frac{8 * 30.000}{2} = €120000$$

Cost reduction per year per machine

$$workdays * hours\ a\ day * diesel\ per\ hour * diesel\ price = diesel\ price$$

$$246 * 8 * 12 * 1{,}528 = €36085$$

$$diesel\ price * percentage = cost\ reduction\ per\ year$$

$$36085 * 0{,}15 = €5413$$

$$36085 * 0{,}15 = €10826$$

Biodiesel

CO_2 emission per litre (B100)

$$CO2\ factor\ biodiesel = CO2\ emission$$

$$0{,}345 = 0{,}345\ CO2/litre$$

CO_2 emission per litre (B20)

$$CO2\ factor\ diesel * percentage = CO2\ emission$$

$$3{,}23 * 0{,}85 = 2{,}7455\ CO2/litre$$

CO_2 reduction per litre

$$CO2\ factor\ diesel - CO2\ emission = CO2\ reduction\ per\ litre$$

$$3{,}23 - 0{,}345 = 2{,}885\ CO2/litre$$

$$3{,}23 - 2{,}7455 = 0{,}4845\ CO2/litre$$

Amount of litre needed

$$\frac{total\ reduction}{reduction\ per\ litre} = amount\ of\ litres$$

$$\frac{173451}{2{,}885} = 60122\ litres$$

$$\frac{173451}{0{,}4845} = 358001\ litres$$

Yearly cost

$$\frac{amount\ of\ litre * extra\ litre\ price}{2} = total\ cost\ per\ year$$

$$\frac{60122 * 0{,}18}{2} = €5.411$$

$$\frac{358001 * 0{,}0764}{2} = €13676$$

Het nieuwe draaien

The amount of driver is calculated to meet the CO_2 reduction goals.

CO_2 emission per driver

$$workdays * hours\ a\ day * diesel\ per\ hour * emission\ factor = CO2\ emission$$

$$246 * 8 * 12 * 3{,}23 = 76280\ kg\ CO2$$

CO_2 reduction per driver

$$CO2\ emission * perecentage\ reduction = CO2\ reduction\ per\ machine$$

$$76280 * 0{,}08 = 6102\ kg\ CO2$$

Amount of drivers needed

$$\frac{total\ reduction}{reduction\ per\ machine} = amount\ of\ machines$$

$$\frac{173451}{6102} = 29\ drivers$$

Investment cost

$$\frac{amount\ of\ drivers * investment\ costs}{2} = total\ investment$$

$$\frac{29 * 250}{2} = €3625$$

Cost reduction per year per driver

$$workdays * hours\ a\ day * diesel\ per\ hour * diesel\ price = diesel\ price$$

$$246 * 8 * 12 * 1{,}528 = €36085$$

$$diesel\ price * percentage = cost\ reduction\ per\ year$$

$$36085 * 0{,}08 = €2887$$