Master Thesis - Energy Science

Thesis Report

Guiding companies toward climate change mitigation

with a digital One-stop-shop

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Contents

List of Figures

List of Tables

Summary

The Netherlands has committed itself to reduce overall greenhouse gas emissions with 49% by 2030 and 95% by 2050 compared to 1990, in order to achieve the climate goals of the Paris Agreement. These targets are only feasible if substantial greenhouse gas emission reduction is achieved in all sectors of the economy. Mobility and built environment together contribute 60% of total emissions originating from non-European trading system. However, these sectors are often part of fragmented policies and regulations that are not sufficient to meet climate goals. This research aims to provide an approach which enables companies in the service sector to reduce greenhouse gas emissions. Potentially a large share of the carbon footprints in this sector originates from activities in mobility and the built environment, and carbon footprints between companies are relatively similar. This research combined company carbon footprint with the carbon budget and marginal abatement cost. In order to calculate the marginal abatement costs, mitigation measures for mobility and the built environment were identified together with their costs and mitigation potentials. A marginal abatement cost curve was used to prioritise the greenhouse gas mitigation measures based on cost-effectiveness. Moreover, mitigation pathways were constructed based on a company specific allocated carbon budget. The introduction of various pathways presented potential trajectories a company could follow to contribute to the climate goals. A case study has been carried out for Royal HaskoningDHV in the Netherlands. Generally, measures in mobility had a negative marginal abatement cost, while in the built environment they were positive. Overall, the mitigation measures implemented in each of the four projected pathways did not meet the 2°C climate goal, mostly due to limited achievable greenhouse gas mitigation potential in scope 3. This showed that there is a large urgency of reducing greenhouse gas emissions as soon as possible. Results also presented that in a pathway where implementation of mitigation measures was earlier in time, less drastic reduction in greenhouse gas emissions were required, as the carbon budget was used more sparingly. Results from the case study showed that the most cost-effective pathway was to start reducing emissions as soon as possible, as this led to a large cumulative reduction in costs with the lowest exceedance in carbon budget.

Keywords: Carbon footprint, Carbon budget, Greenhouse gas emissions, Marginal abatement cost, Marginal abatement cost curve, non-ETS, Linear programming, Service sector, Mobility, Built environment, Pathways.

Preface

This document was written for my Master Thesis in Energy Science at Utrecht University. In the Energy Science masters' programme it is required to conduct independent research and apply the acquired knowledge gained during the various courses of the Master. The research was carried out at Royal HaskoningDHV at the department of Sustainability. Royal HaskoningDHV is an international and independent engineering and consultancy firm, leading in innovation and sustainability. The research focused on guiding companies, in the service sector, towards climate change mitigation in the Netherlands.

1. Introduction

1.1 Background of greenhouse gas reduction targets

As of today, the economic development of a country is coupled with energy use. The largest part of this energy is provided by fossil fuels (Jones and Warner, 2016). However, these fossil fuels are finite and emit greenhouse gasses (GHGs) and other air pollutants. This leads to an increase in global mean temperature due to the greenhouse effect, putting pressure on various Earth systems as well as social- and economic activities (IPCC, 2018). Additionally, population is growing every year (Jones and Warner, 2016). The energy- demand and consumption are projected to keep rising as population and economic development increases. To minimise their impacts on climate change, it is important that GHG emissions are reduced.

To mitigate climate change the Paris Agreement (COP21) has presented a climate goal, by limiting the increase in global temperature to well below 2°C, while aiming for 1.5°C, compared to pre-industrial levels (United Nations, 2015). Every nation included in the Paris Agreement puts forward Nationally Determined Contributions (NDCs), in which binding targets to mitigate GHG emissions are declared. Nations submitted two types of NDCs, with unconditional- and conditional targets. Unconditional targets are implemented without external support, whilst conditional targets require external support and are therefore more ambitious (United Nations Environment Programme, 2019). In 2018, the global mean human-induced warming reached a little over 1°C above pre-industrial levels (IPCC, 2018). Research shows that with the current unconditional- and conditional NDCs global, warming could reach 3°C - 3.5°C by 2100 (United Nations Environment Programme, 2019). This suggests that the global NDCs are insufficient to achieve the climate goal of 2°C (United Nations Environment Programme, 2019).

The NDCs of the European Union (EU) declared that, collectively, they should reduce 40% and 80 - 95% of GHG emissions by 2030 and 2050 respectively (Abels-van Overveld et al., 2019). Recently, the EU renewed their plans and aimed to reduce at least 55% of emissions by 2030 (European Commission, 2020). As this target is shared between EU member states, actual reduction targets vary per member state. In general, member states with a higher GDP have to reduce more GHG emissions compared to lower GDP member states (Carbon Market Watch, 2017). To achieve their NDC targets in the collective goal, member states in the EU formulated specific energy- and climate agreements (Rijksoverheid, 2019).

1.2 The Netherlands

This research focuses on the Netherlands which committed itself to reduce 49% and 95% of GHG emissions by 2030 and 2050 respectively compared to 1990 levels, conform the Dutch National Climate Agreement (Rijksoverheid, 2019). The Netherlands is characterised as a densely populated country, with 17.3 million inhabitants in 2019 (CBS, 2020). It has a growing open economy, being one of the most competitive economies in the world, placing 4th on the Global Competitive index (World Economic Forum, 2019). It has the largest port of Europe and a relatively large and energy intensive petrochemical industry. In total, the Netherlands emitted 214.4 $MtCO_2$-eq (megaton CO_2 equivalents) in 2016. The Dutch GHG emissions can be attributed to five different sectors (Figure 1.1). The sectoral breakdown follows the "Integral National Energy- and Climate plan" (INEK, translated from Dutch: "Integraal Nationaal Energie- en Klimaatplan") consisting of: electricity, transport, agriculture and land use, industry and the built environment (Ministry of Economic affairs and Climate, 2019). This research will specifically focus on GHG emissions of the service sector. Approximately 7.2 $MtCO_2$-eq resulted from direct GHG emissions by fuel use (mostly natural gas) from the service sector in 2018. Indirect GHG emissions are accounted to other the sectors (Abels-van Overveld et al., 2019).

An international and national coherent climate policy framework that addresses all sectors is still lacking. Large energy intensive industries are covered by the European Trading System (EU-ETS) (described in Section 2.1). Sectors outside the ETS (non-ETS sectors), including transport and the built environment, are often part of fragmented policies and regulations that are not sufficient to meet the climate goal (Abels-van Overveld et al., 2019). It has been suggested that indirect emissions by companies in the service sector contribute to a significant part in GHG emission arising from mobility and the built environment (Ge and Lei, 2014). This indicates that companies in the service sector could have a larger impact on the overall non-ETS emissions of mobility and the built environment.

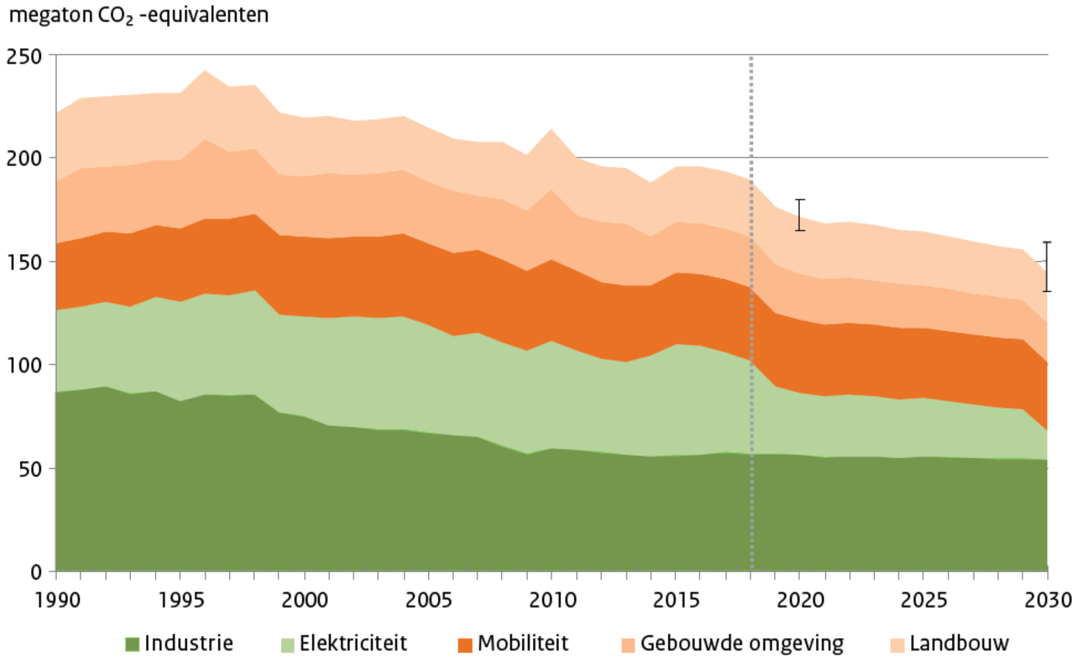

Figure 1.1: Sectoral GHG emissions in the Netherlands, adopted from (Ministry of Economic affairs and Climate, 2019)

Studies on GHG emission reduction for mobility and the built environment have been conducted for the Netherlands. One of which is a policy study on CO_2 emissions reduction in mobility by PBL Netherlands Environmental Assessment Agency and the Energy research Centre of the Netherlands (ECN). The latter study provides more insight in the medium-term (2020) and long-term (2050) climate targets for the Dutch transport sector. They found that for the long term there are three crucial conditions to decarbonise the transport sector: (i) substantially change travel behaviour, travel demand and public acceptance; (ii) availability of zero-carbon or low-carbon fuels; (iii) availability of advanced vehicle technologies. Moreover, they found that the emission reduction potential for passenger car transport is larger than for road freight, aviation and shipping. To reach the climate targets, these transport modes will depend on biofuels and change in mobility demand and behaviour (Hoen et al., 2009).

Another study, addressing an energy-neutral built environment in the Netherlands, provides insight into incorporating energy efficient and renewable energy sources (RES) to the built environment. It states that energy demand should be greatly reduced by insulation, heat recovery and energy efficient appliances. RES should be used as efficiently as possible by optimal use of passive RES, high efficient renewable energy production, balance demand and RES supply, and energy storage. And when using fossil fuels, it should be as efficient as possible by heat pumps, combined heat and power or community systems (Opstelten et al., 2007).

Additionally, research has been carried out in the Netherlands called Climate and Energy Report (KEV, translated from Dutch: "Klimaat en Energieverkenning"). They project that with current policies the GHG emission reduction potential in the Netherlands could reach 35% [28-39] in 2030 compared to pre-industrial levels, indicating that the national emission reduction target is not reached. Therefore, additional measures or policies are necessary (Abels-van Overveld et al., 2019). The National Climate Agreement of The Netherlands report that there is a need for innovative, deep and actual solutions to realise the committed ambitions (Rijksoverheid, 2019).

1.3 Problem definition

To be able to support the climate goals of the Paris Agreement, from a company perspective, various tools have been constructed guiding companies towards climate change mitigation. One of which is the Science Based Targets initiative (SBTi) providing science-based GHG emission targets for companies. Science-based targets are emission targets which are in line with the decarbonization required to limit global warming to 1.5°C or 2°C. One of the tools provided is a science-based target setting for small and medium-sized enterprises (SME). Via this method SMEs can set science-based targets for their scope 1 and 2 emissions (section 2.2) by choosing predefined target options. For this, data on company activities and emissions are required (Science Based Target, 2020).

The GHG protocol provides, next to their accounting standards, multiple tools and data for developing inventories of GHG emissions and help track progress towards climate goals. These tools are aimed at cross-sector, country- and sector specific, or city level (Greenhouse Gas Protocol, 2020). Specifically, tools for countries and cities are of interest when tracking progress to climate goals. The GHG protocol also provides a "Mitigation Goal Standard" and "Policy and Action Standard Calculation Tool". The first aims to help governments set emission-reduction targets and the second aims to estimate the GHG mitigation effect of policies and actions.

Lastly, the CO_2-performance ladder is a well-known certification scheme to stimulate companies to reduce CO_2 emissions in the Netherlands. Each achieved level of certification gives a company a certain competitive advantage in tenders (SKAO, 2015). In the CO_2-performance ladder, a company is certified on four different categories: insight, reduction, transparency and participation. Based on a companies' performance in each of categories a certain level is awarded, the category with the lowest score will give the overall score of the company. This methodology requires companies to set GHG emissions reduction targets based on their own ambition level as long as they are comparable with other companies in that sector (SKAO, 2015).

It is shown that these tools primarily are constructed and used for target setting on various levels or to provide a certification for CO_2 emission reduction. However, these methods and tools can be criticised. First of all, the SBTi does not provide means to get to the specific target, such as GHG reduction measures that should be implemented to reach the desired goal. Moreover, seemingly the GHG protocol tools mostly focus on large scale industries as aluminium, cement, iron and steel, wood, and pulp and paper. Lastly, Rietbergen et al. (2015) concluded that the target setting in the CO_2-performance ladder did not lead to the most ambitious goals for CO_2 emission reduction. Moreover, almost all larger companies achieved the highest level of certification. Thereby, the competition between companies has been halted and companies are punished for not having the benefits of certification instead of being rewarded for it. This results in a downwards trend where it is about achieving the benefits of the CO_2-performance ladder with minimal effort, instead of pursuing sustainability targets (van Dijk, 2017).

The link between science-based target setting and how to adhere to these climate targets for companies is missing, especially for emissions arising in non-ETS sectors. To fill this gap, this research should guide companies in the service sector to support the climate targets of the Paris Agreement for the Netherlands. A methodology will be presented enabling companies in the service sector to create insight in their current emission profile and suggests potential emission mitigation pathways, including emission reduction measures for mobility and the built environment. Moreover, a Excel based tool will be constructed which should provide initial investigation- and avenues of climate change mitigation for individual companies in the service sector up to 2050.

1.4 Research question

This research aims to investigate companies in the service sector and provide them with guidance on GHG emission reduction measures, focused on mobility and the built environment, they could implement to contribute to the climate goals of the Paris Agreement. Therefore, the research question is:

How can a company in the service sector in the Netherlands find the most cost-effective GHG mitigation pathway to adhere to the climate goal of the Paris Agreement by limiting climate change to 2° C, focusing on emission reduction measures in mobility and the built environment?

The main research question is further addressed in detail in the following sub-questions:

- Which GHG emission reduction measures could a company in the service sector implement for mobility and the built environment, and what are the associated costs and GHG emission reduction potentials?
- How can GHG emission reduction measures be prioritised for an individual company, based on cost-effectiveness?
- What is the effect of using a carbon budget for the GHG mitigation strategy of an individual company?

1.5 Relevance

1.5.1 Scientific contributions

This research provides an approach to reduce a companies' GHG emissions with GHG mitigation measures based on cost-effectiveness. Moreover, it translates the climate agreements' GHG emissions reduction targets for an individual company in the Netherlands into a pathway on climate change mitigation. An Excel based tool will be constructed, which provides an adaptable approach for a company to reduce GHG emissions. Furthermore, an overview of their current carbon footprint, potential GHG emission mitigation measures with an indication of costs and GHG emission reduction, and GHG emission monitoring will be provided.

1.5.2 Societal contributions

This research also provides societal contribution by supporting the Sustainable Development Goals (SDGs) in the Netherlands. Especially SDG 13 "Climate Action" is the basis of this research. As this research provides insight into current GHG emissions and shows the most feasible pathway for a company to reduce their GHG emissions. Additionally, the research will contribute to reducing health problems related to anthropogenic GHG emissions, as presented in SDG 3 "Good health and well-being for people" (United Nations, 2020). Moreover, by the simplistic nature of the tool it could also be used to communicate sustainability targets with diverse stakeholders in a company and be the basis for decision making regarding GHG emission reduction.

The remainder of this document reads as follows. Chapter 2 gives insight into the theory used in this research, such as carbon footprint and carbon budget and marginal abatement cost curve. Chapter 3 will go into the methodology of the research, providing information on the approach, data and the constructed model. Chapter 4 describes the identified GHG emission reduction measures with their mitigation potential and marginal abatement cost. Furthermore, results of the case study will be presented in Chapter 5. To conclude, in Chapter 6 a discussion will follow, and in Chapter 7 the research questions will be answered.

2. Background information and theoretical framework

2.1 GHG emission accounting: EU ETS and non-ETS sectors

GHG emissions arising from activities are accounted in the EU ETS or non-ETS sectors. The sectors comprising the EU ETS are: power- and heat generation, energy-intensive industry and commercial aviation. All sectors that are not covered in EU ETS are essentially non-ETS sectors. Generally, these are characterised by the sectors mobility, built environment, small industries, agriculture and waste management (Table 2.1). Emissions from land use and forestry (LULUCF) are separately regulated. Chapter 2.5 provides more information on the current policies.

Table 2.1: Sectors covered by the EU ETS and non-EU ETS (European Union, 2015).

<table>
<tr><th>EU ETS</th><th>non-EU ETS</th></tr>
<tr><td>Energy intensive industry sectors, including:
• Oil refineries
• Steel works
• Iron production
• Aluminium
• Metals
• Cement
• Lime
• Glass
• Ceramics
• Pulp
• Paper
• Cardboard
• Acids
• Organic chemicals</td><td>Mobility:
GHG emissions from transport such as cars, trucks, domestic shipping, non-electric trains are cover by ESR.</td></tr>
<tr><td>Power- and heat generation:
combustion installations with a rated thermal input larger than 20MW are regulated under EU-ETS.</td><td>Built environment:
GHG emissions from heating and cooling of buildings are covered by ESR.</td></tr>
<tr><td>Commercial aviation:
all flight arriving and departing from airports in the European Union, including Norway, Iceland and Liechtenstein are covered under EU-ETS.</td><td>Agriculture:
The non-CO_2 emissions from agriculture are covered by ESR. These are emissions from the livestock sector and the use of fertilisers. CO_2 emissions from agriculture are included in land use, land use change and forestry (LULUCF).</td></tr>
<tr><td></td><td>Industry:
The GHG emissions of smaller energy industries are covered by ESR.</td></tr>
<tr><td></td><td>Waste:
The GHG emissions by solid waste disposal land, wastewater, waste incineration and any other waste management activity are covered by the ESR.</td></tr>
</table>

In 2016, 43% (92 MtCO_2-eq) of Dutch GHG emissions originated from EU ETS and 57% (113 MtCO_2-eq) from non-ETS sectors (Daniëls et al., 2016). The shares of GHG emissions of the Dutch non-ETS sectors are presented in Figure 2.1, showing that roughly 60% of GHG emissions are the result of mobility and the built environment.

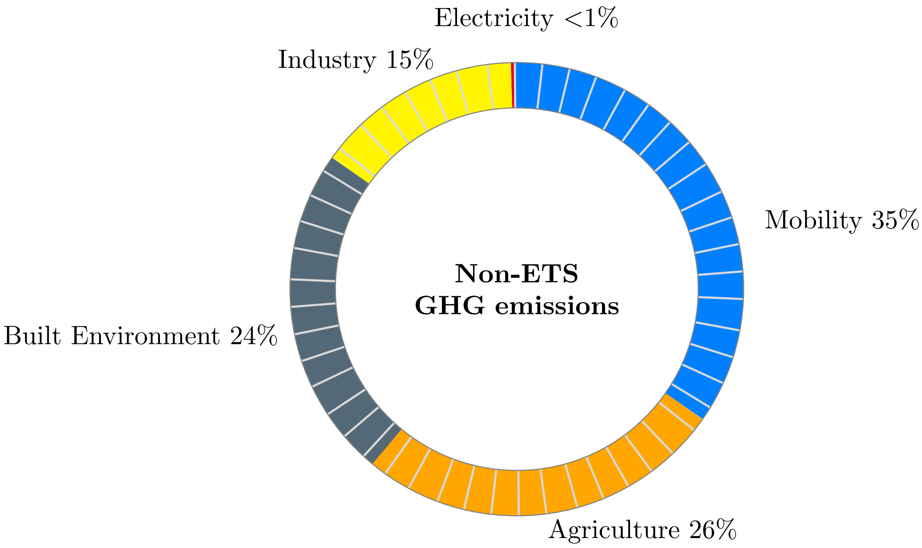

Figure 2.1: Breakdown of the GHG emissions in the Netherlands from non-ETS sectors in 2017, data obtained from (Abels-van Overveld et al., 2019).

2.2 GHG emission accounting: Carbon footprint

The carbon footprint is a well-defined concept of emission accounting, and can be "used to quantify the amount of GHG emissions associated with a company (Corporate Carbon Footprint, CCF) or with the life cycle of an activity or a product/service (Product Carbon Footprint, PCF) in order to determine its contribution to climate change" (Balaguera et al., 2018). The unit for the carbon footprint is CO_2-equivalents (Harangozo and Szigeti, 2017). In the Kyoto protocol, the CO_2 and non-CO_2 emissions are described by using global warming potentials (GWP) with a time horizon of 100 years. This means that each non-CO_2 emission will be converted to CO_2-equivalents, which is the magnitude of GWP compared to CO_2. The six gases described in the Kyoto protocol are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) (United Nations Environment Programme, 2019).

The benefit of using the carbon footprint is that it is a widely known framework and provides results that are easy to grasp (Weidema et al., 2008). However, oversimplification of the carbon footprint could lead to a biased perspective on the actual environmental impact. Additionally, when accounting for GHG emissions attributed to a product or activity, the scope is of importance. In contrast to the accounting method for EU-ETS and non-ETS sectors, using the carbon footprint allows for indirect up- and downstream emissions to be allocated to an individual company (Figure 2.2). Upstream emissions account for indirect GHG emission related to purchased or acquired goods and services (e.g. waste generation, business travel, and commuting by employees). Downstream emissions account for indirect GHG emission related to sold goods and services (e.g. processing- and end-of-life treatment of sold products) (Greenhouse Gas Protocol, 2011). Following the guidelines of the Greenhouse Gas protocol for CCF there are three emissions scopes. These are described as follows:

- **Scope 1: Direct GHG emissions -** occurring from sources that are directly owned or controlled by the company (e.g. boilers, vehicles). Direct emissions from combustion of biomass and GHG emissions are not covered in the Kyoto protocol and excluded from scope 1.
- **Scope 2: Electricity indirect GHG emissions -** based on GHG emissions from purchased electricity consumed by the company, the electricity can also be purchased from outside the company boundaries.
- **Scope 3: Other indirect GHG emissions -** are GHG emissions by activities a company undertakes but are occurring from sources not owned or controlled by the company (Greenhouse Gas Protocol, 2004).

It is argued that in some sectors, scope 3 emissions account for the largest share of GHG emissions compared to scope 1 and 2 emissions (Harangozo and Szigeti, 2017). However, scope 3 emissions are not mandatory to report and are more difficult to measure precisely (Greenhouse Gas Protocol, 2004; Harangozo and Szigeti, 2017). It should be noted that scope 3 emissions are elsewhere actually scope 1 or 2 emissions. In order to reduce scope 3 emissions, it may be required to influence outside the system boundaries. Multiple guidelines on the carbon footprint exist. The two mostly used are the IPCC- and the GHG protocol guidelines.

IPCC guidelines

The Intergovernmental Panel on Climate Change (IPCC) has defined a standardised method to calculate GHG emissions on national level, this is used as annual monitoring of GHG emissions for terrestrial systems (e.g. countries or regions). This method uses the gases outlined in the Kyoto Protocol. It is also adapted to be used on subnational-, regional and city level. However, the IPCC standardised method only accounts for scope 1 and part of scope 2 emissions, thereby neglecting the remaining part of scope 2 and all scope 3 emissions. That is because only direct emissions for sectors and subsectors within city boundaries are reported, regardless of where it is consumed (Caro, 2018). For example, according to the IPCC guidelines, emissions outside the system boundary are not included in the carbon footprint.

Greenhouse Gas Protocol

The Greenhouse Gas Protocol, by the World Resource Institute (WRI) and World Business Council for Sustainable Development (WBCSD), is another standard for GHG emissions accounting and reporting. It can be measured on four levels: national, corporate, facility or project. The GHG protocol comprises two separate standards, one for accounting and reporting, and the other for project quantification. The first standard is used for corporate level and the second on project level (Green, 2010). The GHG protocol became a widely accepted standard for CCF (Harangozo and Szigeti, 2017). The scopes in the GHG protocol are designed to ensure there is no double counting in scope 1 and 2 emissions (Greenhouse Gas Protocol, 2011). Furthermore, the GHG protocol provides guidelines on data collection and calculation for GHG emissions. The GHG protocol approach is therefore used in this research.

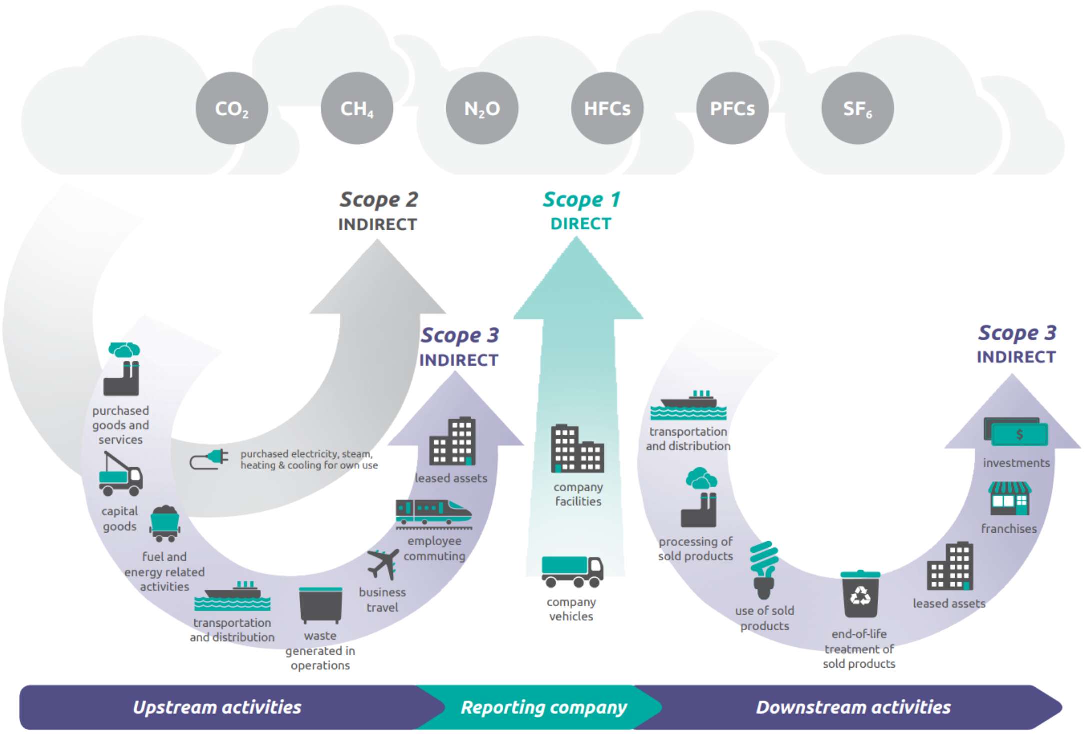

Figure 2.2: Overview of GHG Protocol emission scopes, types of emissions and activities across the value chain (Greenhouse Gas Protocol, 2004)

2.3 Carbon budget

Translating long-term climate goals to mid-term concrete actions is a challenge, especially since global temperature change is measured in GHG concentrations. Because (i) the relationship between emissions and atmospheric concentration is complex, (ii) climate sensitivity is still rather large, and (iii) the time lag between concentration stabilisation and the eventual temperature level (Matthews et al., 2012). Moreover, mid-term mitigation goals (2030) are very dependent on longer term mitigation goals (2050). Vogt-Schilb and Hallegatte (2014a) showed that excluding long-term objectives may lead to policies reaching the mid-term goals, however, may not lead to the achievement of the long-term goals. Current developments in the climate models have presented the opportunity to investigate the climate response in terms of GHG emissions. Cumulative GHG emissions are almost linearly related to global temperature change. As temperature change is independent on the pathway of GHG emissions, it depends only on the total carbon emitted over time (Matthews et al., 2012). This enables target setting based on the cumulative carbon budget.

Carbon budgets can be derived from CO_2-only emissions, but also from multi-gas and aerosol scenarios. Generally, CO_2-only carbon budgets tend to overestimate the total net carbon emissions associated with global warming targets (IPCC, 2018). In its 5th assessment report (AR5), the IPCC calculated the cumulative global carbon budget for the 1.5°C and 2°C scenarios. In the current research, the carbon budget is used in line with the 2°C target with a >66% likelihood. This presents a cumulative global carbon budget from 2018 and onward of 1,170 $GtCO_2$ (IPCC, 2018). Next to the global carbon budget, it can be expressed at a national, sectoral or even company level. To be able to provide a specific carbon budget on each of these levels, allocation of the global carbon budget is required. Various effort sharing approaches for national carbon budgets are researched based on equity principles (van den Berg et al., 2019). In this research, the immediate per capita convergence approach is used, which assumes that all humans have equal rights to global collective goods (van den Berg et al., 2019). Allocation of carbon budget is based on the average population share of a country over the period of 2020 to 2050. Furthermore, to allocate the national carbon budget to a company, relative carbon budget emission shares are used. Thereby, the share of GHG emissions of a company in the most recent year, in this case 2019, is used compared to the national carbon budget. Furthermore, the company carbon budget is divided into each of the scopes, according to their weight in 2019 compared to the total GHG emissions.

2.4 Marginal abatement cost curve

2.4.1 MACC approaches

To mitigate climate change at company level generally decisions are made regarding investments and GHG emission reduction. Therefore, GHG emission reduction measures can be selected based on their marginal abatement cost, this is the cost for reducing one more (the marginal) unit of pollution (van Odijk et al., 2012). Each measure has a specific marginal abatement cost, which can be presented on a marginal abatement cost curve (MACC). This curve could provide useful for companies as well as policy makers, as it can be used to analyse investments and impacts on GHG emission reduction. Moreover, a MACC enables one to find the most cost effective option to achieve a certain target (Levihn et al., 2014).

There are two main approaches to create MACCs, these are the model- or expert based approach. Model based MACCs are top-down and usually projecting macroeconomic interactions. In this approach, market responses to exogenous pressures are modelled. The expert-based approach is a bottom-up approach, aimed at finding the best possible options to achieve a given target by detailed analysis of various options. In terms of a corporate perspective, expert-based MACCs should provide insight in how the market will or should adapt to policy and what the best available options are for future investments and actions (Levihn et al., 2014). This research is interested in finding the most cost-effective path for a company to reduce GHG emissions. In order to do this, expert based MACCs at company level are constructed. The MACC is presented as tonnes of avoided CO_2-eq and on cost per tonne of CO_2-eq. In this way the total area under the MACC gives the total cost for a given GHG emission abatement target. The total abatement costs are determined dependent on the GHG emission reduction target and the shape of the MACC (Levihn et al., 2014).

In an study by Kesicki and Strachan (2011) they concluded that MACC are a useful tool to illustrate and engage stakeholder in a debate about climate change mitigation. It could be give initial guidance in abatement costs and potentials at a given moment in time, while pointing out promising mitigation options. As long as the limitations of the study are shown.

2.5 Policies in the Netherlands

2.5.1 Rules & regulation

Overall, the climate goals of the EU aim to reduce GHG emissions by at least 40% in 2030 compared to 1990. Key policies to achieve the EU climate target are the European Trading System (EU-ETS) for industry, Renewable energy directive II (RED II) promoting the use of energy from renewable sources, and the Effort Sharing Regulation (ESR), former Effort Sharing Directive (ESD). Two main policies to combat climate change are used, (i) EU ETS - with 43% reduction in GHG emissions by 2030 compared to 2005, and (ii) ESR - with 30% reduction in GHG emissions by 2030 compared to 2005. Next to these there are separate regulations for LULUCF. Moreover, the "Meerjarenafspraak Energie-efficiency ETS-ondernemingen" (MEE) aims to improve energy efficiency for large industrial companies in the ETS. Additionally, "Meerjarenafspraak Energie-effiency 2001-2020" (MJA3) is mainly focused at non-ETS companies. Both covenants will be stopped at the beginning of 2021 (Abels-van Overveld et al., 2019). The EU ETS works on a cap and trade principle. This means that there is a total amount of GHG allowances which are reduced over time, so that the total amount of emissions reduces. Companies in the EU ETS receive or buy allowances, which can also be traded with other EU ETS companies. Every year EU ETS companies have to surrender the amount of allowances equal to their GHG emissions. However, the non-ETS sectors do not have such a clear system. The ESR sets an overall GHG reduction target for the sectors it covers, but it does not specify where, how and with what policies a country should reduce its emissions. The choice of measures is therefore the responsibility of each member state.

Emissions from non-ETS sectors in the Netherlands described in the ESR has a reduction target of 36% by 2030 compared to 2005. EU member states are allowed to use various forms of flexibility in the ESR so that the climate targets could be achieved in a least costly manner. Flexibility can be used over time, between countries, with the EU ETS, and with the land use sector (LULUCF). Over time, there can be banking of overachieved targets and be use in another year. Borrowing of carbon budget from following years up to 5% of annual targets is also allowed. Additionally, when a member state overachieves its target for a given year, the surplus can be transferred to another member state. This can also be done based on projections which show overachieving of targets, and thus transfer the surplus of allocated carbon budget to another member state (up to 5%). Moreover, limited amount of EU ETS allowances can be used to achieve the ESR, meaning that EU ETS allowances get subtracted. Lastly, if the LULUCF sector absorbs more carbon than it emits, this can be used to offset emissions under ESR. All this flexibility imposes some drawbacks, as it undermines the low-carbon transition for non-ETS sectors by allowing more GHG emissions under the ESR up to 2030.

2.5.2 Support policies

As part of the European Union, the Netherlands is committed to reduce 49% of GHG emissions by 2030. Thereby, the Netherlands aims to reduce 48.7 Mt CO_2-eq by 2030 compared to 1990 as part of the national Dutch target (Ministry of Economic affairs and Climate, 2019).

In the transport sector, there are EU policy directives. The Fuel Quality Directive (EU FQD) is an important element in reducing GHG emissions from transport. It applies to petrol, diesel, biofuels used in road transport and gasoil in non-road-mobile machinery. EU legislation requires GHG intensity by transport fuels used in vehicles to be reduced by a minimum of 6% in 2020. Additionally, as Europe needed to increase the use of energy from renewable sources, the Renewable Energy Directive (RED-I) establishes an overall policy for the production and promotion of energy from renewable sources in the EU. It requires the EU to fulfil at least 20% of its total energy needs with renewable energy by 2020. All EU countries must also ensure that at least 10% of their transport fuels come from renewable sources by 2020. This directive is recast with the Renewable Energy Directive (RED-II). At the moment, RED-II provides targets for Renewable energy sources consumption. The overall target is increased to 32% by 2030, where the consumed fuel for road- and rail transport must be supplied with a minimum of 14% as renewable energy. Next to these there are national policies for the Netherlands, consisting of (i) stimulating sustainable energy carriers, (ii) stimulating electric vehicles while aiming for 100% renewable car sales in 2030, (iii) decreasing 8 billion business kilometres in 2030, (iv) making logistics more sustainable, and (v) adopting national policies for shipping and air transport. The target is to reduce 2 Mt GHG emissions by 2030 (compared to 2020) (Ministry of Economic affairs and Climate, 2019).

In the built environment the target is to reduce GHG emissions by 3.4 Mt in 2030 (compared to 2020). Currently the "Invoering Omgevingswet", "Energiebelasting - Opslag Duurzame Energie (ODE)" and "Energie-investeringsaftrek (EIA)" will be continued after 2020. These policies aim to implement more GHG emission reduction measures, make an energy switch by levying more tax on natural gas, and provide fiscal benefits for energy efficient investments. Additionally there is a Stimulation of Sustainable Energy Transition (SDE++) subsidy available in the Netherlands for companies and non-profit organisations including the built environment. This subsidy is focused on renewable energy production such as wind-, and solar power, but also renewable heat from biomass and geothermal energy as well as low CO_2 alternatives (hydrogen electrolysis and CO_2capture & storage). Companies can either apply for EIA or SDE++. Next to the existing policies, new policies are aimed to provide multiple forms of financing and make new to build-, existing housing and utilities more sustainable (Ministry of Economic affairs and Climate, 2019). For both sectors, the GHG emission reduction targets by 2030 are leading up to the targets of 2050. Although, sectoral GHG emission reduction targets after 2030 are not specified in the INEK. The target for 2050 is to reduce total GHG emissions by 95% compared to pre-industrial levels, indicating that almost in all sectors the GHG emissions should be strongly reduced.

3. Methodology

3.1 Scope

The main goal of this research is to reduce GHG emissions of companies to contribute to the climate goals of the Paris Agreement. The service sector is selected, where not only the direct scope 1 emissions are accounted for, but scope 2 and 3 emissions are also included. Thereby the overall coverage of GHG emissions by the service sector is larger than suggested by their direct emissions. The focus is on company specific GHG emissions attributed to mobility- and the built environment activities. The timescale of the research is from the current situation (2020) up to 2050. The system boundaries are following the carbon footprint scopes, as defined in the GHG protocol (section 2.2). GHG emission reduction measures are identified that could be applied to activities in each of these scopes, thereby reducing the carbon footprint of the company. Following some characterisations of the approach:

- **Time period:** In this research pathways are developed which span a period of 2020 up to 2050. The allowed carbon budget for 2°C (1,170Gt)[1] is used in settings targets over time. In the constructed pathways (section 3.2) all of the carbon budget is used up to 2050, this implicates that after 2050 the GHG emission should be reduced to zero immediately, as any emissions at that point will exceed the allocated carbon budget.
- **Technology scope:** Current available measures to reduce GHG emissions are included. Technological developments over time (e.g. innovation and learning) are excluded, as the goal of the approach is to present strategic insight for emission mitigation for the mid-term (2030). Next to this, it shows the consequences for measures which have to be implemented in a lookout beyond 2030.
- **Region:** This approach is applicable for companies with their respective GHG emissions located in the Netherlands.
- **Impact categories:** In this approach the global warming impact category is used, expressed as potential global warming due to emissions of GHGs into the atmosphere (in kgCO_2-eq).

3.2 Reduction pathway

The main goal is to present implications of a static carbon budget in combination with a specific mitigation strategy. Therefore, four pathways are constructed, these are the "fast pathway" - reducing maximum GHG emissions as early as possible, "middle pathway" - Balancing mitigation potential and cost, the "delayed pathway" - starts in 2028 to reduce GHG emissions, and the "policy pathway" - which follows the climate goal of 49% and 95% reduction of GHG emissions compared to 1990 by 2030 and 2050 respectively. However, carbon footprint data of companies is unavailable for this period, therefore the pathway is constructed from most recent data (2019). The other pathways use the carbon budget as a constraint on the total amount of GHG emissions over the period of 2020 to 2050. Lastly, a cost factor is included in the modelling of the pathways. The cost factor is reduced from the 2020 up to 2050, therefore it becomes most cost effective to implement GHG emission reduction measures as late as possible. All pathways are constructed with a linear programming optimisation, which is described hereafter.

[1] The carbon budget is determined from 1.1.2018. By deducing the global emissions of 36.7 Gt for 2018, the carbon budget is corrected for 2019.

The decision variable in the constructed model is the total GHG emissions in each year (GHG_{EMIS}(t)), meaning that the model will determine for each year (indicated by t) the allowed GHG emissions following the constraints given in the model. For the delayed pathway, there is chosen to postpone reduction in GHG emissions up to 2028, to show the effect of a delayed reduction path.

Decision variables: GHG_{EMIS}(t)

The objective of the program is to minimise the total GHG emission reduction cost. Therefore a cost factor and discount rate (r) is introduced to allow for the model to determine in which year it is most effective to reduce GHG emissions while keeping the costs as low as possible. In the middle and delayed pathway the discount rate will decrease over time. Only for the fast pathway, the discount rate is reversed, as this allowed reduction in GHG emissions to be introduced as soon as possible.

Objective Function:

$$\sum \left[\Big(GHG_{EMIS}(t-1) - GHG_{EMIS}(t) \Big) \times COST \times \frac{1}{(1-r)^{t-t_{start}}} \right]$$

Constraints are given which the model has to adhere to. First of all is the balancing constraint. The sum of all GHG emissions over each year from 2019 to 2050 should not exceed the allocated carbon budget, as exceeding the carbon budget results in over consumption of the fair share. This might lead to additional warming above the 2°C climate target. This is presented in the model as:

Balance constraint:

$$\sum GHG_{EMIS}(t) - Carbon\ Budget = 0 \quad \forall\, t$$

The second constraint are boundary conditions to the model, where (i) the year on year difference in GHG emissions should not be too excessive (V. Daioglou, personal communication, 8 September 2020) as this may disrupt the current business/function. Moreover, (ii) the yearly emissions have to be less or equal to that of the previous year, by assuming that implemented GHG emission reduction measures will only be scaled up, and not removed. These boundary conditions are adapted to construct the three scenarios. For the middle pathway the year or year difference in GHG emissions should not exceed 10%. Where for the delayed- and fast pathway they can change up to 30%. Additionally, for the delayed pathway, up to 2028 the GHG emissions remain equal and GHG emission reduction begins in 2029.

Capacity constraint:

$$GHG_{EMIS}(t) \leq GHG_{EMIS}LIN(t) \quad \forall\, t$$
$$GHG_{EMIS}(t) \leq GHG_{EMIS}(t-1) \quad \forall\, t$$

The third constraint introduces a non-negativity in yearly GHG emissions. It is assumed that a company is not able to provide negative emissions by their GHG emission reduction measures in mobility or built environment. Therefore negative GHG emissions are excluded.

Non-negativity constraint:

$$GHG_{EMIS}(t) \geq 0$$

The result of this program are three potential pathways (fast, middle and delayed) for GHG emission reduction for an individual company, additionally a policy pathway is added. An example for a company emitting 100tCO_2-eq is given in Figure 3.1. Each of those are an illustration of GHG emission reduction strategies. A company should not have to strictly follow one of these pathways, as long as they are matching or below the given yearly emissions budget their fair share in the carbon budget is not exceeded. Comparison between the pathways show that there are implications of the modelling differences, each of them has benefits and drawbacks. "The middle pathway" is a balance between GHG mitigation and costs. It ensures an almost linear reduction in GHG emissions up to approximately 2040. By this GHG emissions are reduced in a sufficient speed while costs are divided over multiple years. "The fast pathway" will reduce GHG emissions as soon as possible. This may result in higher overall costs as prices of GHG emission reduction measures tend to decrease over time as technology develops, however, if measures are cost effective this can lead to a decrease in costs. Simultaneously, by reducing GHG emissions immediately there is room for evaluating when the next GHG emission reduction measure will be implemented, as the allocated carbon budget is consumed slower. Additionally, when only considering the carbon budget, potentially less measures are required to still stay within the carbon budget. This gives more flexibility in the future for GHG emission mitigation. Lastly, "the delayed pathway" will postpone implementation of GHG emission reduction measures. However, at a given time, emissions have to be reduced to reach the committed targets of the Paris Agreement, in this case in 2028 emission reduction will begin. By delaying the GHG emission reduction there is no choice left when to implement measures, as quickly the carbon budget will be exceeded, showing a steep decline in GHG emissions over a period of about 10 years. Afterwards there is a period where the emissions will be steady up to 2050. By delaying GHG emission reduction, more drastic emission reductions are required to stay within the allocated carbon budget. Finally, one could follow the "policy Pathway" where each year to 2030 and later to 2050 a linear reduction of GHG emission reduction takes place (Figure 3.1). For 2030 there is a reduction target of 49% and 95% for 2050. However, when linearly reducing, this could lead to cumulative emissions which are greater than the carbon budget. Thus this is the only pathway exceeding the allocated carbon budget.

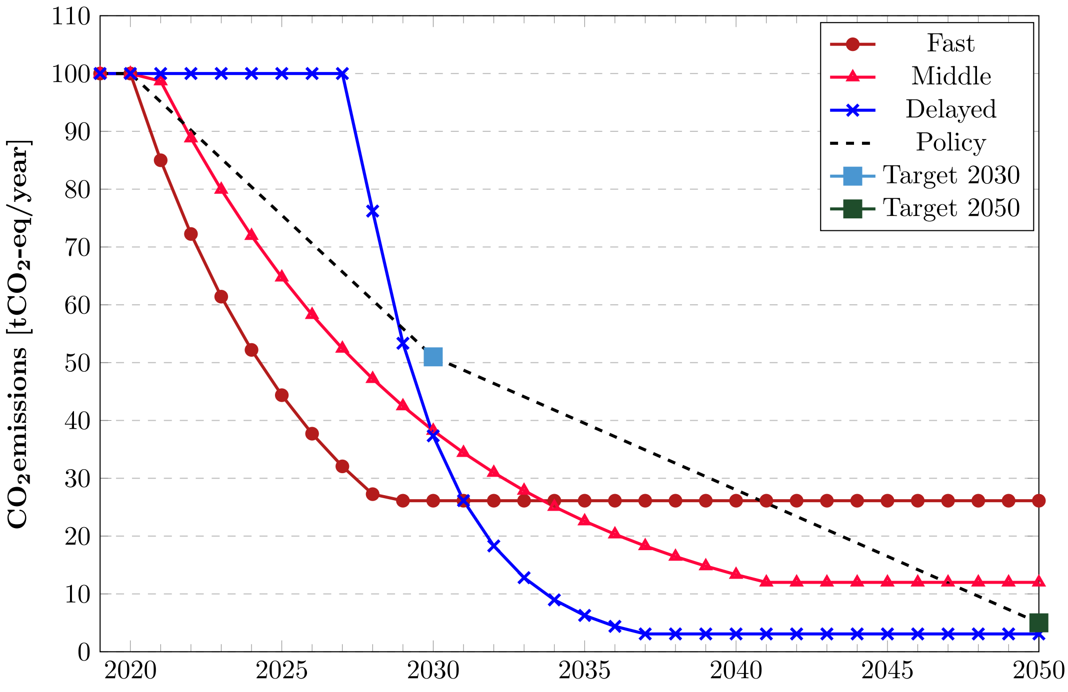

Figure 3.1: Four potential GHG mitigation pathways an individual company could follow, illustrated with a company that emitted 100 tCO_2-eq in 2019, consisting of: the fast pathway where immediately GHG emissions are reduced; the middle pathway which reduced GHG emissions year by year; the delayed pathway, which postponed GHG emission mitigation up to 2028; and the policy pathway, following the 49% and 95% reduction in 2030 and 2050 respectively. The area under the lines represent the actual carbon budget used. Note that the policy pathway area is larger compared to the other pathways.

3.3 Stepwise procedure to calculate a mitigation strategy of an individual company

The research is organised in five main steps. First, before being able to systematically reduce a companies' GHG emission, the current situation on GHG emissions is identified. Second, GHG emission reduction measures are identified, which include information on cost of GHG emission reduction and amount of GHG emission reduction potential. Data on these GHG emission reduction measures will be gathered and summarised into a overview. From this overview a MACC is constructed. Third, the MACC is used to select feasible GHG emission reduction measures. More information on the identified measures and is described in Chapter 4. Fourth, various pathways are defined which present potential trajectories of GHG emission mitigation. Allocation of the carbon budget is used to scale the defined pathway for an individual company. The selection of measures to follow one of these pathways depends on costs and GHG emission reduction potential, where the trade-off between costs and GHG emission reduction potential is important (Vogt-Schilb and Hallegatte, 2014b). Information will be based on scientific publications, reports, company specific data, semi-structured interviews and policy documents. Lastly, monitoring is of importance to provide insight on how company specific GHG emissions are changing over time. Periodically monitoring their GHG emissions is therefore required. Due to the time-frame of this research only the methodology of the monitoring will be described.

Additionally, an Excel based model will be constructed which has to provide guidance to a company by reducing GHG emissions from the built environment and mobility. This method has to prioritise GHG emission reduction measures based on costs, total GHG emission reduction potential, and allocated carbon budget. Moreover, it should include interaction between measures and emission reduction.

3.3.1 Step 1: Identification of the Carbon footprint

During the first step, the goal is to investigate the current activities of the company and the associated GHG emissions. An inventory is made which contains all activities and emission sources of the company. The inventory includes the types and amounts of fossil resources used. In combination with the emission factors (EF), which are the average emission rates of a given resource relative to that activity or process (Cheremisinoff, 2011), it allows to calculate the GHG emissions from activity data. Well-to-Wheel emission factors are used, thereby emissions in the production- as well as use phases are included . Moreover, the emission factors used are expressed in CO_2-eq. Examples of activities in a company are heating & cooling, electricity use, commuting travel, business flights, and the lease- & private car fleet. Multiplying the activity data with the emission factor, the total GHG emission from an activity can be calculated following Equation 3.1. The unit of activity and EF is dependent on the type of activity and their units (e.g. kilometres, tonne-kilometres, kilograms, Nm^3, kWh, or litre). The type and location of the activity determines where the calculated GHG emission should be allocated to scope 1, 2 or 3. Activity data is given over a certain timescale, therefore the sum of all these activities presents the total carbon footprint of a company over that timescale (e.g. one year). Data on activities carried out and fossil resources used will be gathered for the case studies. EFs will be used from the actual case study itself when available, otherwise they will be based on secondary data from `www.co2emissiefactoren.nl`.

$$Carbon\,Footprint_x = \sum Activity_y \times EF_y + Activity_z \times EF_z + ... \tag{3.1}$$

With:
CF = Carbon footprint in [tonne CO_2-eq]
Activity = Resources use by activity in [unit]
EF = Emission factor in [kgCO_2-eq/unit]

3.3.2 Step 2: Investigation of GHG reduction measures

In step 2, investigation of GHG reduction measures for activities in mobility and the built environment is carried out. Two types of reduction measures are identified: those which address activities within a company (behaviour), and those that address technological aspects (e.g. electric vehicles, PV panels and insulation). Identification of measures for mobility are based on the three conditions: travel behaviour change, zero-carbon fuels, and advanced vehicles technologies (section 1.2). For the built environment GHG emission reduction measures with a large reduction potential are shell retrofitting, including insulation, especially windows and walls, space heating systems and efficient lighting. Measures which are less expensive are efficient peripheries followed by ventilators and air-conditioners. Moreover, water heating equipment and lighting practices (such as a building management system) can help to reduce energy use (Ürge-Vorsatz et al., 2007). GHG emission reduction measures following these criteria are identified and analysed in this research. The goal is to construct a database with key-figures on GHG emission reduction measures with additional information on barriers and subsidies.

3.3.3 Step 3: Ranking of GHG mitigation measures using the Marginal Abatement Cost Curve

The third step is to prioritise GHG emission reduction measures for a company. For this a MACC is used, the MACC presents a ranking of GHG emission reduction measures based on their MAC. The reduction in GHG emissions could be a result from reduction in EF (i.e. renewable energy is used instead of fossil fuels) or activity (i.e. improvement in lightning efficiency). Data on GHG emission reduction measures are collected and presented in an overview, Chapter 4 will provide details on the GHG emission reduction measures. Additional information on the subsidies and potential barriers will be discussed in Chapter 4. There are several methods to calculate a marginal abatement cost (MAC). For the GHG emissions reduction measures a reference- and measure specific costs can be used to calculate their cost per tonne CO_2-eq (Equation 3.2), however if more specific data is available (e.g. company specific cost for an activity) these will be used. Based on the activities of a company, which are identified in the carbon footprint, applicable GHG reduction measures can be presented on the MACC.

$$MAC_i = \frac{Mitigation\,Costs_i}{Mitigation\,potential_i} = \frac{(Cost_{new,i} - Cost_{ref,i})}{(Activity_{ref,i} \times EF_{ref,i} - Activity_{new,i} \times EF_{new,i})} \tag{3.2}$$

With:
MAC = Marginal abatement cost in [€/tonne CO_2]
Mitigation Costs = Cost for a measure in [€]
Mitigation potential = CO_2 avoided for a measure in [tonne CO_2]
Ref. costs = Reference cost in [€]
Ref. emissions = Reference emissions in [tonne CO_2]

When GHG emission mitigation measures require investment costs and benefits are generated over the lifetime of a measures, the discount rate is introduced. The discount rate ensures that costs and benefits over different time periods are compared in today's value of money. The marginal abatement cost of a measure (MAC_i) is dependent on the net present value (NPV_i) and the GHG abatement potential of a measure ($Abatement_i$), following equation 3.3. The NPV of a measure is calculated by the discounted sum of all investment costs minus benefits for each year over the lifetime of a GHG reduction measure, with a private discount rate (r) of 7% (Eory et al., 2015). For each GHG emission reduction measures their maximum lifetime is used. This approach is similar to that of Eory et al. (2015).

$$MAC_i = \frac{NPV_i}{Abatement_{i,j}} \tag{3.3}$$

$$NPV_i = \sum_{j=0}^{n} \frac{(Cost_{i,j} - Benefit_{i,j})}{(1+r)^j} \quad (3.4)$$

Interaction between measures

Based on MAC and emission reduction potential a static MAC curve (or MACC) is constructed. This type of MACC is only applicable when measures are not overlapping in costs or emission reduction. Allowing for interactions between measures feedbacks have to be included which could affect mitigation costs but also mitigation potential. There could be measures that affect the mitigation potential of another measure, thus reducing their effectiveness. An example is the introduction of electric cars and increased uptake in public transport, in a situation where cars are substituted by public transport. The share of public transport grows while the share in car travel decreases. In turn the mitigation potential of the electric cars decreases, as there is less car travel in general. Meaning that when selecting both measures, the reduction in emissions is not the sum of the two, but their effect is a fraction of both. This should be taken into account to prevent double counting of GHG mitigation options and to assure that the calculated mitigation potential can actually be achieved. Next to the decrease in mitigation potential, the MAC could change. In this example the cost of the electric cars for a company could increase, as the company buys/leases less electric cars (decreasing economy of scale benefits). To enable for these feedbacks to occur, interaction between measures should be taken into account. Interactions based on costs are excluded as these are more complex, and require extensive modelling to precisely adjust for cost interactions between measures. Inclusion of interactions between measures is based on selection of the first (with the lowest MAC), where the other abatement potentials of all measures were modified according to the impact (Eory et al., 2015). Subsequently, for each of the measures (from lowest MAC to more expensive) interaction on other measures is determined. The interaction between measures are based on the effect on activity (such as commuted distance).

First, a MACC is presented which shows the maximum abatement potential for every single mitigation measure when it is the only measure implemented. Via semi-structured interviews with experts and policy makers in RHDHV NL on future emissions reduction plans, information on applicability and effectiveness for is gathered. Then GHG mitigation measures are identified and selected for the case study of RHDHV NL. Moreover, the theoretical maximum abatement potential is converted to the achievable abatement potential through these input parameters. These input parameters should be set by the user in the Excel based tool. This is translated into the inclusion or exclusion of measures, combined with a utilisation parameter. With this information a second MACC is constructed which accounts for the achievable potential and interaction between measures.

3.3.4 Step 4: Construction of company specific GHG reduction pathways

In the fourth step, reduction measures are projected on the four constructed pathways. With the information from the MACC, measures will be selected based on costs and mitigation potential. The main rule is that the constructed pathways should not exceed the allocated carbon budget as described in section 3.3.4. With this approach there are multiple potential pathways for companies to reduce their GHG emissions. In this research four predefined pathways are presented in section 3.2. Next to those pathways, the users of the tool are also able to edit and construct their own pathways.

Allocation of the global carbon budget to individual companies

Mid-term climate goals are very dependent on the long-term climate goals, as path dependency plays a large role in reduction in GHG emissions (discussed in Chapter 2). To construct a GHG emission pathway up to 2050, the carbon budget is used as proxy for the cumulative maximum GHG emissions over the period to 2050. To be able to use the carbon budget on a company level, requires allocating the global carbon budget to a company in the Netherlands. Allocation on company level is done by using the global carbon budget and converting this to a national level, whereafter a share of the national carbon budget is allocated to an individual company. An approach is used where all sectors have to reduce their GHG emission (intensity) by the same percentage. A drawback of this approach is that it neglects the relative GHG mitigation potential in sectors and specific companies. Some could have a lower limit in GHG emissions due to processes or activities (e.g. freight transport) (Krabbe, 2015). However, as the service sectors mostly comprises of smaller non-industrial companies, it is not considered an issue for this research.

$$National\ Carbon\ Budget_{country} = \sum_{t=0}^{t} \frac{Pop._{country,t}}{Pop._{world,t}} \times Global\ Carbon\ Budget \tag{3.5}$$

$$Carbon\ Budget\ Company_x = \frac{Carbon\ Footprint_x}{National\ Emissions_{country}} \times National\ Carbon\ Budget_{country} \tag{3.6}$$

First the national carbon budget is calculated based on the global carbon budget and the relative population share (Equation 3.5), following the concept immediate per capita convergence approach (section 2.3). Data on population trends are used from the United Nations World Population Prospects 2019 (United Nations Department of Economic and Social Affairs, 2019).

The calculated national carbon budget is used to determine the carbon budget for an individual company. Each company in a given year has a certain amount of GHG emissions, their share compared to the national GHG emissions is used to determine their carbon budget, as shown in equation 3.6. This results in a maximum cumulative GHG emission budget a company in the Netherlands is able to emit up to 2050. The allowed carbon budget is dependent on which data is used for allocation. In this research the most recent data, which is 2019, is used for company carbon footprint, population projections, and national emission.

3.3.5 Step 5: Company specific GHG emission monitoring

The last step is to monitor the actual GHG emission after implementation of GHG reduction measures. This requires a company to construct their carbon footprint periodically (e.g. each year). Essentially the method of carbon footprint identification is the same as in the first step. However, one should be aware of changes within the system (e.g. change of system boundaries). For example the inclusion or exclusion of activities could lead to increased or reduced in GHG emission compared to previous carbon footprints, while actually only the boundaries for GHG emission accounting changed. With the proper monitoring the GHG emissions can be compared to the trajectory modelled in the GHG reduction pathway. As the GHG reduction trajectory could differ from the GHG reduction pathway, it might require adaptation in the GHG mitigation strategy. Moreover, the monitoring will provide guidance in effectiveness of measures, time of implementation and amount of GHG emission reduction. This can be used to update the GHG reduction tool with specific data from experiences gained during other projects.

As indicated in the problem definition (section 1.3), a methodological tool is required to provide guidance to non-ETS companies, such as the service sector, in term of emission reduction in accordance with the Paris Agreement. By combining the steps described in the stepwise procedure a Excel based model is constructed (Figure 3.2).

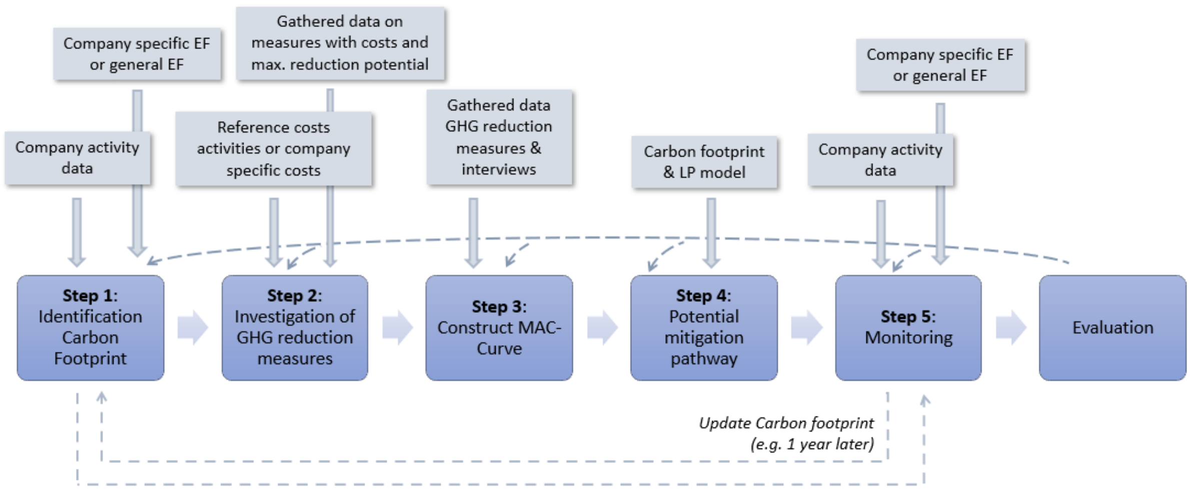

Figure 3.2: General process of the GHG reduction tool, with the steps taken in the GHG emissions reduction tool (blue boxes) and data sources (light grey boxes). Four steps will be carried out, whereafter evaluation takes place and feed back to the GHG reduction tool.

3.4 Case study - Royal HaskoningDHV NL

Royal HaskoningDHV is an international engineering project management consultancy firm. International projects focus on services in the field of aviation, buildings, energy, industry, infrastructure, maritime, mining, transport, urban and rural development and water. A case study is carried out for Royal HaskoningDHV situated in the Netherlands using the constructed approach.

3.5 Interviews

During this research semi-structured interviews are held within the organisation of RoyalHaskoningDHV. The aim is to gain an understanding of employees which are involved in business sustainability and GHG emissions reduction. This increases the understanding the audience which are going to be presented by the tool, and gains knowledge of the criteria and information needed for those decision makers to plan their GHG emission pathway. Moreover, during the semi-structured interviews, potential barriers for implementation of measures in mobility and the built environment are discussed.

3.6 Evaluation

After all the steps are carried out in the model there is an evaluation on each of the steps, as the overall GHG reduction tool can be expanded and improved iteratively. Results from the other case studies can be used to improve the input data, accessibility and output of the tool. As the GHG reduction tool will be used in various projects, more insight will be generated, and has to be translated back to the tool to maintain the required accuracy and provide the best possible recommendations for a company. The process of the GHG reduction tool is visualised in Figure 3.2, where after each cycle the process will be evaluated.

4. GHG emission reduction measures for the selected case study of Royal HaskoningDHV

GHG emission reduction measures were identified with the focus on company emissions from mobility and built environment. Two types of measures were identified: those which address activities within a company (behaviour), and those that address technological aspects (e.g. PV panels and insulation). Each measure is shortly described and when needed an analysis is conducted to calculate the MAC and emission factor.

4.1 Mobility

Generally, mobility has a large impact on the total carbon footprint of a company. In this category, emission reduction measures address business trips as well as commuting travel. For both categories, GHG emission reduction measures are proposed.

4.1.1 Business trips

Avoid order related flights

Aviation is an important source of emissions (EASA, EEA and EUROCONTROL, 2019), where especially short haul flights are the greatest emitters (Baumeister, 2017). Company flight travels can be related to business development and projects (order related), or internal meetings and conferences (not order related). In case of RHDHV NL, order related (OR) flights accounted for the largest share of total flights, being responsible for higher emissions in the carbon footprint compared to not order related (NOR) flights. A reduction in GHG emissions from OR flights could be achieved by reducing the need for these flights. However, for some companies or business lines, OR flights are necessary for their business.

A data analysis was carried out for RHDHV NL, using the information from the travel booking tool. In this booking tool, all flights for RHDHV Netherlands are recorded, including costs, estimates of CO_2-eq emissions, flight distance, departure- and arrival destination, flight routing, type of flight (OR/NOR). We found that 77% of all flight kilometres were order related. About 23% of all number of flights are shorter than 700 kilometres (Figure 4.1). From these short haul flights, one third travelled from Amsterdam to London or vice versa. Stimulating alternative modes of transport for these short haul flights is a good opportunity to reduce GHG emissions. About 13% of the flights travelled 700 to 1,300 kilometres. The remaining 64% of all flights were long-haul flights (>1,300 kilometres). In the total number of flights, 83% was related to three business lines within RHDHV NL. Furthermore, for OR flights, the average cost per kilometre was 0.08€ and average emissions were 0.16 $kgCO_2$-eq/km. This resulted in a MAC of -500€/tCO_2-eq for avoiding OR flights.

There are multiple GHG mitigation options for reducing order related air travel. In general, there are a few measures which promote the awareness of employees in regard to air travel. These measures are: an intern CO_2 emission tax on plane tickets, a company- or business line specific carbon budget on OR flights, and head of departments decide if the air travel is needed. Additionally, facilitating digital meetings would reduce the need for OR flights. A benefit of this is that time can be used more efficiently, and therefore potentially more meetings could take place. Lastly, the use of other, more sustainable, modes of transport can be promoted (especially for the short haul flights). As short haul flights have a hefty share in the total OR flights and may be the easiest to tackle.

Reduction in OR flights had a negative MAC, meaning that reduction in GHG emissions as well as costs were possible. However, there were some barriers identified during the semi-structured interviews. One of the key barriers is the habit and culture in a company which result lock-in in the current situation, as many employees are accustomed to travelling for business by plane. Additionally, the booking tool only offers air travel and not other modes of transport, making it harder for individuals to choose another mode of transport. Lastly, in terms of alternative modes of transport main criticisms were that the duration of travel is longer than by plane. Moreover, especially for the train tickets last minute booking is almost impossible as the train is already full, and comfort/ease of use is lacking. Booking in advance can be partly overcome, when tickets are booked timely for meetings that are already planned. Comfort and effectiveness during travel may even increase as e.g. trains have a longer time actual travelling instead of waiting time between travel modes.

Avoid not order related flights

Identically to the OR flights, the data from the booking tool was used for avoiding NOR flights. The remaining quarter (23%) of all flights were NOR flights. The total NOR CO_2 emissions had a similar share of about one fifth of the total CO_2 emissions. The share of short haul NOR flights ($\leq$700 kilometres) compared to the total NOR flights was 43% (Figure 4.1). About 9% of NOR flights were between 700 - 1,300 kilometres. The remaining half (48%) are flights longer than 1,300 kilometres. Also here the NOR flights are the highest in same business lines as for the OR flights. When combining OR and NOR flights, around 80% of the total number of flights was the result of these three business lines that which also accounted for 83% of total flight kilometres. This provided a focus on where the emissions were originating from the company. Furthermore, for NOR flights, the same costs and emissions applied as to the OR flights, and this resulted in a MAC of -500€/tCO_2-eq for avoiding OR flights.

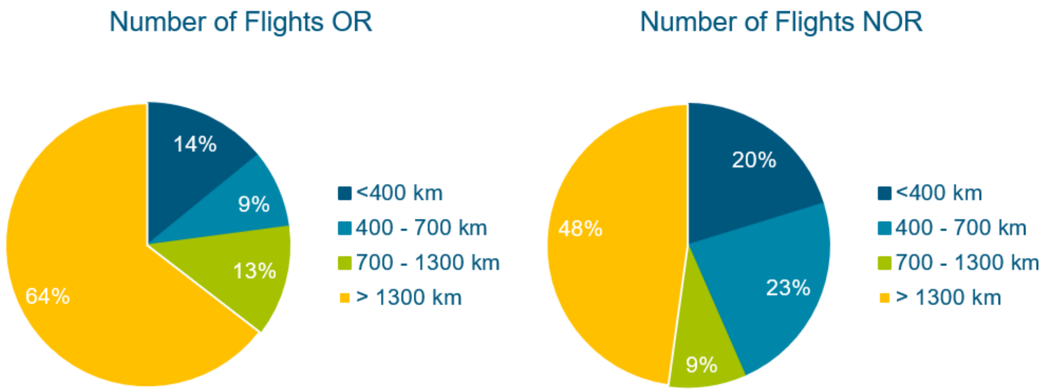

Figure 4.1: The number of order related (OR) and not order related (NOR) flights within Royal HaskoningDHV divided into short haul ($\leq$700 kilometres), medium haul (700 - 1300 kilometres) and long haul (>1300 kilometres).

To reduce NOR flights the same reduction measures and barriers as for the OR flights applied (see section 4.1.1). However, as NOR travel is not necessary for projects, there should also be discussed if this type of travel is needed.

Promote public transport - business trips

Next to reducing the need for business related travel, is to travel in a more sustainable manner. One potential measure is to reduce GHG emissions from business related trips from ICEVs by promoting the use of public transport. The average emission factor from the lease fleet of RHDHV NL was 0.235 kgCO_2-eq per vehicle kilometre (vkm), while EF by train was 0.006 kgCO_2-eq per passenger kilometre (pkm). Based on the kilometre shares of lease vehicles (25% private, 22% commuting travel) the total distance travelled for business was approximately four million kms. There was an average commuting allowance for business related travel of 0.27€/km, while costs for the train were 0.13€/km. The MAC for substituting business travel by lease vehicles to train transport, assuming same distance is travelled, was -600€/tCO_2-eq. Main barriers identified were the ease of use of other modes of transport (mainly cars). As business related trips by vehicles are not bound to specific location to get on- or off the train.

Electric company lease vehicles - business trips

Company owned vehicles which are used for business travel, such as lease vehicles, are allocated to scope 1 in the carbon footprint of a company. At the moment, 60% of the company lease fleet of RHDHV NL consists of electric vehicles (EVs). Further reduction in GHG emissions from lease vehicles can be achieved by electrification of the remaining company lease fleet, especially when this is combined with charging from RES.

Data from the carbon footprint and finances of RHDHV NL in 2019 was used to determine the emissions- and cost reduction potential. Based on the total business lease kilometres and EF the current CO_2 emissions were calculated. On average, a lease vehicle at RHDHV NL drives 15,000 kilometres per year. With a change in transport mode from internal combustion engine vehicles (ICEVs) to EVs, the EF is reduced. The EF of electric vehicles was 0,027 kgCO_2/km based on a electricity mix of 75% wind and 25% fossil resources, which RHDHV NL uses for their carbon footprint, based results of a pilot project. While the average EF of a lease ICEV at RHDHV NL was 0.235 kgCO_2-eq/km. Based on the car cost index from Leaseplan[2], total costs of ownership in corporate lease of an EV in the Netherlands was 10,500€/year and of an ICEV this was 9,400€/year (LeasePlan, 2019). This resulted in a MAC of 0€/tCO_2-eq.

Company lease vehicles are not directly in control of the company. This creates a barrier, because a company is leasing the vehicles from a lease company. Additionally, the lease contract is agreed on for a certain period, meaning that implementing changes during that period could be inconvenient. Next to this, for the lease company investments for electric vehicles are higher than the fossil counterparts, however total cost of owner ship (depreciation, maintenance, fuel) are lower. Moreover, not all lease vehicles can be run on an alternative fuel without losing their function. For example, for small freight vehicles which drive longer distances, it is more difficult to become more sustainable, as they are limited by the availability of alternative fuels (Hoen et al., 2009).

Electric rental vehicles

Lastly, a share of the scope 1 GHG emissions were attributed to rental vehicles. Potentially, rental vehicles could be EVs instead of ICEVs. In 2019, approximately 3.7 million kilometres were travelled by rental vehicles for RHDHV NL. A comparison between an ICEV and EV was made to determine the MAC. No specific data about rental vehicles was available, therefore in this study, two similar rental vehicles are compared from Europcar. Assumed is that all vehicles are only rented for one day at a time. Additionally, on average an rental vehicles travels 200 kilometres per day, with 100 kilometres included in the rental costs, the remaining 100 kilometres cost 0.17€ (ICEV) and 0.21€ (EV) per kilometre (Europcar, 2020). This resulted in an average cost per kilometre of 0.61€ and 0.98€ for the ICEV and EV respectively. Based on the emission factor for a ICEV of 0.220 kgCO_2-eq/km and EV of 0.027kgCO_2-eq/km, the MAC was approximately 1,200€/tCO_2-eq.

A barrier is that there is a lack of alternative rental companies that provide more sustainable modes of road transport. One of the most prominent reasons is that EVs are not rented out sufficiently, therefore it is quite expensive for a rental company to own these vehicles compared to their traditional ICEVs.

[2]Based on: average of all costs over the first three years, with 20,000 kilometres driven per year.

Table 4.1: Measures to reduce GHG emissions for business travel

Mobility - Business trips	
Measures	MAC [€/tCO_2-eq]
Reduce Order Related (OR) flights	-500
Reduce Not Order Related (NOR) flights	-500
Promote public transport - business trips	-600
Electric lease cars	0
Rental cars	1200

4.1.2 Commuting travel

Promote working from home

One of the key measures to reduce energy consumption and GHG emissions, is to enable employees to work from home. However, a good balance between working from home and at the office has to be established. The impact of working from home, compared to working in an office, depends on various factors: (a) type of organisation, (b) type of work, (c) location of employees and workplace, (d) commuting distance, (e) travel modes for commuting, (f) home environment, and (g) weather (seasonal differences). It was also shown that productivity increases when working from home (Swift and Stephens, 2014), therefore working from home can be more directed at tasks where focus and concentration is required, where days at the office can be used for social interactions.

Working from home impacts the commuting distance, by limiting the number of days that require commuting travel. This in turn saves energy as well as GHG emissions for these commutes. A rebound effect of working from home is the additional need for energy (e.g. lighting, charging and heating) at the dwellings. The trade-off between commuting to the office with the respective GHG emissions and working from home was therefore analysed. Most prominent in the energy demand when working from home was the heating behaviour, while increase in electricity consumption is negligible (Swift and Stephens, 2014). The increase in heat consumption at the dwellings depended on whether the house is occupied normally during the working hours, if rooms or the whole house needs to be heated, and the efficiency of the heating equipment as well as insulation grade (Swift and Stephens, 2014). Effects on the energy use for the companies office(s) were excluded, these may add additional energy savings.

The energy use for a general household was calculated based on two archetypes, in this research “medium sized dwelling built before 1992” and “medium sized dwelling built after 1992” were distinguished. The natural gas usage was 1.510 m^3 and 1.170 m^3 respectively (CBS, 2020). For both these archetypes the average daily natural gas usage was used. With the increase in working from home, there was an increase in time the dwelling is occupied. Based on the interviews at RHDHV NL, it was deemed achievable that employees could work from home for an average of 1.5 days per week. This resulted in 4 hours longer heating per working day at home (Swift and Stephens, 2014), leading to an increase of 12% in natural gas usage. On average, the CO_2 emission increase was 73 $kgCO_2$/year and 57 $kgCO_2$/year for the pre-1992 dwellings and dwellings after 1992 respectively.

The current situation in GHG emissions and costs were illustrated using the data from RHDHV NL from 2019. Only commuting travel is accounted for, all business related road travel is excluded (which are the commutes by lease- and private- car as well as public transport). These emission sources combined, emitted a total 3,100 tCO_2-eq in 2019. The costs for commuting travel in 2019 were approximately 3M€. With the introduction of working from home these emissions as well as costs could potentially be decreased. In general, the introduction of 1.5 days per week working at home reduced the commuting distances over the three categories. The reduction in GHG emissions were 935 tCO_2-eq per year for RHDHV NL. This resulted in an average reduction in emission of 310 $kgCO_2$-eq/year per employee.

Resulting in a MAC of -400€/tCO_2-eq. Here, employees that already travelled by public transport reduced less emissions and costs.

Cost reduction for less commuting travel were equal to the decrease in public transport and kilometre allowance. Using an average of 1.5 days working from home per week, resulted in yearly reductions of 900k€. Office supplies are needed to enable employees to work from home. Investment for these supplies were required, estimated at 850€/employee (interview RHDHV NL). Assumed is that all employees required office supplies at home. The total investment for the office supplies were therefore 2.5M€. A possibility is to invest in secondhand office supplies increasing the circularity and reducing investment costs. Estimated was that these supplies cost approximately 400€/employee, resulting in a total investment of 925k€.

One of the main barriers was the inability of working from home due to insufficient office supplies. Another was the social barrier and the fear that working from home may result in isolation (Swift and Stephens, 2014) and missing interaction with colleagues. Additionally, there were company policies in place which might prohibit working from home, or some professions are not able to work from home. Therefore, some form of investigation of the company is necessary to determine the potential of working from home. Lastly, working from home might interfere with existing policies about lease vehicles (which require a minimum travel distance per year), and how these should be adapted. To overcome the first barrier, a company should provide the office supplies to their employees. It is shown that this might be even financially beneficial for a company to invest in office supplies to enable employees to work from home. Moreover, there should be a good balance in homeworking and being at the office to prevent the isolation of employees to happen. One example is by scheduled regular meeting to socialise to help prevent isolation.

A study by Walls and Safirova (2004) reported that reduction in commuting travel for an employee also results in significant trip reduction for daily trips. Moreover, in the future companies could choose to reduce office space, as less people will be present at the office at the same time. Reducing the office space not only decreases energy use and GHG emissions, but can also reduce costs on energy use as well as on lease costs.

Promote public transport - commuting

Identical as to promoting public transport for business trips, commuting by public transport greatly reduces the GHG emissions. The average emissions from the private vehicles were 0.22 kgCO_2-eq/vkm, while the emission factor of the train was 0.006 kgCO_2-eq/pkm. In total approximately 12 million kilometres were commuted in 2019, with an average kilometre allowance of 0.19€/km for commuting travel by private vehicle and 0.13€/km for the train. The MAC of promoting public transport compared to private vehicles was -280€/kgCO_2-eq.

Electric company lease vehicles - commuting

A fraction of the total distance covered by lease vehicles is used for commuting travel. For RHDHV NL this was approximately 25% of total lease vehicles kilometres in 2019. In the approach, it was assumed that when electric lease vehicles were implemented for business trips, the same relative share is applied to commuting travel. Overall, the MAC of the electric company lease vehicles were similar to that of the business trips, at 0€/tCO_2-eq.

Electric private lease vehicles

Commuting travel by private vehicles caused a significant portion of the overall carbon footprint in case of RHDHV NL. Reduction could be achieved by promoting the uptake of EV by providing benefits for adopting an EV instead of a new ICEV. Similar to the electrification of company lease vehicles, the private lease vehicles can reduce GHG emissions for a individual company in scope 3.

Data from the carbon footprint and finances of RHDHV NL in 2019 were used to determine the emissions- and cost reduction potential. Based on the total commuting kilometres by private vehicles and EF of 0.235 $kgCO_2$-eq/km, the current GHG emissions were calculated. The EF of electric vehicles was assumed at 0,027 $kgCO_2$-eq/vkm (electricity mix of 75% wind and 25% fossil resources). Costs for a private lease EV were generally higher than for their fossil counterpart. Lease costs for an EV were assumed at 429€/month (ANWB, 2020), while the ICEV lease costs were 294€/month. Both are for a lease period of 60 months, with 15.000 allowed kilometres. With the average fuel consumption of 24 km/l and 6 km/kWh, the average cost per kilometre was 0.07€/km and 0.06€/km respectively for ICEV and EV. Total monthly costs for ICEV were 380€ and 415€[3] for EV. To promote the uptake of private EVs, a company could choose to give a benefit to employees. In this example, on top of the kilometre allowances, the cost-gap between the two lease vehicles could be provided by the company at 35€ per month. With this, the company would be able to reduce the scope 3 emissions from commuting travel by private vehicles at a MAC of 80€/tCO_2-eq.

An additional benefit to this GHG emission reduction measure is that employees travelling privately also reduce their footprint. Results in a pilot carried by RHDHV NL showed that up to 25% of driven kilometres in lease vehicles were actually not work-related. Assumed is that the same applies for private vehicles, resulting in a reduction of GHG emissions outside company boundaries.

Barriers for implementation of this measure were the range of an electric vehicle, which is still limited compared to ICEVs. Generally, employees could be more reserved, as they are dependent on their lease vehicles. Moreover, a balanced subsidy should be provided by the company, as owning EVs could become much cheaper than leasing a new ICEV. And therefore, other initiatives such as promoting public transport or going by bicycle would become less interesting. Lastly, company policy is not suited for this measure, which would require revisiting company policies.

Table 4.2: Measures to reduce GHG emissions for mobility

Mobility - Commuting travel	
Measures	MAC [€/tCO_2-eq]
Promote working from home	-400
Promote public transport	-280
Electric company lease vehicles - commuting	0
Electric private lease vehicles	80

4.2 Built environment

Energy use in the service sector is predominantly from space heating and lighting. Other functions, such as ICT, hot tap water, and cooling & ventilation are the smaller contributors. The energy sources of these functions are mainly from natural gas and electricity (RVO, 2018). A study conducted by Ürge-Vorsatz et al. (2007) presented that in developing countries GHG emission mitigation measures with a large potential are shell retrofitting, including insulation, especially windows and walls, space heating systems and efficient lighting. Therefore, these types of GHG emission reduction measures were identified and analysed in this research. The GHG emission reduction measures were categorised in reducing heating load, reducing cooling load, and electricity supply. In total 14 measures are described. Data for the identified measures in the built environment was used from internal sources at RHDHV NL. For the calculation of the MACs a lifetime of 25 years with a discount rate of 7% was applied, when no additional information is provided.

[3]Subsidy for EV is included, which were a maximum of 5.000€ over a period of 48 months, thus 83€/month reduction in costs.

4.2.1 Heating demand

Measures identified for reduction in heating load were insulation, window thermal insulation, and heat pumps. An overview of the measures and MACs is presented in Table 4.3.

Insulation

Insulation ensures that heat transfer between the inner- and outer part of the building is reduced. Following the laws of thermodynamics heat flows from a higher temperature to a lower temperature. When the outside temperature is different from inside, energy will be transferred. The higher the insulation grade, the harder it becomes for heat to transfer between the two spaces. During the winter good insulation prevents heat from getting out, while in summer it prevents heat coming in. In essence: reducing the heating load but also the cooling load. However, it is possible to overinsulate a building, by this during warmer periods heat is trapped inside the building and therefore cooling loads increase (Li et al., 2013). Insulation can be applied in various places and forms in a building, such as wall insulation, roof insulation, floor insulation and window insulation.

The costs and energy savings potential of a buildings by increasing the insulation grade, depends on the current status of a building. For this research key figures provided by RHDHV NL were used, these key figures were determined and fine-tuned by experts over various projects carried out by the organisation. The key figures exclude co-benefits such as increased thermal comfort or noise reduction. In previous research, it is even suggested that co-benefits are just as important as the costs by energy savings (Ürge-Vorsatz et al., 2007). Assumptions had to be made to calculate these MACs: a wall to floor ratio of 60% was used, and a window to wall ratio of 10%. Based on the key figures for each measure and activity data of RHDHV NL, a MAC was calculated using the method described in Chapter 3, with a private discount rate of 7% and a service life of 35 years (Kono et al., 2016). Average costs for natural gas in the Netherlands were 0.283€/Nm^3 (Eurostat, 2020). Costs for roof insulation were 140€/m^2 and the energy savings were 230 MJ/m^2yr^{-1} roof (Rc=1 to Rc=6), resulting in a MAC of 300€/tCO_2-eq. Costs for wall cavity insulation were 20€/m^2 and the energy savings were 430MJ/m^2yr^{-1} facade (Rc=0.4 to Rc=2.5), resulting in a MAC of -20€/tCO_2-eq. Costs for floor insulation were 180€/m^2 and the energy savings were 230MJ/m^2yr^{-1} floor, resulting in a MAC of 400€/tCO_2-eq.

Windows thermal insulation

Heat transfer through the windows can be a dominant part of energy losses in a building. Increasing the window thermal insulation will reduce the amount of heat transfer, same as for normal insulation. The largest effect in reducing heat losses is to replace the current windows with less conductive ones, in some cases it may be beneficial to also replace the window frames. This increased air tightness and reduces the heat losses through the window frames.

Various forms of increased window thermal insulation exist. Costs and energy reduction potential varies between them. In this research three types were distinguished: first, replacing the current single glazing to high efficient windows (HR++) at a cost of 180€/m^2 and saving about 970 MJ/m^2yr^{-1}, the MAC was 80€/tCO_2. Second, is replacing double glazing to HR++ costing 165€/m^2 and saving up to 390 MJ/m^2yr^{-1}, the MAC was 280€/tCO_2. The third option is to replace the glazing and the window frames by wood, costing 430€/m^2 with energy saving up to 970 MJ/m^2yr^{-1}, the MAC was 300€/tCO_2.

The two types of insulation measures introduced are considered as reducing heating load. Therefore, the energy savings were only attributed to a reduction in natural gas usage, while also cooling load will be reduced. However this impact is expected to be minimal (Li et al., 2013).

Heat pump

An alternative source for heating could be a heat pump, which provide heat by electricity. A heat pump can use the temperature difference between two heat sources and add electricity to increase the lower grade heat to a higher grade. A high temperature (HT) heat pump costs approximately 700€/kW and energy savings are 4,800 MJ/kW^{2}yr^{-1}. However, uses 225 kWh/kW/year. Investment costs are determined based on required installed capacity of the heat pump. Based on a average dwelling which uses 1,200 m^3 natural gas per year, requiring a 7.5 kW heat pump. This is scaled according to the total heat demand of a company. Moreover, the cost benefits were determined from the savings in gas compared to electricity consumption, based on the average load over one year. The MAC for a HT heatpump was approximately 160€/tCO_2-eq.

Table 4.3: Identified measures to reduce heating load

Reduce heating loads	
Measures	MAC [€/tCO_2-eq]
Insulation Roof	300
Insulation Wall	-20
Insulation Floor	400
Windows thermal insulation - HR++	180
Windows thermal insulation - Double HR++	280
Windows thermal insulation - Glazing & frames	430
Heat pump - High temperature	160

4.2.2 Electricity demand

The following measures are predominantly to reduce the cooling load in a building. By reducing the cooling load, energy is saved in form of electricity. This results in less electricity used, thus saving costs and potentially CO_2 emissions (when "grey" electricity is used). An overview of the measures and MACs are presented in Table 4.4.

External & internal shading

During warmer periods, the sun will provide a lot of heat by radiation. To reduce the cooling load in a building, shading the windows could provide cover from this heat. This can be done by attaching external- or internal shutters on windows. Costs for external shutters were 320€/m^2 and energy savings were 25 kWh/m^2 per year. Costs for inside shutters were 200€/m^2 and energy savings were 20 kWh/m2 window area per year. This resulted in MACs of 160 €/tCO_2-eq and 80€/tCO_2-eq respectively.

Night-time ventilation

Night-time ventilation during warmer periods, such as summer, can be used to built thermal mass in a building by using the cooler air during the night. This cooler air mass will heat up slowly during the day, where at a certain point the temperatures reaches its limit and the cooling system will provide additional cooling. However, by using the energy stored in the cool air, less electricity is needed for cooling. In turn reducing costs and GHG emissions. Costs for this were 1.20€/m^2 floor area and energy saving potential is 3 kWh/m^2 floor area, resulting in a MAC of -130 €/tCO_2-eq.

LED lighting

Currently the LED lighting provides a good quality light source which is very efficient. Replacing fluorescent and incandescence lamps will decrease energy use significantly. Costs for LED armatures were 35 €/m^2 and energy savings were 50 kWh/m^2/year compared to TL-lighting. The MAC for this measure was -90€/tCO_2. Additional effects of LED lighting were not included in this research. However, efficient lighting not only reduces the electricity usage, but also decreases the generated heat by the lighting sources. As the lights are more efficient, more electricity is used to provide luminance and less electricity is converted to heat. During the warmer period this will reduce the need for cooling. However, during cooler period this will increase the need for heating (Li et al., 2013). Although heating from the heating source is more efficient that heating as byproduct from the light source.

Automatic lighting

Lighting can be controlled manually or at building level or automatically. Potentially electricity can be reduced when lighting is controlled automatically based on motion sensors or timers. Costs were 2.50€/m^2 and energy savings were 6 kWh/m^2yr^{-1}. At maximum electricity reduction, the MAC was -130€/tCO_2.

Table 4.4: Identified measures to lower electricity consumption

Lower electricity consumption	
Measures	MAC [€/tCO_2-eq]
External shading	160
Internal shading	80
Night-time ventilation	-130
LED lighting	-90
Automatic lighting	-130

4.2.3 Electricity supply

Measures identified for more sustainable electricity supply were purchasing of guarantee of origins and photovoltaics. An overview of the measures and MACs are presented in Table 4.4.

Guarantee of Origin

One of the most cost effective ways to reduce GHG emissions in a company is to purchase Guarantees of Origin (GoO). A GoO ensures that the electricity is from a specific energy source. For electricity mainly the renewable energy sources are issued. By purchasing GoO's the final consumer can be traced back to the supplier. This ensures that the consumers purchasing GoO's for their electricity use the emissions factor is zero. By purchasing GoO's one is stimulating the market and investments in the renewable energy resources. However, GoO's are more expensive than the regular "grey" electricity. Therefore, a premium on top of the electricity price has to be payed. The price of a GoO depends on the supply and demand. Additionally, the source of the renewable energy plays a role, as consumers are more willing to pay for local renewable energy production. Costs were assumed at €2.50/MWh (CE Delft, 2016) and GHG emission savings for the company were 0.263 $kgCO_2$-eq/kWh. Assuming that electricity usage remains the same, the MAC for this measure was 5€$\hat{C}O_2$.

Photovoltaics

Another way to generate renewable electricity is by photovoltaics (PV), these could be building attached (placed on the roof or attached to the facade). Generally, attaching PV panels to roofs and other constructions (e.g. carports) is a common business practice. By local electricity generation the preferred method of electricity consumption is by self consumption (use the electricity immediately in the building). When more electricity is generated than consumed, electricity will be sent back to the electricity grid resulting a decrease in the total electricity costs. However, in most cases the cost for electricity is higher than the profits of sending it back to the grid. In term of GHG emission savings, direct consumption results in a emission factor of zero for that company, while electricity from the grid (when GoO's are not purchased) has a higher EF.

Costs for PV panels depend on the quality and power of a specific panel. Currently 320kWp (kiloWatt-peak) is a panel that costs about 215€/m^2 and generated 168 kWh/m^2yr^{-1} electricity. Here, a correct placement (where most of the sunlight is directed at the PV panel in an angle of around 35 degrees) in the Netherlands is assumed. The amount of GHG emission reduction and cost savings depend on the rate of self consumption. As grid electricity may not be at an emission factor of zero and costs for grid electricity are most likely higher than net metering from the PV panels. For this research the self consumption rate was assumed to be 100%, resulting in a MAC of 0€/tCO_2-eq.

Table 4.5: Identified measures for renewable electricity supply

Renewable energy resources	
Measures	MAC [€/tCO_2-eq]
GoO purchased	0
Photovoltaics	0

5. Results of the Royal HaskoningDHV case study

5.1 Identified carbon footprint

An overview of the total annual GHG emissions of Royal HaskoningDHV is given in figure 5.1, and data over 2019 was used. In total, RHDHV NL emissions from scope 1,2 and 3 accounted for 13,188 tCO_2-eq over 2019. In scope 1, the emissions were the result of business lease vehicles, rental vehicles and space heating by natural gas. Scope 1 accounted for 2,270 tCO_2-eq emissions (17% of total GHG emissions). Scope 2 GHG emissions originated from purchased electricity and heat. In total 5,200 MWh electricity was used, however due to the purchased GoO's, zero emissions were accounted for. Potentially, when grey electricity was used, the emissions by electricity were 1,372 tCO_2-eq. The purchased heat resulted in 133 tCO_2-eq emissions (1%). In scope 3, the GHG emissions arose from commuting travel by private- and lease vehicles, business flights (OR/NOR), public transport (commuting and business related), and paper usage. These activities resulted in 10,875 tCO_2-eq emitted in scope 3 (82%). Herein, half of the scope 3 emissions resulted from business flights, and another 45% was related to commuting travel by private vehicles.

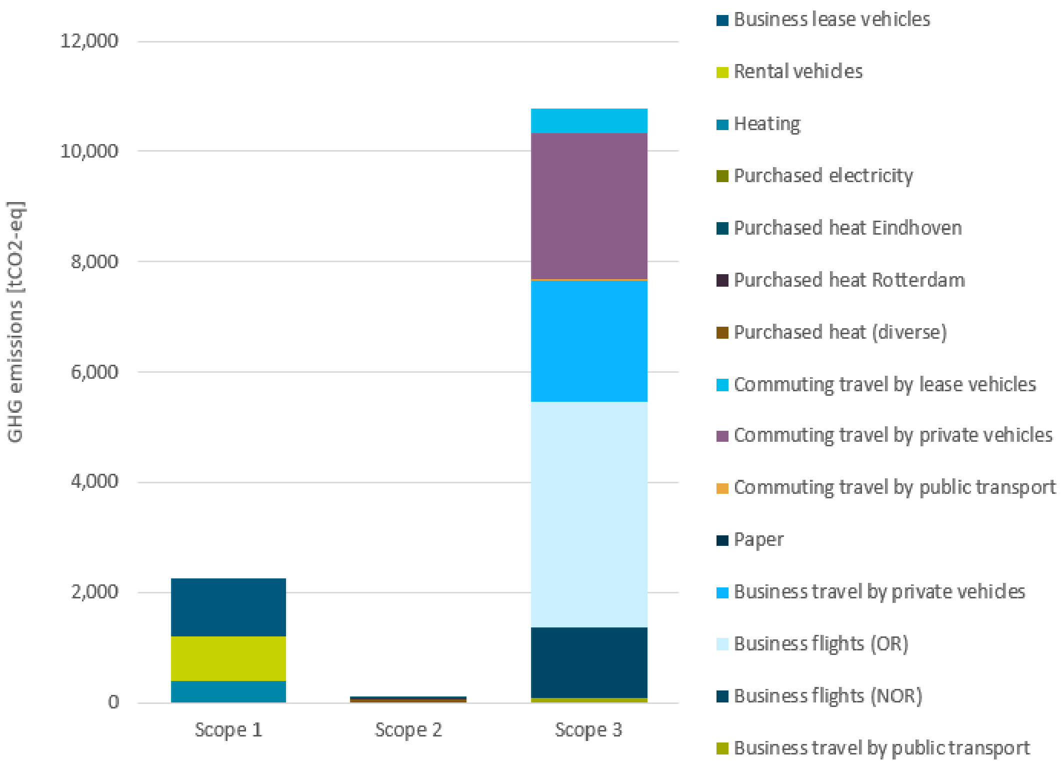

Figure 5.1: Carbon footprint of Royal HaskoningDHV NL in 2019, categorised in scope 1, 2 and 3 following the GHG protocol.

5.2 Theoretical and achievable MACC

All of the GHG mitigation measures identified in this research are presented in Chapter 4. Conform the most promising mitigation options (section 3.3.2), in total 22 measures were identified. All measures are rough estimations of MACs based on cost and emission reduction data, combined with assumptions. Therefore, the MACs were rounded to their nearest ten, and mitigation potential to their nearest hundred. First, the MACC with all the abatement options and their maximum abatement potential of each individual measure is given (Figure 5.2).

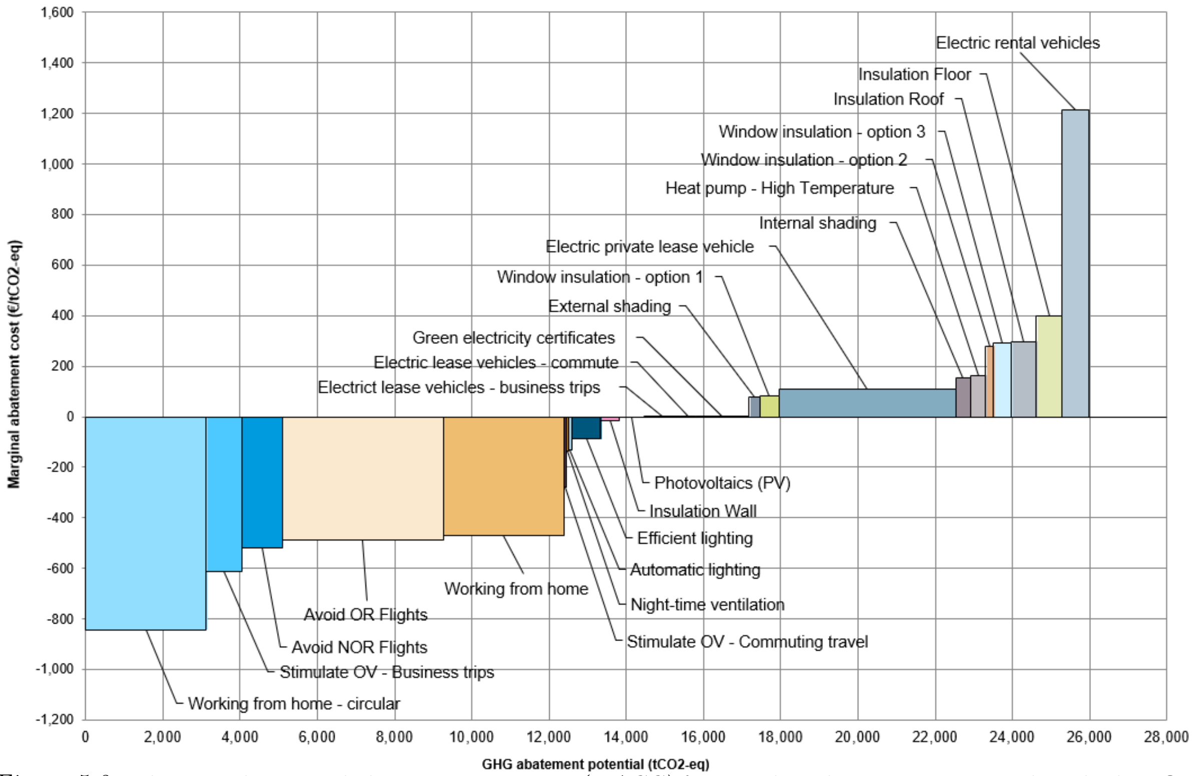

Figure 5.2: Theoretical marginal abatement cost curve (MACC) for Royal HaskoningDHV NL with each identified measure presenting its maximum abatement potential. Note that marginal abatement costs are rounded to their nearest ten and GHG abatement potential to the nearest hundred.

A second MACC was constructed which accounts for the achievable potential allowing interaction between measures to occur (Figure 5.3). Assumptions on the achievable potential of mitigation measures were based on the interviews. The results showed that most GHG mitigation measures in mobility have negative MACs, this is due to types of measures. Especially for reduction in business flights, no investments are needed - reduction in GHG emissions go hand-in-hand with a reduction in costs. Excluded from this analysis were the co-benefits and hidden costs. Measures that required upfront investments (e.g. insulation or a heat pump) could result in positive MACs. However, when annual benefits over the lifetime were larger than the investment, this resulted in a negative MAC. In mobility only the electric rental vehicles had a positive MAC. This is caused by increased costs for rental with no additional financial benefits. The MACs for the measures in the built environment were generally the opposite to those in mobility. Larger upfront investments were required to install the measures, where over time the fossil resource usage is reduced, resulting in mitigated GHG emissions and costs. When cumulative discounted cost benefits over the lifetime of a measures is greater than the initial investment (a negative MAC is associated with this), the measures were financially attractive to utilise. For the built environment only the efficient electric lighting, automatic lighting, and cavity wall insulation had negative MACs. Although, in some cases, it may be necessary to implement more expensive measures to stay in line with the mitigation pathway. In the remainder of this section the selected measures and assumptions for this case study are presented, divided into their respective scope.

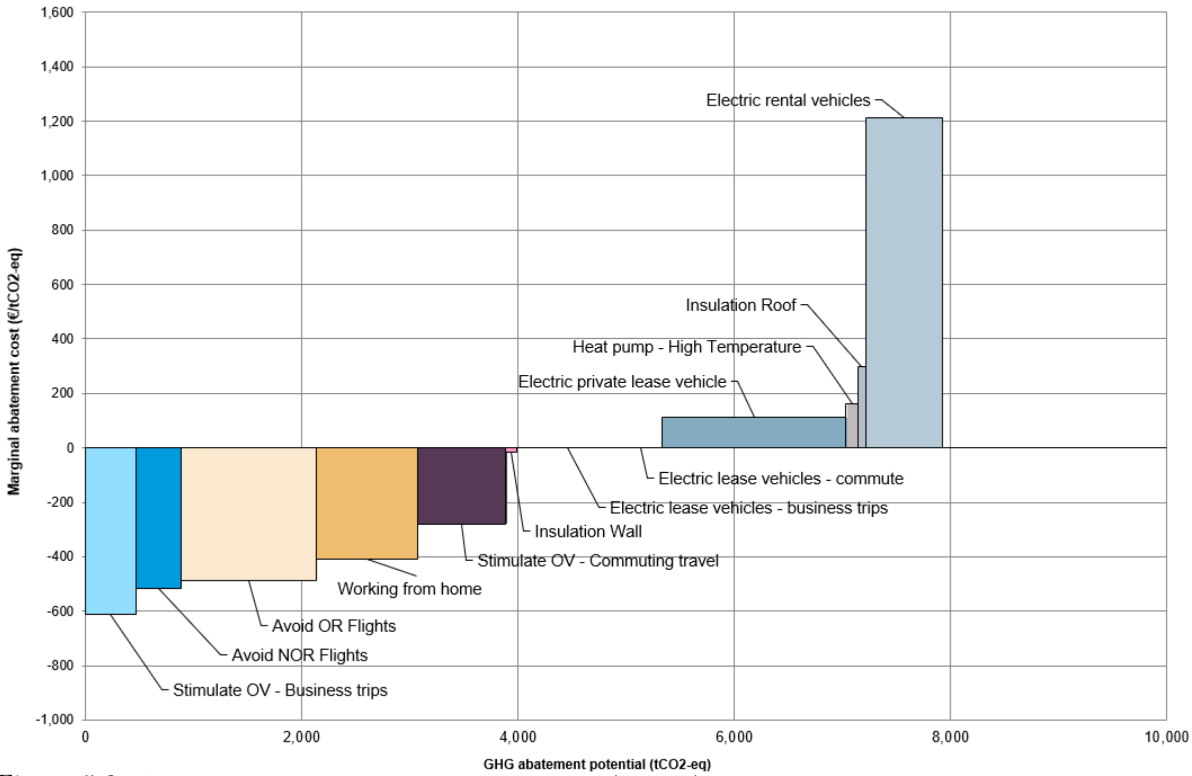

Figure 5.3: Achievable marginal abatement cost curve (MACC) for Royal HaskoningDHV NL with identified measure. Note that marginal abatement costs are rounded to their nearest ten and GHG abatement potential to the nearest hundred.

In scope 1, GHG emissions from company lease vehicles can be reduced with the measure *electric company lease vehicles*. It was assumed that 100% electrification of the lease vehicles can be obtained, however it requires time to achieve a switch of all lease vehicles to be electric. At a MAC of -35€/tCO_2, the current GHG emissions from lease vehicles can be reduced up to 994 tCO_2-eq. This is just over 8% of total GHG emissions of RHDHV NL. Emission reduction by rental cars was also achieved by usage of *rental EVs*. Potentially all rental cars can be EVs, saving 717 tCO_2-eq annually. Lastly, heating was attributed to scope 1 by natural gas burning, and also to scope 2 by purchased heat outside the company. Reduction in heating demand could arise from multiple measures, *insulation* (roof/wall/floor), and *thermal insulation of windows*. Furthermore, the insulation grade the achievable potential for insulation (roof/wall/floor) was 20% and 30% for the windows relative to the theoretical potential. Moreover, assumed was that *heat pumps* could provide heating for the office of RHDHV NL in Amersfoort, which accounted for 40% of total natural gas consumed in 2019. The impact on GHG emission reduction by heat reducing measures was limited, as the share in GHG emissions by heating is about 4% of the total carbon footprint in 2019. In scope 2, purchased electricity could have GHG emissions. However, as RHDHV NL already purchases GoO's for their electricity consumption, the achievable reduction potential was excluded. GHG emissions in scope 3 were dominantly the result of mobility related activities. For *OR flights* a reduction of 30% was potentially achievable. For the *NOR flights* this was assumed to be 40%. Commuting travel was the main emission source of the private vehicles, accounting for one fifth of the total CO_2-eq emissions in

2019. Additionally business travel was partly carried out in private vehicles, these two combined resulted in 37% of total CO_2-eq emissions. It was assumed that all commutes are going to be travelled by EVs. This resulted in an GHG reduction of 2,508 tCO_2-eq in private vehicles commuting travel. Over the total carbon footprint of RHDHV NL this saved 19% in CO_2-eq emissions. Next to commuting travel, private cars are also used for business travel. Thus CO_2 emission reduction also takes place for road business travel by vehicles. This resulted in an extra reduction of 14% GHG emission compared to total emissions of RHDHV NL. Lastly, increase in the use of *public transport* reduced GHG emissions in scope 3, as the EF of public transport is significantly lower compared to ICE vehicles. Assumed was that uptake in public transport could reach up to 50% of total commuting travel, reducing the total GHG emissions in scope 3 by 1,300 tCO_2-eq.

Table 5.1: Selected measures for the achievable MACC for the case study of RHDHV NL.

Measure	Assumption	Share of total carbon footprint
Scope 1		
Company electric lease vehicles	100%	8%
Electric rental vehicles	100%	6%
Wall insulation	20%	< 1%
Roof insulation	10%	< 1%
Floor insulation	10%	< 1%
Window insulation	30%	< 1%
Scope 2		
-	-%	-%
Scope 3		
Reduce OR flights	30%	9%
Reduce NOR flights	40%	3%
Electric private lease vehicles	100%	39%
Working from home	30%	7%
Promote public transport	50%	14%

5.3 Potential greenhouse gas mitigation pathways

Each emission scope could potentially utilise one of four pathways. The combination of the pathways for each of the scopes combined presents the overall company specific pathway. The results of the combined pathway are presented the following section, whilst the results per scope are presented in the appendix (Chapter 8). In the presented results all emission scopes were addressed following the same pathway.

5.3.1 Pathways for scope 1,2 and 3

According to their carbon footprint, total GHG emissions from RHDHV NL was 13,188 tCO_2-eq in 2019. With the constructed pathways (section 3.2) these emissions are scaled over time to limit global warming to the 2°C emission reduction target. The cumulative carbon budget over all three scopes of RHDHV NL was 152,000 tCO_2-eq.

In the following section various graphs for the mitigation pathways are presented. The layout of these graphs follows the same approach. Here, the blue line and the grey bars represent the level of GHG emissions in a given year. The dashed red line represents the actual emission level after implementation of measures in that year. The yellow bars between the blue- and dashed red line represent unidentified measures, which are required to achieve the reduction potential of the pathway. Bars above the dashed red line represent implemented measures (each measure is indicated by a different color), and a larger bar represents a larger GHG mitigation potential. The green area behind the bars represents the remaining positive carbon budget in each given year, where the red area presents the exceeded allocated carbon budget.

The **fast pathway** (Figure 5.4) showed, due to the limited abatement potential in scope 2, that already in 2021 the carbon budget is exceeded. Up to 2025, the emission reduction potential of the measures is almost sufficient in line with the achievable emission level. GHG abatement potential in scope 1 is sufficient to stay in line with the projected fast pathway. From 2025 and onward, scope 3 abatement potential becomes limited, and GHG emission reduction is insufficient to follow the predefined pathway. The impact of limited abatement potential in scope 3 is far larger than in scope 2. In general, the most cost effective measure is implemented first. At the moment where additional GHG emission reduction is required the measure is scaled up, or when the maximum achievable potential is reached, another measure is implemented. The cumulative carbon budget is exceeded by 60,000 tCO_2-eq by 2050. The actual required level of GHG emission in 2050 should be 3,200 tCO_2-eq, however, due to the limited GHG mitigation potential it results in 5,900 tCO_2-eq emissions. Thus additional measures or the achievable potential should be scaled up (i.e. more ambitious). Cumulative costs over the period of 2020 to 2050 is projected at -22M€ in comparison to the current situation (Table 5.2).

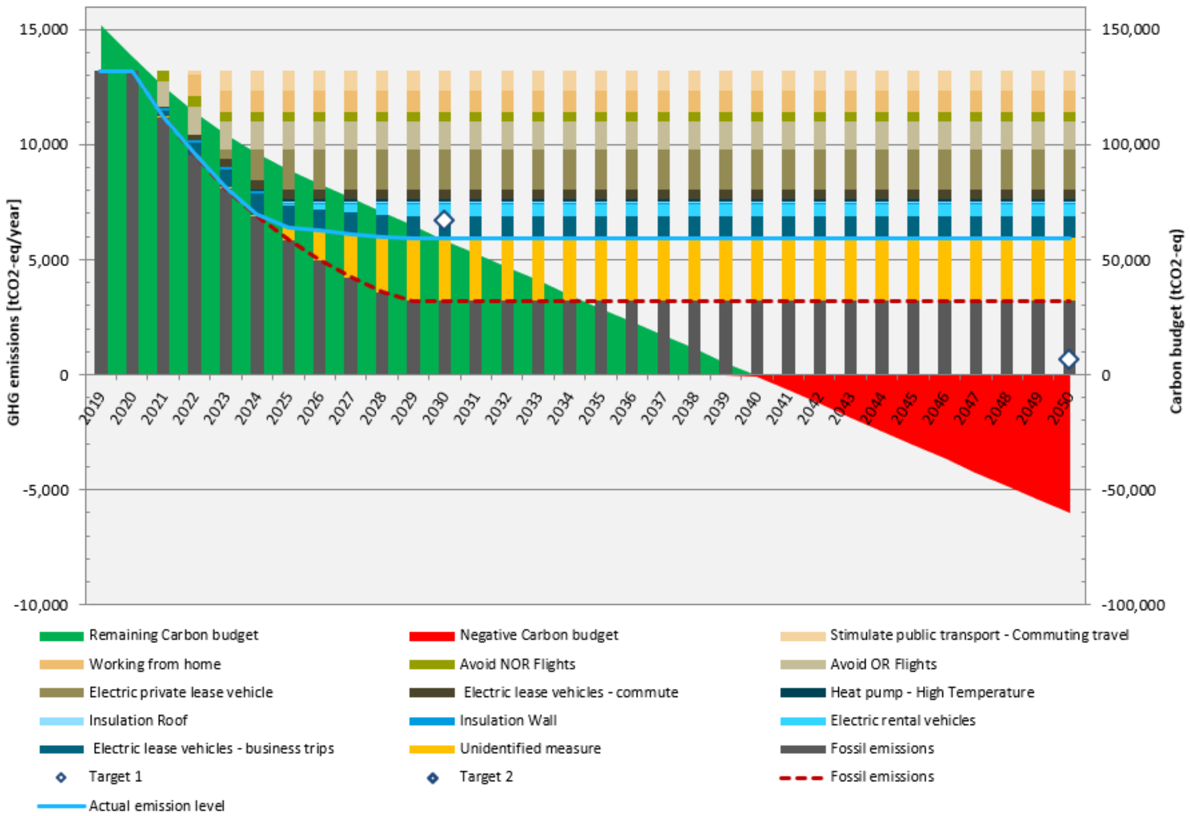

Figure 5.4: Progress towards emission targets for the fast pathway with the remaining carbon budget in scope 1,2 and 3.

In the **middle pathway** (Figure 5.5), same as for the fast pathway, the GHG abatement potential is insufficient as soon as 2021, which is due to the limited mitigation measures in scope 2. Emission reduction in scope 1 is almost able to stay in line with the achievable emission level. However, in 2040 the abatement potential becomes limited, and a gap of 100 tCO_2-eq arises by 2050. In 2028, scope 3 abatement potential becomes limited and GHG emission reduction is insufficient to follow the predefined pathway. As the middle pathway reduces GHG emissions slower than the fast pathway, suggesting more GHG emission reduction is required. Thereby, the carbon budget is exceeded by 70,000 tCO_2-eq in 2050. The actual required level of GHG emission in 2050 should be 1,500 tCO_2-eq, however due to the limited achievable GHG mitigation potential, it results in 5,700 tCO_2-eq emissions. Cumulative costs over the period of 2020 to 2050 is projected at -20M€ in comparison to the current situation.

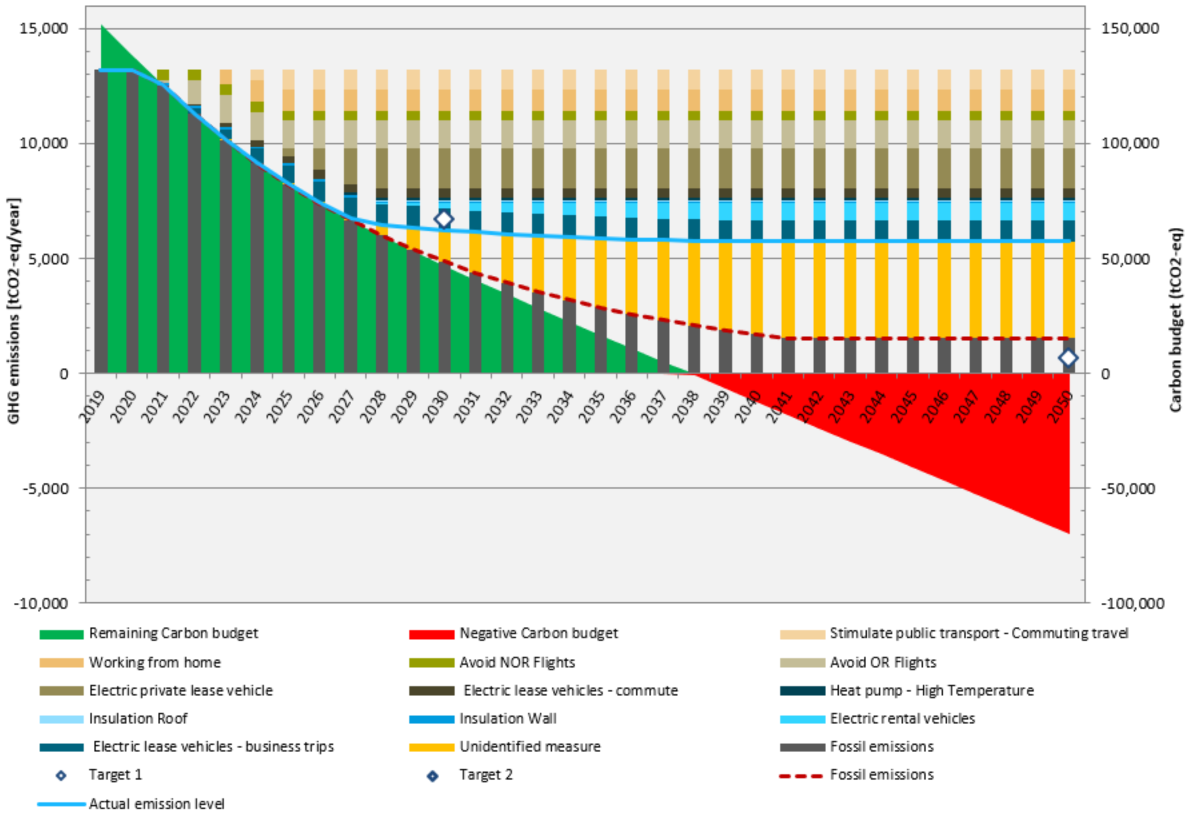

Figure 5.5: Progress towards emission targets for the middle pathway with the remaining carbon budget in scope 1,2 and 3.

The **delayed pathway** (Figure 5.6) shows insufficient GHG abatement potential as soon as 2028 due to the scope 2. The actual impact on the cumulative carbon at this time is minimal. Scope 1 emissions are sufficient up to 2033, by 2050 the gap between the achievable emission level and projected emission level is 300 tCO_2-eq. In 2030, scope 3 abatement potential becomes insufficient due to the limited achievable GHG emission reduction potential, resulting in projected GHG emission to be not in line with the constructed delayed pathway. The carbon budget is exceeded by 98,000 tCO_2-eq by 2050. The actual required level of GHG emission in 2050 is projected at 200 tCO_2-eq, however, due to the limited GHG mitigation (especially in scope 3), the emission levels are projected at 5,700 tCO_2-eq. Cumulative costs over the period of 2020 to 2050 are projected at -11M€.

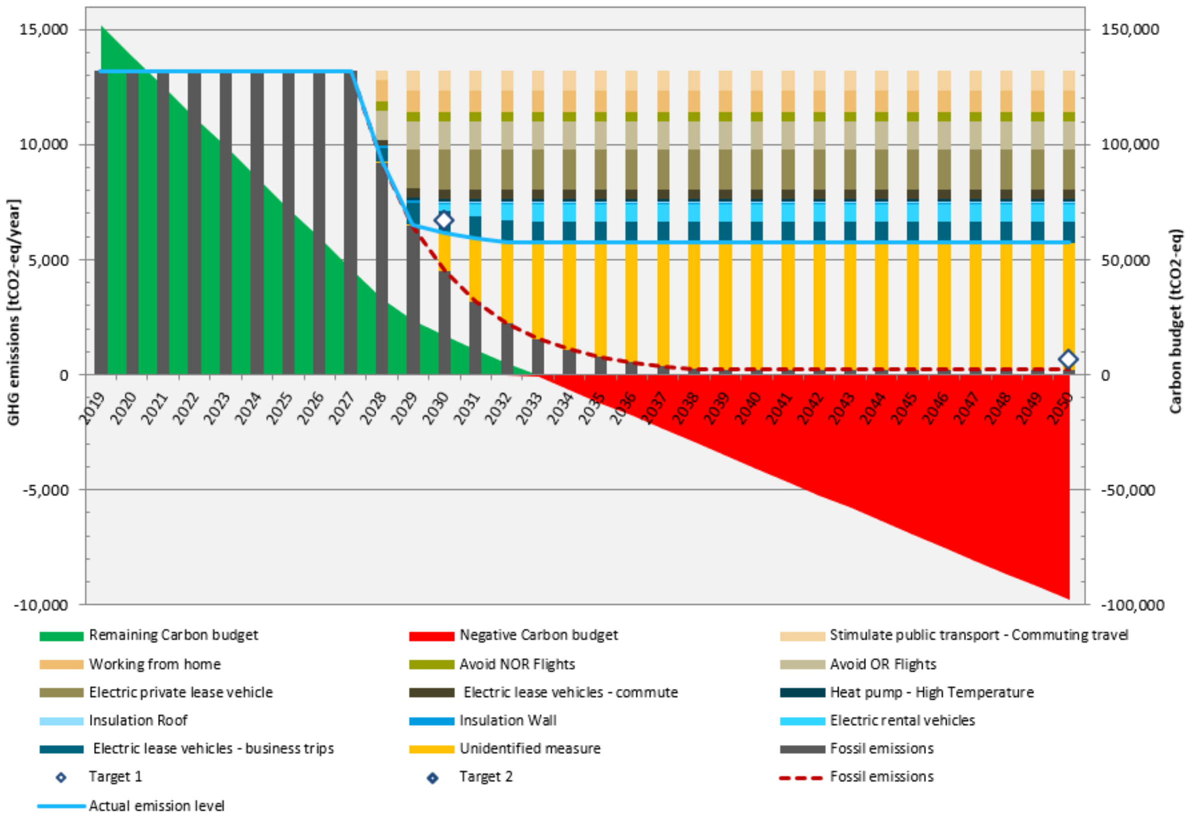

Figure 5.6: Progress towards emission targets for the Delayed pathway with the remaining carbon budget in scope 1,2 and 3.

Lastly, the **policy pathway** (Figure 5.7) shows a similar trend as the other pathways, where scope 2 is limiting the actual GHG emission potential to stay in line with the pathway. In scope 1 and 3, up to 2029, the measures are able to stay in line with their pathway. Afterwards, identified measures in scope 3 are limited in their abatement potential and actual emission level exceeds the required GHG emission reduction projected by the policy pathway. Measures in scope 1 are sufficient to adhere to the pathway up to 2047. Over the three scopes, by 2050, additional GHG emission reduction potential of 5,100 tCO_2-eq is projected. Over the period of 2020 to 2050, the allocated cumulative carbon budget is exceeded by 86,000 tCO_2-eq in 2050. Cumulative costs over this period are projected at -25M€.

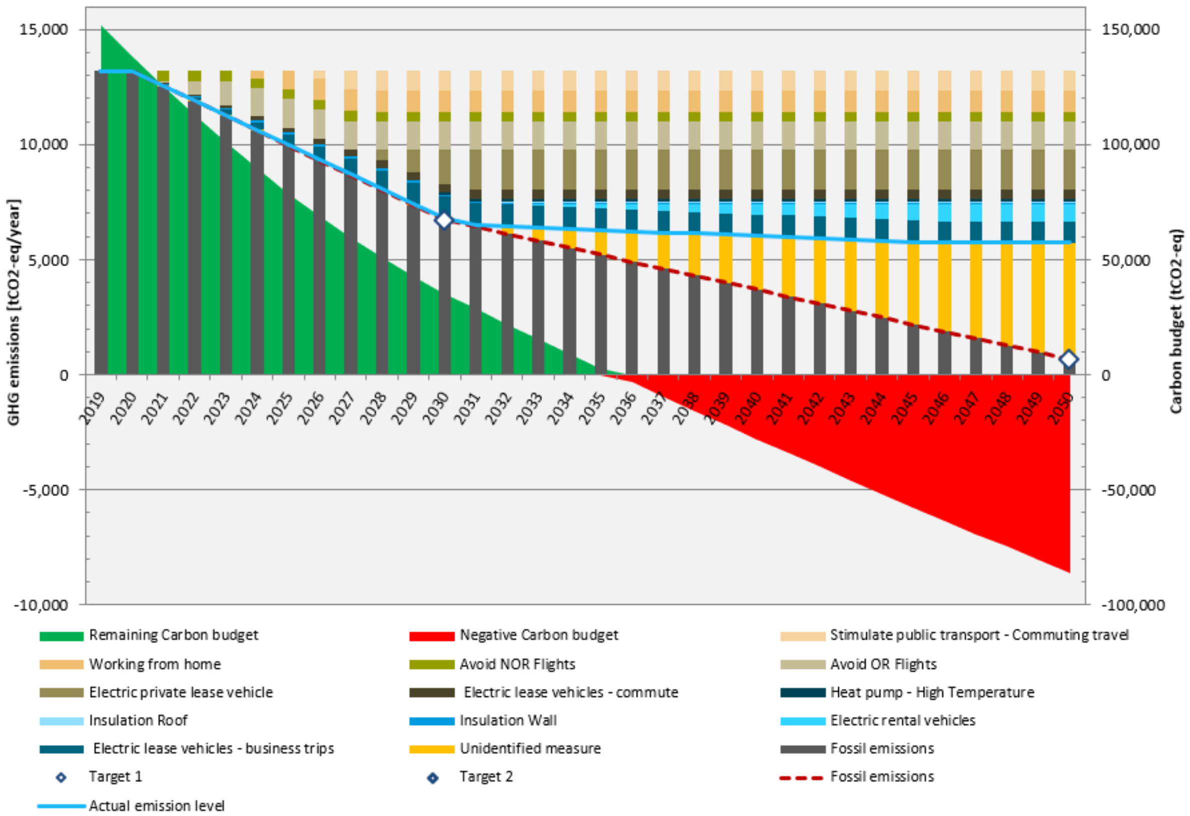

Figure 5.7: Progress towards emission targets for the policy pathway with the remaining carbon budget in scope 1,2 and 3.

Table 5.2: Overview of the four defined pathways for Scope 1, 2 and 3 combine. With their cumulative costs over the period of 2020 to 2050, required emission level as defined in that specific pathway by 2050, actual emission levels in 2050, and cumulative carbon budget exceeded by 2050. All data is presented for scope 1 in the case study of RHDHV NL.

Pathway	**Cumulative costs to 2050 [€]**	**Pathway specific GHG emission level in 2050 [tCO_2-eq]**	**Actual GHG emission level in 2050 [tCO_2]-eq**	**Cumulative carbon budget in 2050 [tCO_2-eq]**
Delayed	-€11M	200	5,700	-98,000
Middle	-€20M	1,500	5,700	-70,000
Fast	-€22M	3,200	5,900	-60,000
Policy	-€25M	700	5,700	-86,000

6. Discussion

6.1 Main findings

The dominant part of the carbon footprint of RHDHV NL in 2019 could be attributed to GHG emissions in scope 3 (82%). Here, main emission sources are business flights and commuting travel by private vehicles, which is similar to findings of other consultancy companies in the Dutch service sector (Arcadis, 2019). Scope 2 emissions of RHDHV NL are very slim in comparison to scope 1 and 3, due to the purchased GoO's for electricity use, this was also observed for other companies and institutions in this sector. However, for institutions as the Utrecht University (Utrecht University, 2019) and Wageningen University (Wageningen University, 2018), it can be observed that heating by natural gas is one of the largest emission sources, then followed by commuting and air travel.

In this research, the MACCs combined all mitigation measures into a theoretical maximum mitigation potential. Hereby, a wide portfolio of potential mitigation measures is presented, and the MACC was used to select measures from least expensive to more expensive. Herein, it was found that most mobility measures have negative MACs, as reduced travel saves GHG emissions as well as financial costs. Measures for the built environment mostly have positive MACs, as higher upfront investments are required and because financial benefits over the lifetime are relatively small (Beaumont and Tinch, 2004). An advantage is that the MACCs can be communicated effectively and are widely applicable in the service sector due to its adaptability. Achievable reduction potentials are considered well substantiated, as GHG emission scopes are assessed separately and double counting within the same scope is avoided. Potential future pathways are explored by studying different mitigation pathways, which can support decision making in regards to climate mitigation. It shows cost-effective implementation of mitigation measures over time to stay in line with the projected pathway. Due to the use of the carbon budget, the path dependencies of the GHG emissions are included.

Results from the case study showed that in the fast pathway, the cumulative costs over the period 2020 to 2050 were lowest, due to implementation of measures early in time with a negative MAC. However, even the fast pathway, where the GHG emission levels were relatively high in 2050, was unable to stay within the allocated carbon budget mainly due to scope 3. When considering scope 1, the identified achievable mitigation potential was sufficient, however mitigation costs were relatively high (Appendix 8.1). This suggests that for RHDHV NL, additional mitigation measures should be introduced or the identified measures should be more ambitious. As the other constructed pathways have a slower uptake of GHG reduction measures, thereby the carbon budget is consumed at a faster rate, thus the required emission level in 2050 is lower compared to the fast pathway. The achievable mitigation potential of the identified measures creates a larger emissions gap between the projected pathway and the achievable emission level. This indicates that there is, indeed, a large urgency and need for ambitious plans to contribute to the climate goal (Rijksoverheid, 2019).

6.2 Limitations of the research

A limitation in this approach is that the accounting method was unable to direct GHG emission reductions from one specific measure over multiple emission scopes. As this would result in double counting of the mitigation potential between these scopes. Moreover, some simplifications were made in the method and modelling in order to make a general approach, as the goal is to inform companies about potential differences between GHG mitigation pathways.

One reoccurring limitation is that the data used in this research was based on a "snapshot" in time (2019). Firstly, emission factors of current activities are static and do not change over time, whilst technological innovations could lower emissions for a specific activity (e.g. advancements in aviation). This indicates that developments could occur in the future, affecting the remaining emission reduction that is required in the respective scope. An example can be given for the mitigation measure of *avoiding flights*, where it is expected that flying can be reduced by 30 - 40%. At the same time, future advancements in aviation (e.g. retrofits, aircraft designs) enable lower emissions in remaining flights. This means that, potentially, the carbon footprint of the remaining share of flight emissions could be lower than projected in this research (IATA, 2020). Secondly, energy price developments (e.g. natural gas, electricity or gasoline) are excluded. The MAC of GHG mitigation measures is determined by the financial cost and benefit based on the current situation. When energy costs increase, the financial benefits of a mitigation measure could change, as savings would increase (and vice versa). Thirdly, fixed costs are used for determining the MAC of a specific measure. However, similar to emission factors and energy prices, the cost of implementation of measures could develop over time. Most likely, costs of measures will decrease when the measures becomes more developed, due to a higher adoption rate, learning rate or economies of scale. An example is that of the steep decline in price for solar photovoltaics over the last decade (European Union, 2019). Lastly, potential structural changes in a company, such as growth or changes in activities, and their subsequent carbon footprint are not accounted for. Thus an increase in GHG emissions could arise over time, requiring more GHG emission mitigation than projected in this research. Moreover, in this research potential GHG mitigation measures for scope 2 are excluded. As for the case study of RHDHV NL, GoO's are purchased and zero emissions are accounted for electricity consumption. However, reduction in resource use should always be encouraged when aiming to become more sustainable (European Communities, 2012). Measures are identified for reduction in electricity demand, and could be used for companies which do not purchase GoO's. Or compare them with GHG emission by grey electricity.

In this research, measures were selected based on their cost effectiveness. However, Vogt-Schilb and Hallegatte (2014b) showed that strategies of GHG emission reduction depend on the timescale of the objectives, the cheapest option may not always be the most feasible and most effective option for reaching the long-term goals. Implementation of GHG reduction measures may be limited due to knowledge availability, capital or institutional constraints. Therefore, it is important that mitigation measures are updated regularly with technological innovations. Additionally, the determined MACs were an estimation of costs, whilst co-benefits are not included (such as health impact). Moreover, indicators such as cultural barriers are generally not accounted for in a MACC (Harmsen et al., 2019), which was also the case in the current research.

In this research, the concept of immediate per capita convergence is used to determine the national carbon budget. However, many other forms of allocating the carbon budget can be applied. For example, this could be based on GHG emission share or gross domestic product (GDP). The latter one allocates the global carbon budget to nations by their share in the GDP in a given base year. In 2017, the Netherlands had a GDP share of approximately 1% in the world (WorldOmeter, 2020). Applying this concept would result in a carbon budget that is five times larger in the 2°C scenario compared to the immediate per capita convergence. The carbon budget of limiting global warming to 1.5°C, would give a carbon budget of approximately 1.8 times of the immediate per capita convergence. This means that the use of convergence per capita could be considered to be relatively strict for industrialised countries. However, other allocation methods where historic emissions are taken into account, and thus represent the historic contribution of these countries to global warming, could result in a negative carbon budget for industrialised countries (van den Berg et al., 2019).

The described limitations mostly regard the use of static assumptions for future developments. However, such assumptions and uncertainties about future drivers are rather inherent to (climate) modelling studies (Stehfest et al., 2014). By recognising the limitations and by offering research transparency, avenues for future studies are promoted.

6.3 Added value of the research

This research aimed to discover new knowledge about potential mitigation strategies for individual companies in the service sector, based on the cost-effectiveness of GHG mitigation measures. Despite the described limitations of this research, it is an initial step that pro-actively contributes to achieving the Dutch climate goals, specifically through a company perspective in the service sector. This research provided a versatile approach that is easy to grasp, and could be extended with additional knowledge in follow-up studies. Moreover, the portfolio of GHG mitigation measures for mobility and the built environment could be used by other companies in the service sector. By combining theory about the carbon footprint with the carbon budget and the climate goals, insight is created on current emission levels as well as projections of climate mitigation for a company. Moreover, by using a global carbon budget allocated to an individual company, target setting becomes more practical. In contrast to the climate policy targets that were based on emission data from 1990, which is often unavailable at company level. As was the case for RHDHV NL, where historic data on the carbon footprint dated back to 2012.

The results showed that the fast pathway (fast implementations of measures) does reduce the carbon footprint of RHDHV NL greatly, however, the pathway does not reach the 2°C climate goal with the identified measures. Particularly the indirect scope 3 emissions of RHDHV NL could not be reduced sufficiently, meaning that these emissions could be mitigated elsewhere. Therefore it is advised that other companies, apply a similar approach to explore mitigation potentials in addition to general policy measures (e.g. RED II).

Further research could be directed at exploring the effect of price developments and cost reduction for GHG mitigation measures by investigation of energy price projections. This would present a more thorough representation of actual costs- and benefits for the identified GHG mitigation measures. The impact on MAC is thereby interesting, as this might change the selection of measures for a given pathway. Furthermore, this research shows the effect of different mitigation pathways for a company in the service sector. However, it could be expanded upon, by identification of additional mitigation measures, to make the approach compatible with companies from different sectors. Moreover, the impact of supporting policies for mitigation measures or changes in regulation are of interest as this might change the overall approach to GHG emission mitigation. An example is the comparison of electric vehicles with ICE, a regulation (e.g. EURO-6 norm) which introduces new vehicles with less GHG emissions in comparison to the older models. Lastly, the whole life-cyle of an measures could be investigated, instead of well-to-wheel. To show if the total GHG emissions by substitution for GHG mitigation is actually reduced over the lifetime.

7. Conclusion

During this research an approach is constructed which should guide companies in the service sector to reduce GHG emissions conform 2°C climate goal of the Paris Agreement. The carbon budget is used as main concept on cumulative GHG emissions and the global temperature response. The primary focus was on company emissions resulting from mobility and the built environment. GHG emission reduction measures are identified and prioritised based on their MAC and visualised in a MACC. Four pathways were defined up to 2050, of which three followed the carbon budget approach and one followed the current policy targets (49% and 95% in 2030 and 2050 respectively). Results of the case study show that there is a large urgency in reducing GHG emissions as soon as possible, as in many pathways the allocated carbon budget is largely exceeded. The research questions are answered following this approach.

Which GHG emission reduction measures could a company in the service sector implement for mobility and the built environment, and what are the associated costs and GHG emission reduction potentials?

Mitigation measures for mobility activities mostly addressed changes in travel behaviour, working from home and advanced vehicles technologies. Measures for the built environment consisted of reducing heating- and cooling load, reducing electricity consumption, and increasing the uptake of renewable energy resources. In total, 22 measures were selected and analysed to reduce GHG emissions for companies in the service sector. Based on the case study of RHDHV NL, MACs of mobility measures were generally lower compared to measures in the built environment, considering direct costs and benefits. Moreover, the GHG reduction potential of mobility is substantially greater than that of the built environment. However, the abatement potential of the identified measures depends on the activities of a company as well as their capability and/or ambition to implement measures.

How can GHG emission reduction measures be prioritised for an individual company, based on cost-effectiveness?

Using the costs and reduction potentials of the identified measures, MACs were determined. Subsequently, the MACs and reduction potentials were visualised in a MACC. Two types of MACC were constructed: first, a theoretical maximum MACC showing the mitigation potential and costs for each individual measure. Second, an achievable MACC is created with specific data from the company, to determine the actual mitigation potential when the measures would be implemented simultaneously. Many of the mitigation measures are based on the situation of RHDHV NL, and resulted in a theoretical maximum reduction potential of 26,000 tCO_2-eq. The achievable reduction potential resulted in 8,000 tCO_2-eq.

The MAC gives an initial focus of potential mitigation measures in the service sector which are most cost-effective. This MACC approach is versatile, and enables companies to introduce new mitigation measures and adapt current identified measures for their specific situation. By introducing such changes, the prioritisation of measures are potentially different from this research.

What is the effect of using a carbon budget for the GHG mitigation strategy of an individual company?

The global carbon budget was used to construct a national carbon budget via per capita convergence. Subsequently, the national carbon budget was allocated to a company, via relative emission share. By using the carbon budget approach on company level the path dependency of emissions is taken into account. Results from the case study of RHDHV NL showed, when considering all scopes, that neither of the pathways were sufficient to stay within the allocated carbon budget. Only scope 1 in the fast pathway is able to follow the projected pathway. The other pathways showed a larger exceedance, as the gap between the projected pathway and the mitigation potential accumulates over the studied period. This shows the urgency of mitigating GHG emissions as soon as possible. Furthermore, allocated carbon budgets enable companies to set climate targets based from recent data, instead of a reference year (e.g. 1990 emission levels).

How can a company in the service sector in the Netherlands find the most cost-effective GHG mitigation pathway to adhere to the climate goal of the Paris Agreement by limiting climate change to 2,0°C, focusing on emission reduction measures in mobility and the built environment?

Carbon footprints of companies in the service sector have substantial scope 3 emissions, which indicates that they could have an impact on the overall non-ETS emissions of mobility and the built environment. Additionally, companies in the service sector have comparable carbon footprints. To guide these companies towards climate change mitigation strategies, this research combined the carbon budget and MACC. By using the carbon budget, the path dependency of the carbon footprint of a company can be accounted for. The introduction of various pathways presented potential trajectories a company could follow to contribute to reach the climate goals. Moreover, the MACC presented a simplistic overview of identified measures based on MACs and GHG abatement potential. With data from RHDHV NL, the achievable GHG mitigation potential was determined. The results of the fast pathways showed that earlier implementation of mitigation measures leads to less drastic reduction in GHG emissions, as the carbon budget is used more sparingly. Conversely, the other pathways required deeper and more expensive measures and resulted in a costlier reduction path. Overall, the GHG reduction measures implemented in each of the pathways do no meet the 2°C climate goal. This is mostly due to limited emission reduction in scope 3. Here, the annual emission gap between the projected pathway and achievable emission level was largest, and cumulatively exceedance of the carbon budget was the highest. This shows the urgency of reducing GHG emissions as soon as possible. Scope 3 emissions from an individual company could be reduced when other companies reducing their direct scope 1 emissions. Additional reduction could be achieved by expanding the portfolio of mitigation measures and/or increasing their ambition level. Moreover, the results of the case study presented that the costs were dominated by measures with a negative MAC, therefore the cumulative costs were largely negative over the period up to 2050. While in the slower pathways more expensive options were required (e.g. electric company lease vehicles). However, important to note that each company is different, indicating that mitigation measures and achievable mitigation potential should be adjusted to an individual company. Yet, this research provides the initial insights about mitigation measures which could be investigated further.

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8. Appendices

8.1 Pathways in scope 1 of Royal HaskoningDHV NL

According the carbon footprint, total scope 1 GHG emissions in 2019 was 2,270 tCO_2-eq. The allocated cumulative carbon budget for scope 1 of RHDHV NL was 26,945 tCO_2-eq. With the constructed pathways, measures from the achievable MACC will be implemented based on cost-effectiveness.

In the **fast pathway** (Figure 8.5) the least expensive measure, *electric company lease vehicles*, is introduced in 2021 and scaled up to its full potential in 2024. Additionally, *wall insulation* is implemented in 2021, accounting for a emission reduction of 99 tCO_2-eq. In 2024, *heat pumps* are implemented, which reaches its total achievable potential the next year. Moreover, *roof insulation* is implemented in 2025 to the maximum achievable potential. The combination of these measures was not sufficient to meet the required GHG mitigation potential in 2025. Therefore, the most expensive measure for *rental EV vehicles* is implemented to a limited extent. In 2029, where the maximum reduction potential is required, the rental vehicles are utilised up to 70% of their maximum achievable potential. The required GHG emission level in 2050 is 555 tCO_2, cumulative costs over the period of 2020 to 2050 are projected at 15M€ compared to the reference situation in 2020. Based on the marginal cost, most costs originate from implementation of rental EVs.

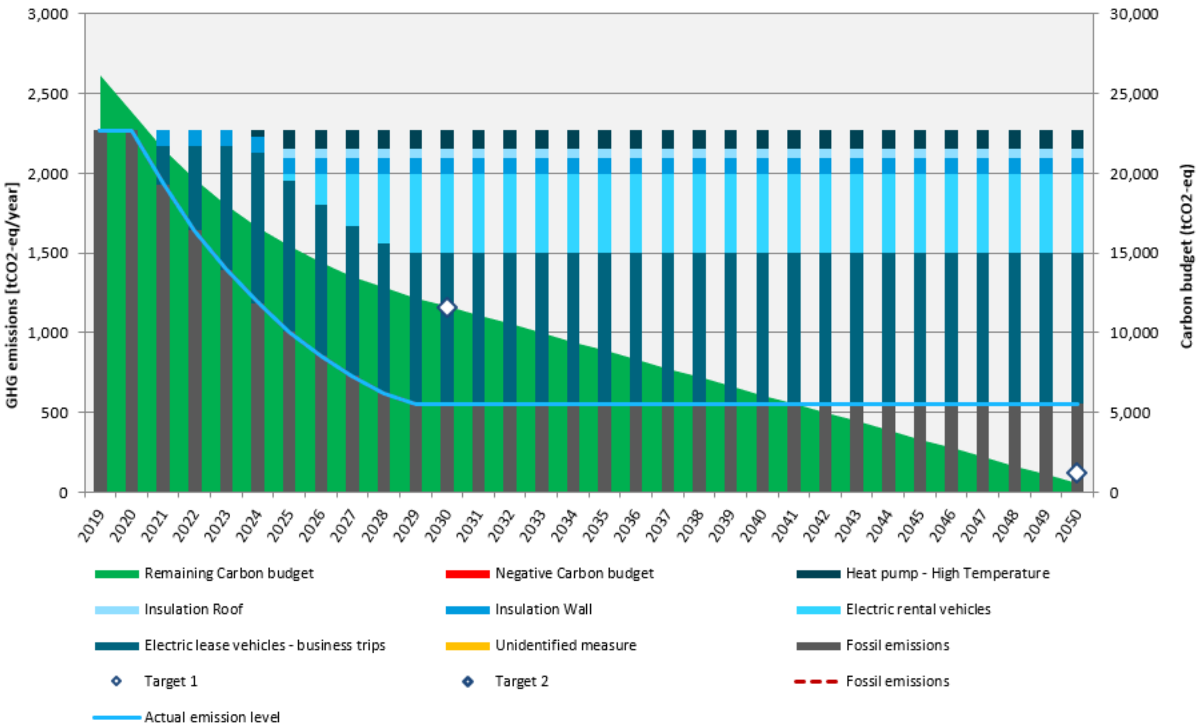

Figure 8.1: Progress towards emission targets for the Fast pathway with the remaining carbon budget in scope 1. The grey bars and yellow line represent the CO_2 emissions in each year.

In the **middle pathway** (Figure 8.6) the least expensive measure *wall insulation* is implemented to its maximum achievable potential. Additionally, *electric company lease vehicles* were introduced in 2021 and slowly scaled up to 2027. In 2028, *heat pumps* as well as *roof insulation* and *electric rental vehicles* are introduced. In 2039 all identified measures reached their maximum achievable reduction potential. In this year, the actual GHG emission level that can be reached deviates from the projected pathway, the gap was 71 tCO_2-eq. In 2050 approximately 400 tCO_2-eq of the allocated carbon budget in scope 1 is exceeded. In general the latter measures can be introduced later and scaled up slower compared to the fast pathway. The GHG emission level in 2050 would reach 333 tCO_2, cumulative costs are projected at approximately 17M€.

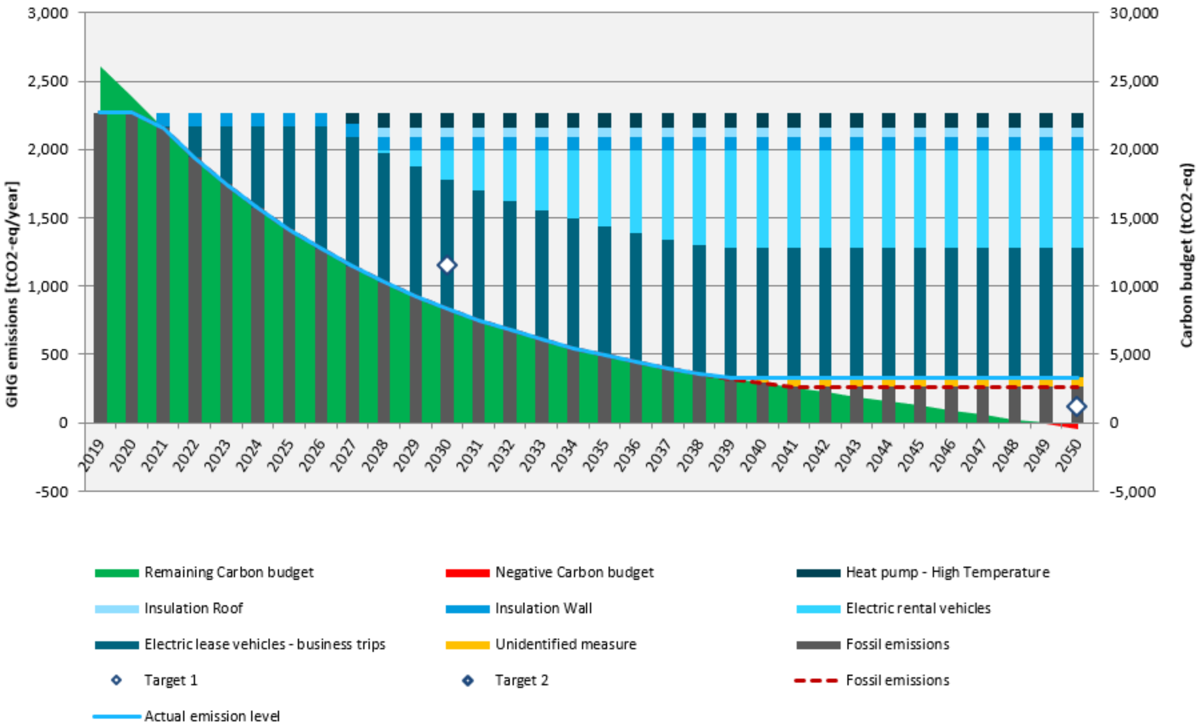

Figure 8.2: Progress towards emission targets for the Middle pathway with the remaining carbon budget in scope 1. The grey bars and yellow line represent the CO_2 emissions in each year.

In the **delayed pathway** (Figure 8.7), *wall insulation* and *electric company lease vehicles* are introduced in 2028 and scaled up to their full potential in 2029. This is followed by the implementation of *heat pumps* in 2029. The next year *roof insulation* is implemented to the maximum achievable potential, and *electric rental vehicles* are introduced. In 2033, the identified measures do not achieve the required GHG emission potential, which increases to a gap of 293 tCO_2-eq in 2050. Eventually, this leads to the carbon budget being exceeded in scope 1 by 4,400 tCO_2-eq cumulatively in 2050. Cumulative costs over the period of 2020 to 2050 are projected at 18M€.

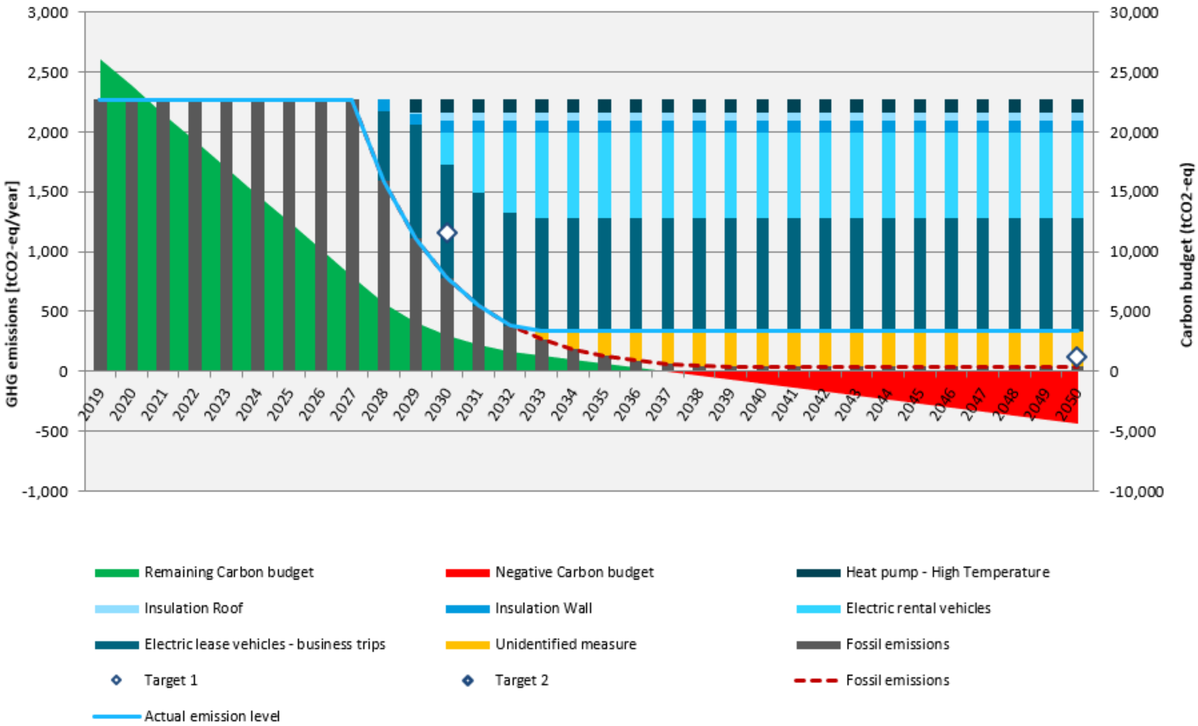

Figure 8.3: Progress towards emission targets for the Delayed pathway with the remaining carbon budget in scope 1. The grey bars and yellow line represent the CO_2 emissions in each year.

Lastly, the **policy pathway** (Figure 8.8) applied *wall insulation* first, in 2021. In that same year, a limited amount of GHG emissions are reduced by *electric lease vehicles*, which reaches its maximum achievable reduction potential in 2030. Here, also *heat pumps* are introduced, followed by the introduction of roof insulation in the next year. In 2033, *electric rental vehicles* are rented, and the reduction potential is scaled up to 2046. In that year, all measures reached their maximum achievable GHG reduction potential, thus a gap between the projected pathway and the actual GHG emission level arises. Although the gap is 219 tCO_2-eq in 2050, the allocated budget for scope 1 is exceeded by 7,500 tCO_2-eq. Cumulative costs over the period of 2020 to 2050 are projected at 11M€.

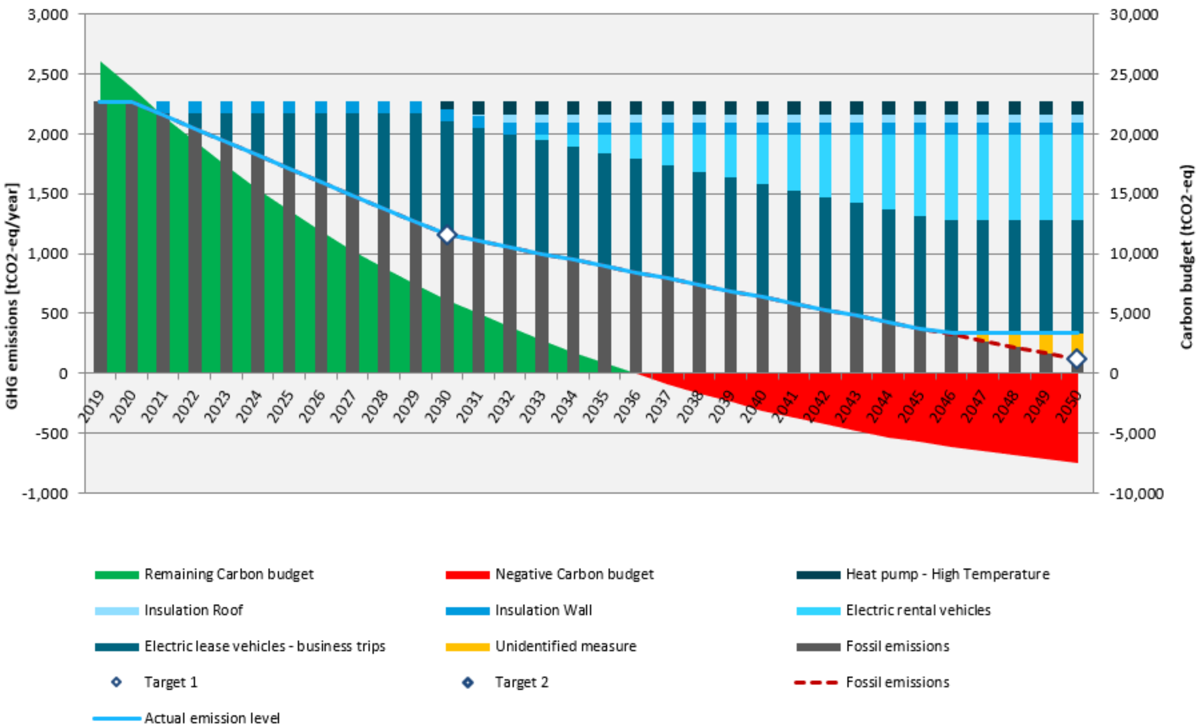

Figure 8.4: Progress towards emission targets for the Policy pathway with the remaining carbon budget in scope 1. The grey bars and yellow line represent the CO_2 emissions in each year.

The most important details of each of the pathways for scope 1 are presented in table 8.1.

Pathway	**Cumulative costs to 2050 [€]**	**Pathway specific GHG emission level in 2050 [tCO_2-eq]**	**Actual GHG emission level in 2050 [tCO_2]-eq**	**Cumulative carbon budget in 2050 [tCO_2-eq]**
Delayed	€18M	40	333	-4,400
Middle	€17M	262	333	-400
Fast	€15M	555	555	-
Policy	€11M	114	333	-7,500

Table 8.1: Overview of the four defined pathways for Scope 1 with their cumulative costs over the period of 2020 to 2050, required emission level as defined in that specific pathway by 2050, actual emission levels in 2050, and cumulative carbon budget exceeded by 2050. All data is presented for scope 1 in the case study of RHDHV NL.

8.2 Pathways in scope 2 of Royal HaskoningDHV NL

Based on the identified carbon footprint of RHDHV NL, scope 2 emissions in 2019 accounted for 133 tCO_2-eq. The allocated cumulative carbon budget for scope 2 of RHDHV is 1,582 tCO_2. Emission in this scope arise only from heating via purchased heat outside company boundaries. As electricity is purchased with GoO's, in accounting an EF of 0 $kgCO_2$-eq/kWh can be used. Potentially, when grey electricity would be used, the emissions from electricity consumption could be as high as 1,372 tCO_2-eq in 2019. Moreover, measures to reduce heating demand are already allocated to scope 1 GHG emissions. Therefore, measures for reducing GHG emissions by heating are excluded in scope 2 to avoid double counting. In scope 2, all constructed emission pathways are unfeasible with the identified emissions reduction measures. (Table 8.2).

In general emission reduction measures are excluded from scope 2, therefore in the **fast**, **middle**, **delayed** and **policy pathway** the allocated carbon budget in scope 2 are all exceeded. However, there are measures which enables reduction in electricity consumption from the electricity grid although on the accounting basis no additional GHG emissions are reduced.

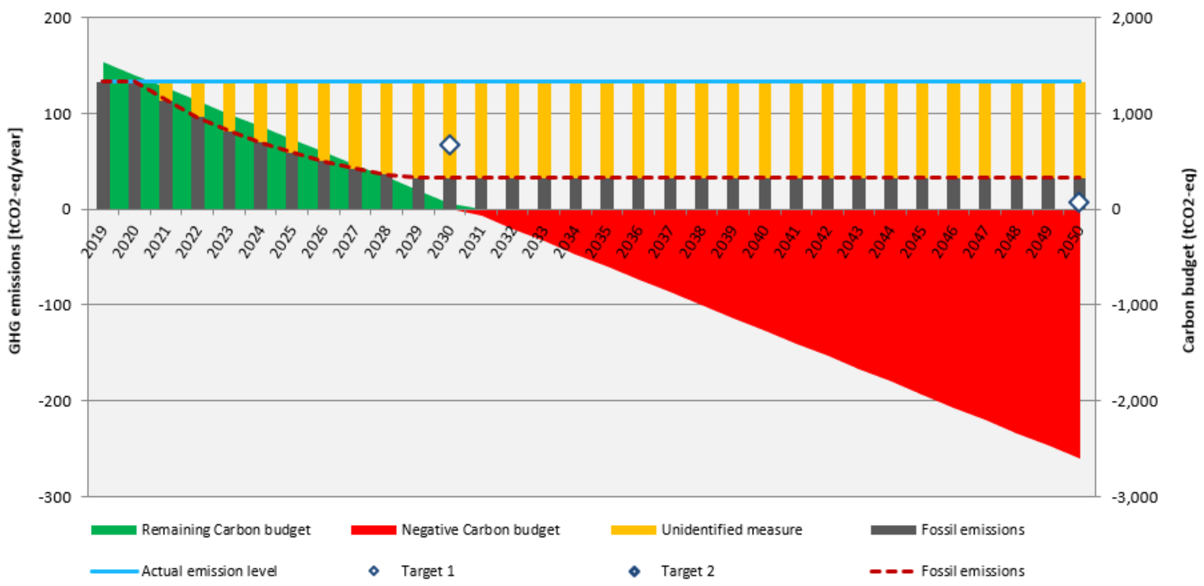

Figure 8.5: Progress towards emission targets for the Fast pathway with the remaining carbon budget in scope 2. The grey bars and yellow line represent the CO_2 emissions in each year.

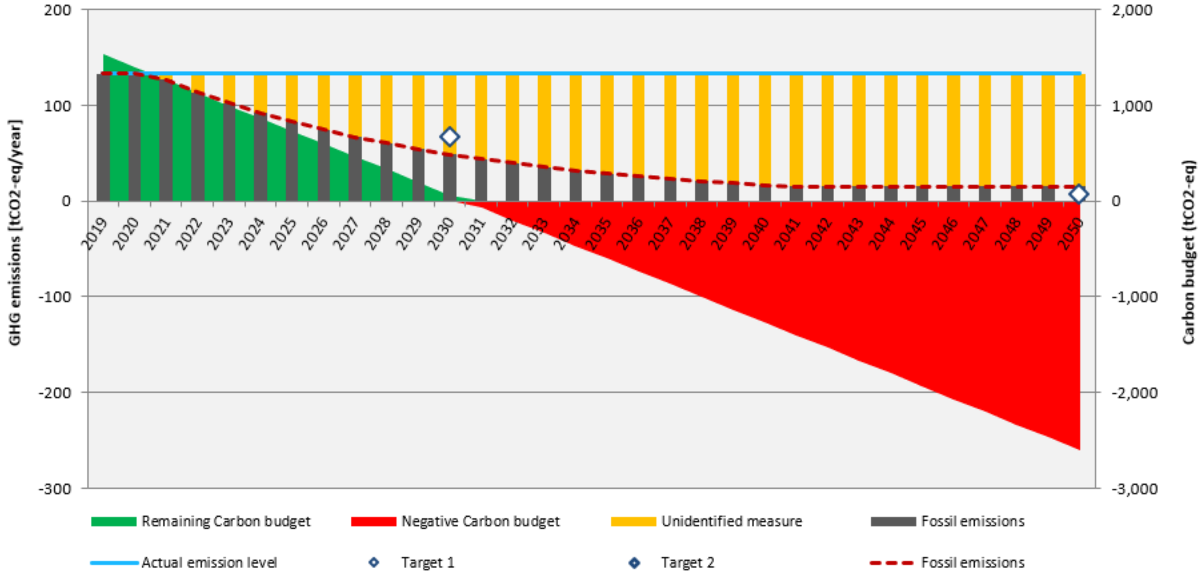

Figure 8.6: Progress towards emission targets for the Middle pathway with the remaining carbon budget in scope 2. The grey bars and yellow line represent the CO_2 emissions in each year.

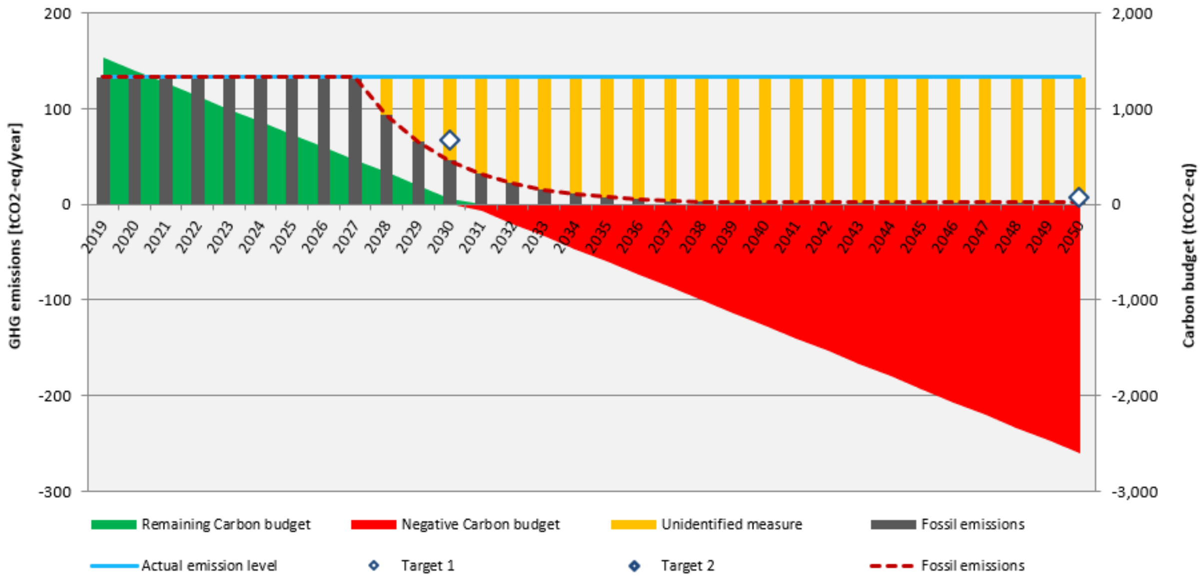

Figure 8.7: Progress towards emission targets for the delayed pathway with the remaining carbon budget in scope 2. The grey bars and yellow line represent the CO_2 emissions in each year.

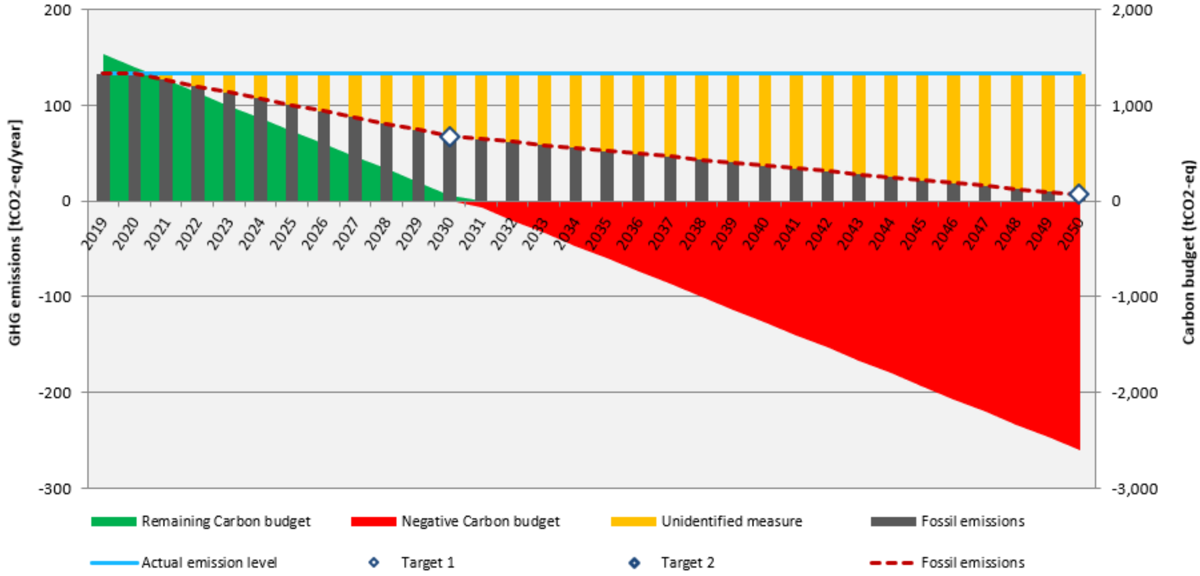

Figure 8.8: Progress towards emission targets for the Policy pathway with the remaining carbon budget in scope 2. The grey bars and yellow line represent the CO_2 emissions in each year.

Pathway	**Cumulative costs to 2050 [€]**	**Pathway specific GHG emission level in 2050 [tCO_2-eq]**	**Actual GHG emission level in 2050 [tCO_2]-eq**	**Cumulative carbon budget in 2050 [tCO_2-eq]**
Delayed	-	2	133	-2,600
Middle	-	15	133	-2,600
Fast	-	33	133	-2,600
Policy	-	7	133	-2,600

Table 8.2: Overview of the four defined pathways for Scope 2 with their cumulative costs over the period of 2020 to 2050, required emission level as defined in that specific pathway by 2050, actual emission levels in 2050, and cumulative carbon budget exceeded by 2050. All data is presented for scope 1 in the case study of RHDHV NL.

8.3 Pathways in scope 3 of Royal HaskoningDHV NL

According to the carbon footprint, scope 3 emissions of RHDHV NL were 10,785 tCO_2 in 2019. The allocated cumulative carbon budget for scope 3 therefore remains at 127,996 tCO_2.

In the **fast pathway** (Figure 8.9), the most cost effective measures of *avoiding OR* and *NOR flights* are implemented in 2021. Moreover, *electric lease vehicles* are used for commuting travel, even though this is not the most cost effective measure. This measure is implementation in scope 1 in that year and therefore, also in scope 3 a share of the commuting travels are by electric lease vehicles. In the next year *working from home* is implemented to it's maximum achievable potential. Meanwhile, also more commuting travel is directed to *public transport*. In 2023, both these measures reached their maximum GHG abatement potential, and one additional measure is implemented, namely *electric private lease vehicles*. In 2025, all measures are implemented to their maximum achievable potential. At this moment in time the actual GHG emission level will not be able to stay in line with the projected pathway. The allocated cumulative carbon budget is exceeded by 58,000 tCO_2-eq in 2050. Cumulative costs over the period of 2020 to 2050 would be -37M€, thus cost would be saved in comparison to the current situation.

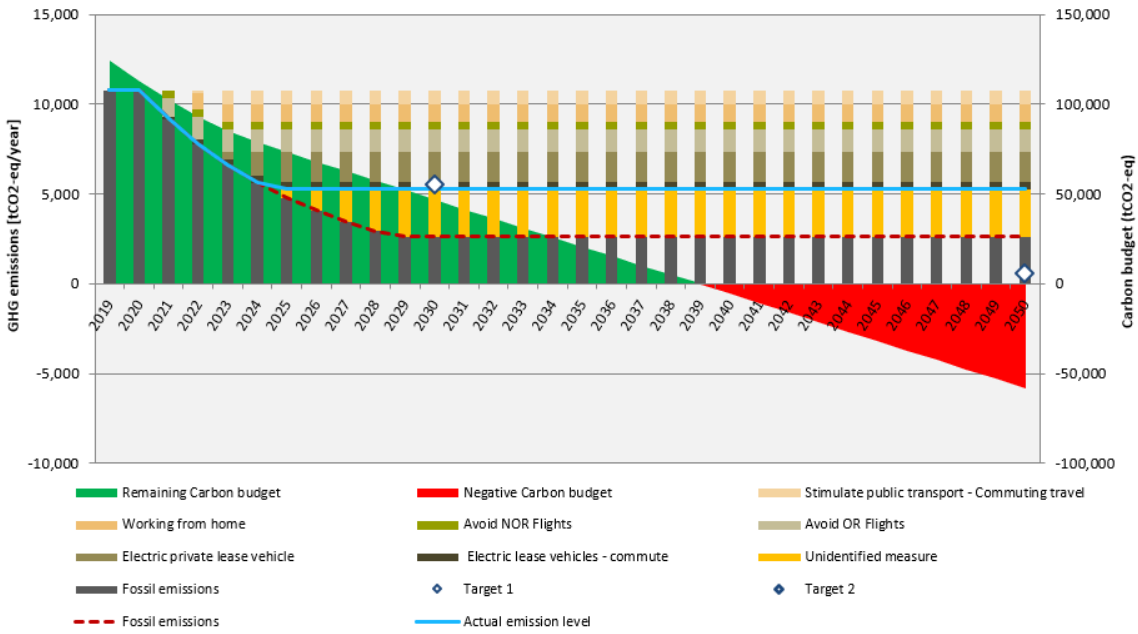

Figure 8.9: Progress towards emission targets for the Fast pathway with the remaining carbon budget in scope 3. The grey bars and yellow line represent the CO_2 emissions in each year.

In the **middle pathway** (Figure 8.10), *avoiding NOR flights* is introduced in 2021 to the maximum achievable potential. Moreover, part of commuting travel is done by *electric lease vehicles* (due to implementation in scope 1) and *OR flights* are partly avoided. The latter is scaled up until two years later, where also *working from home* is implemented. In the next year, this is followed by stimulation of *public transport* for commuting travel. In 2025, when the maximum achievable potential of working from home is reached, also *electric private lease vehicles* are introduced. In 2028, the identified measures are not able to provide the required GHG emission reduction potential. Therefore, a gap between the actual GHG emission level and the projected pathway arises. By 2050 the gap is 4,000 tCO_2-eq, resulting in a exceeded cumulative carbon budget by 66,700 tCO_2-eq in that same year. Cumulative costs over the period of 2020 to 2050 are -36M€.

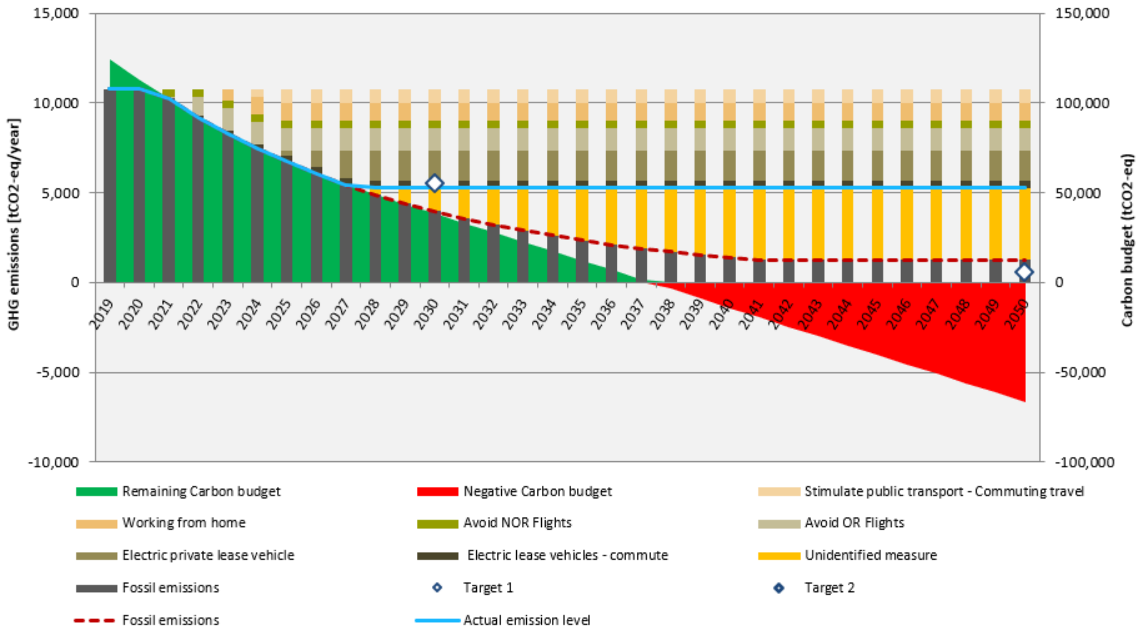

Figure 8.10: Progress towards emission targets for the Middle pathway with the remaining carbon budget in scope 3. The grey bars and yellow line represent the CO_2 emissions in each year.

In the **delayed pathway** (Figure 8.11) emission reduction measures are introduced in 2028, consisting of *avoidance of OR* and *NOR flights*, *working from home*, and stimulation of *public transport*. In the next year, *electric company- and private lease vehicles* are introduced. These measures are scaled up to 2031. Similar to the other pathways, the emission reduction measures are insufficient to adhere to the delayed pathway. In 2050 a total of 5,100 tCO_2 emissions should be additionally reduced, next to the mitigation measures already implemented. Cumulatively over the period of 2020 to 2050 the carbon budget is exceeded by 91,000 tCO_2-eq. Cumulative costs over the same period are -29M€.

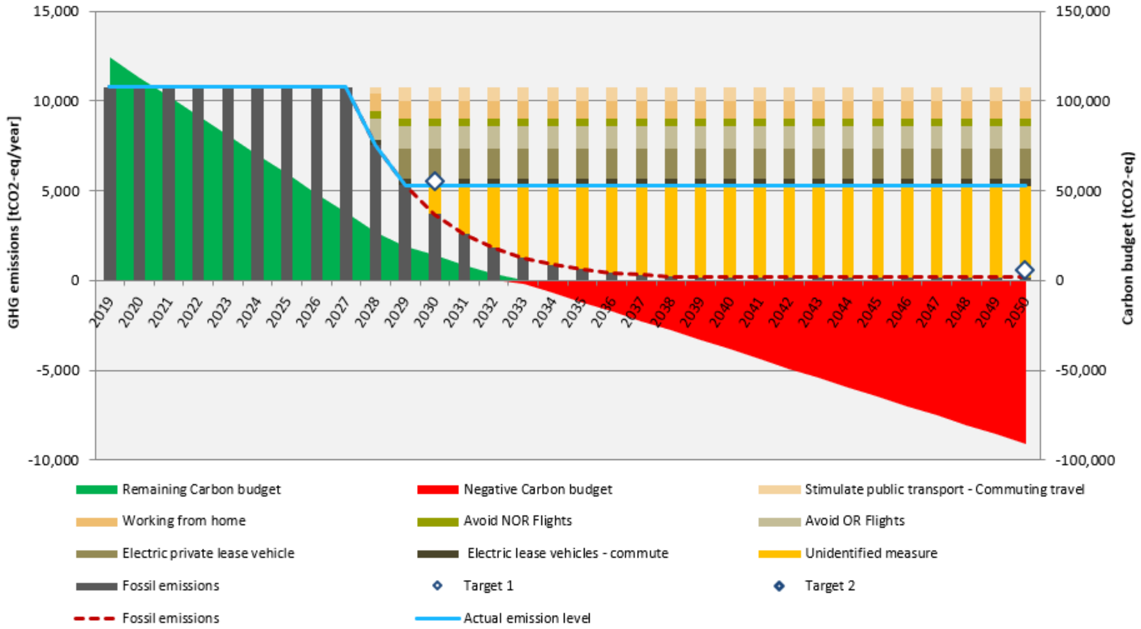

Figure 8.11: Progress towards emission targets for the delayed pathway with the remaining carbon budget in scope 3. The grey bars and yellow line represent the CO_2 emissions in each year.

Lastly, the **policy pathway** (Figure 8.12) implements *avoiding NOR* and part of *OR flights* in 2021. Up until 2024, these measures are scaled up, whereafter *working from home* is introduced. The next year also stimulation of *public transport* is introduced. In 2027, part of commuting travel is done by *electric company lease vehicles*. The next year *electric private lease vehicles* are introduced. In 2032, the identified GHG emission reduction measures are not as far reaching as required to stay in line with the policy pathway. By 2050 additional GHG reduction is required up to 4,700 tCO_2-eq. The allocated cumulative carbon budget for scope 3 is exceeded by 76,000 tCO_2-eq. Cumulative costs for this pathway over 2020 to 2050 are approximately -36M€.

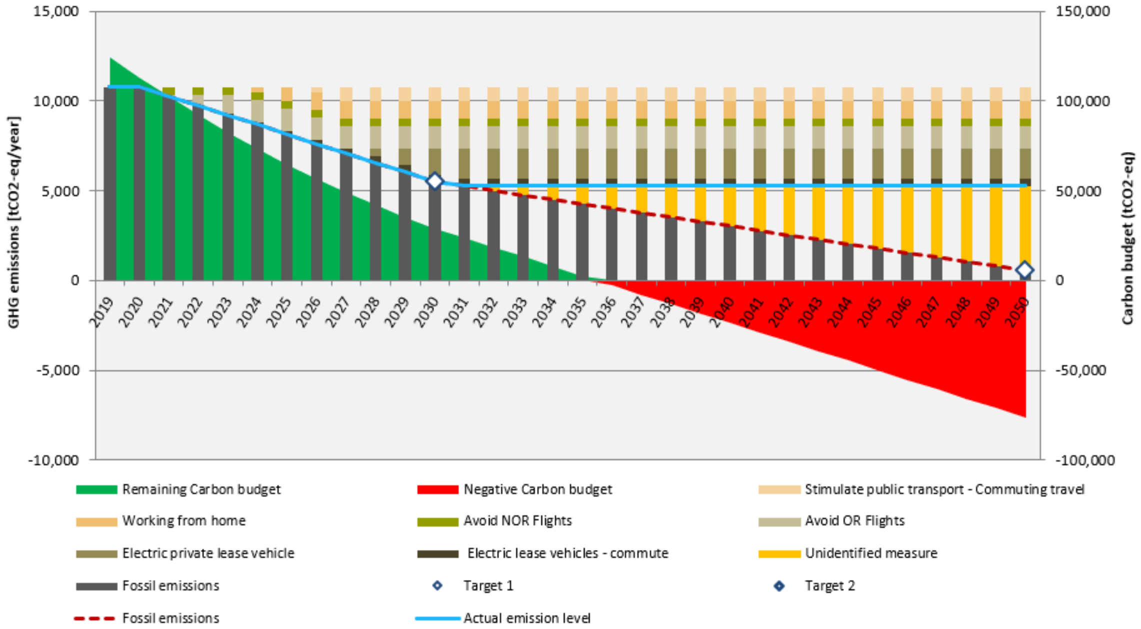

Figure 8.12: Progress towards emission targets for the Policy pathway with the remaining carbon budget in scope 3. The grey bars and yellow line represent the CO_2 emissions in each year.

Pathway	**Cumulative costs to 2050 [€]**	**Pathway specific GHG emission level in 2050 [tCO_2-eq]**	**Actual GHG emission level in 2050 [tCO_2]-eq**	**Cumulative carbon budget in 2050 [tCO_2-eq]**
Delayed	-€29M	118	5,300	-91,000
Middle	-€36M	1,245	5,300	-67,000
Fast	-€37M	2,600	5,300	-58,000
Policy	-€36M	539	5,300	-76,000

Table 8.3: Overview of the four defined pathways for Scope 3 with their cumulative costs over the period of 2020 to 2050, required emission level as defined in that specific pathway by 2050, actual emission levels in 2050, and cumulative carbon budget exceeded by 2050. All data is presented for scope 1 in the case study of RHDHV NL.

8.4 Excel based tool for Greenhouse gas emission reduction

Initially, RoyalHaskoningDHV provided a concept of the GHG reduction tool, consisting of an outline of possibilities and calculations in the GHG emission reduction tool. Information on carbon footprints, GHG mitigation measures (and thus MAC) and potential pathways was missing. Moreover, interaction between mitigation measures was not accounted for. The aim of the model is to provide insight in a company's current emissions, as well as the targets for 2030 and 2050 as presented in the Paris Agreement and allowed carbon footprint. Moreover, it should provide GHG emission reduction measures in non-ETS emissions of mobility and built environment. The methodology of the model will be described below.

Criteria are presented for the Excel based GHG reduction tool in the form of technical possibilities as well as interpretation of results.

Technical

- Expansion (e.g. insert a new measure) of model should be possible;
- The tool should not only select cheapest option on short-term but also account for the long-term targets;
- The tool should account for interactions between mitigation measures (e.g. double counting) based on costs;
- The tool should account for interactions between mitigation measures (e.g. double counting) based on CO_2-eq emission reduction potential;
- Users should be able to interact and change specific parameters to construct new GHG mitigation pathways.

Interpretation

- The tool should be easy to use;
- Results from the tool should be easy to interpret (visualisation of results);
- The tool should provide a clear overview of current GHG emissions and CO_2 mitigation pathway;
- The tool should provide a short term (2030) and long term (2050) outlook.