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TNO report

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Potential impact and challenges of logistics measures for improving sustainability on the Rotterdam-Venlo corridor

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Summary

This study aims to evaluate the effectiveness of logistics measures in reducing CO_2 and NO_x emissions in the hinterland and continental freight sector in the Netherlands. To conduct this analysis, a case study was selected that focuses on the corridor Rotterdam-Venlo. The transportation on this corridor involves heavy-duty road, inland shipping and rail transport and only includes transportation that have an origin and destination in the COROP regions (division of the Netherlands for statistical purposes) in which Rotterdam and Venlo are located. To assess the impact of different logistics measures on reducing emissions on this corridor, this study makes use of the toolbox called *DeCaMod*. DeCaMod has a database that contains information on tonnes, kilometres and emissions in the Dutch transport sector and how they are distributed over several logistics segments. Hence, DeCaMod can help to identify where in the logistics sector emissions are concentrated. Additionally, DeCaMod can calculate the potential impact of logistics measures and technological measures on emission reduction within the Dutch logistics sector. Therefore, DeCaMod aids in understanding the extent to which various measures can contribute to lowering emissions and reaching climate goals. Its analysis provides valuable insights for policymakers and stakeholders seeking to implement effective strategies to reduce emissions in the logistics sector.

Results
In this study three different scenarios, each consisting of a range of logistics measures with varying effectiveness, were calculated for the Rotterdam-Venlo corridor to show to what extent they can potentially contribute to reducing emissions and reaching climate goals. Figure 1 gives a summarized overview of the results. This shows that the CO_2 reduction in 2030 varies between 10.4% to 15.8% in three scenarios, which all include the same technical measures and have an increasing level of application and subsequent impact of logistics measures. The reference for these reduction percentages are the emissions in 2030 based on the projected growth of volumes. This *reference* scenario (see Figure 1) does not include any technological improvements (the same fleet composition as in 2020 is assumed for this reference scenario, so stricter regulations for vehicle emissions are not taken into account) nor any logistics measures are taken.

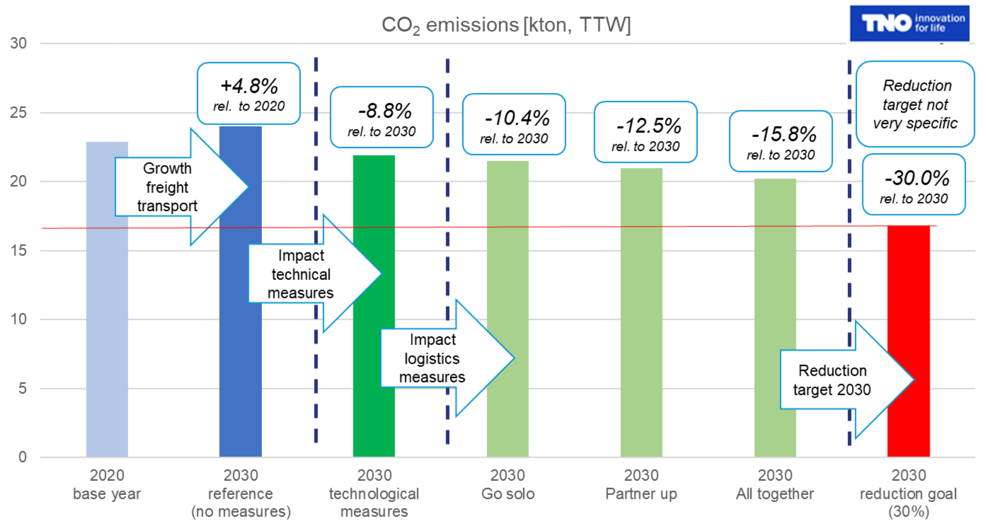


Figure 1: Overview of DeCaMod results: three CO_2 reduction scenarios with logistics measures on the corridor Rotterdam-Venlo.

Considering the 30% reduction target for hinterland and continental freight by 2030, as outlined in the Dutch Climate Agreement, it is necessary to achieve an additional reduction of 14.2% to 19.6% in CO_2 emissions in these three scenarios.

Conclusions

Decamod

- The analysis shows that DeCaMod is a useful tool to give insights into the impact of (combinations of) measures (both logistics and technological) within segments (such as road transport or inland shipping, or by type of goods) and in the logistics sector overall.

Measures

- The results show that a combination of technological and logistics measures is necessary for significant impact on reducing emissions.
- The contribution of logistics measures to the overall impact can be substantial.
- A wide range of measures, including both technological and logistics measures, is necessary to maximize impact on the short term.

Reduction goals on corridor

- The target set for hinterland and continental freight in the Dutch Climate Agreement is ambiguous. It does not specify the reference year for the intended 30% reduction in 2030.
- The impact of the measures that are included in the three scenarios remains uncertain as it hinges upon factors such as the feasibility of the measure, the future growth of transport volume and potential rebound effects.
- To achieve the established climate goals, it is necessary to implement measures with a significantly greater impact.

Discussion

The following actions and issues are identified as relevant for further improvement and extension of our understanding of the potential for CO_2 emission reduction on logistic corridors and facilitating collaboration between stakeholders to develop and implement reduction strategies:

Reduction goals on corridor

- Further exploration of measures is necessary to gain insights into the specific (additional) measures that are required, their applicability to different segments and the impact of these measures on each segment and in total.
- What measures and actions are necessary to reach the climate goals in 2030?

Estimation of impact of measures

- Conduct a sensitivity analysis by varying in growth scenarios, type of measures and effect of measures.
- Improve the estimation of the effect of specific measures by doing more extensive literature research, measuring the effects through pilot implementation or using modelling techniques to capture the effect of measures.
- Perform an analysis of indirect effects and rebound effects associated with the included measures.
- Extend the exploration of measures and their impact to beyond 2030 and include scenarios for 2040 and 2050.

DeCaMod

- Use DeCaMod to start interactive discussions about measures and their impact on segments and in total:
    - On the corridor Rotterdam-Venlo;
    - On other corridors, for specific regions and for the Netherlands.

Contents

1 Introduction

This study aims to examine the potential impact of logistics measures (that aim to improve logistics efficiency) on reducing CO_2 and NO_x emissions in the context of hinterland and continental freight (HCF). To analyse this, the study will conduct a case study that focuses on the logistics trajectory between Rotterdam and Venlo, which involves heavy-duty road transport, inland shipping and rail freight transport. This only includes transportation that has their origin and destination within the COROP regions[1] of Rotterdam and Venlo. The study will explore to what extent logistics measures can potentially contribute to achieving the CO_2 emission reduction targets for HCF by 2030, as established in the Dutch Climate Agreement, and to what extent they can be effective. To demonstrate the potential impact of these logistics measures, the study will use *DeCaMod*[2], a toolbox that can provide valuable insights into the potential emission reductions in (specific segments of) the Dutch logistics sector by calculating the effect of various emission reduction measures. Additionally, challenges associated with introducing these logistics measures, optimizing their effectiveness and meeting long-term climate goals – i.e. achieving zero emission transport – are discussed.

1.1 Context – Dutch climate agreement holds a big challenge for hinterland and continental freight

In 2019 the Dutch Climate Agreement (*Het Klimaatakkoord)* was adopted. By that agreement, the Netherlands is putting the 2015 Paris Agreement – by which governments worldwide committed to limit global warming to 2 degrees Celsius compared to pre-industrial levels while striving for 1.5 degrees – into practice (UNFCC, 2022). For the logistics sector specifically, the Dutch Climate Agreement specifies measures up to 2030, but boils down to eliminating a minimum of 95% of the CO_2 emissions resulting from transport and logistics by 2050. As part of the agreement, the Dutch government set the objective of reducing 30% of CO_2 emissions of hinterland and continental freight (HCF) by 2030. The Climate Agreement does not specify the amount of emissions to which this 30% target applies, nor does it provide a reference year, making the target unclear.

However, to achieve this target, the Climate Agreement has identified two focus areas that could reduce 1.9 megatonnes (Mton) CO_2 by 2030:

- Improving logistics efficiency – 0.9 Mton (including 0.5 Mton as estimated in base projections by PBL);
- Implementation of governmental policies – 1.0 Mton (0.8 Mton European source policy[3]; 0.2 Mton by the implementation of a Heavy Goods Vehicle Charge[4]).

[1] A COROP region is a division of the Netherlands in 40 regions used for statistical purposes. These regions are also used in the EU division of NUTS 3.

[2] www.tno.nl/decamod

[3] European source policy entails legislation that regulates the emissions of vehicles, ships and mobile machinery.

[4] Heavy Goods Vehicle Charge: Dutch and foreign trucks (above 3.5 tonnes) will pay to use Dutch roads on a per-kilometre-driven basis. The government believes that a distance based heavy goods vehicle charge will act as an incentive, encouraging the sector to opt for cleaner trucks and more efficient transport. The net proceeds will be invested in innovative and sustainable measures in the transport sector (Min IenW, 2022).

Furthermore, as part of the Climate Agreement, TLN, Evofenedex and Topsector Logistiek have committed to developing an integrated sectoral approach with the objective to improve the logistics efficiency by on average 2% annually.

To put the decarbonisation targets into perspective, Figure 2 displays the estimated CO_2 emissions of the logistics sector in 2019, that account for approximately 10.6 Mton (Tank to Wheel). This amount can be divided between hinterland and continental freight, accounting for 6.9 Mton, and city logistics that accounts for 3.6 Mton CO_2.

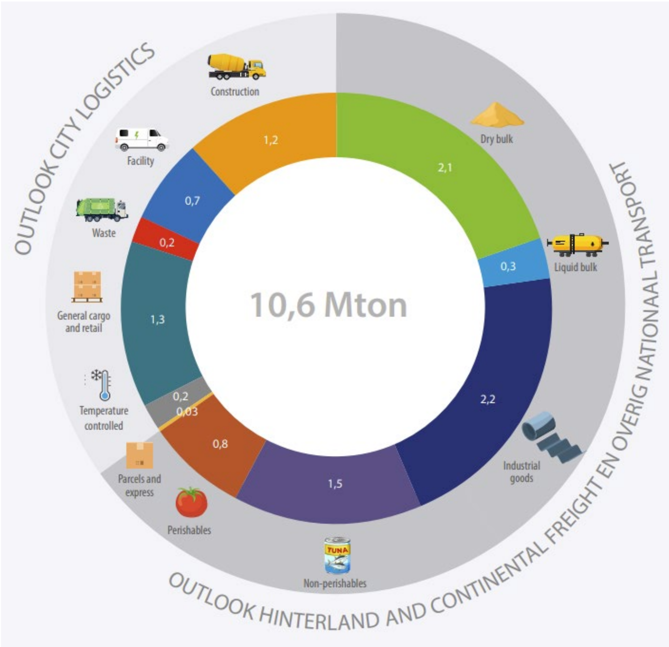


Figure 2: Overview of total CO_2 emissions (Tank to Wheel) of freight transport in the Netherlands for road, rail and inland shipping in 2019 with a breakdown to logistic segments. These CO_2 emissions include domestic transport, import, export and transit excluding transhipment (TNO, 2021).

1.2 Objective – Exploration of decarbonisation measures for hinterland freight on the Rotterdam-Venlo corridor

In this report we focus on hinterland and continental freight (HCF) specifically. We adopt the scope and definition of HCF of the Outlook Hinterland and Continental Freight 2018 (Van de Lande, et al., 2018, p. 16):

> *"HCF focuses on land-based international transport passing through the Netherlands or having its origin or destination in this country. The modes considered here are road, rail and inland waterway transport (IWT). All the hinterland transport that these modes entail is considered, i.e. all freight entering or leaving the Netherlands via a Dutch mainport with an origin or a destination in the Netherlands or abroad. Aviation and maritime shipping are not covered, because there is no undisputable way of assigning CO_2 emissions from those modes and because under the IPCC allocation rules, the emissions of international aviation and shipping are not allocated to countries."*

Over the past few years two Outlook studies on Hinterland and Continental Freight were conducted to provide insights into the possible pathways for HCF transport and logistics in the Netherlands to contribute towards meeting the goals of the Paris Climate Agreement:

- *Outlook HCF 2018* – defines transition paths for five HCF segments – dry bulk, liquid bulk, perishable goods, non-perishable consumer goods and semi-finished products – on an aggregate level (Van de Lande, et al., 2018).
- *Outlook HCF 2020* – defines what needs to be done in the medium term (after 2030) in order to meet the Paris decarbonisation objectives (Otten, et al., 2020).

The studies show that the five different HCF segments follow varying paths towards achieving zero emissions and that certain modes of transport, particularly heavy-duty vehicles and inland ships, may face limitations in adopting zero-emission technologies in the short and medium term (Otten, et al., 2020). The studies highlight that to meet the Paris decarbonization objectives, it is necessary to apply a wide range of decarbonization measures and to adopt a system-level approach. As TNO (2017) also suggests, an integral systems approach is necessary to design and implement effective pathways for realising a sustainable transport system. Thus, it is evident that specific logistics measures must be defined and implemented to reach the target of reducing HCF's CO_2 emissions by 30% by 2030.

To facilitate this process, this report builds further on the knowledge developed in the Outlook studies. Specifically, the objective of this report is to:

Explore the extent to which logistics measures can contribute to emissions reduction of HCF transport on the Rotterdam-Venlo corridor by 2030 and to identify additional actions to accelerate the transition towards a zero emissions corridor by 2050.

The Rotterdam-Venlo corridor is chosen as a case study, as this allows for a detailed look at the various HCF segments and the (in)feasibility for various logistics measures within these segments. This exploration focuses on *physical* measures (measures that physically bring about emission reduction by altering the system), rather than *policy* measures (aimed at enforcing, stimulating or facilitating the implementation of physical measures (such as the Heavy Goods Vehicle Charge)) (TNO, 2017). Physical measures include *technological* measures related to vehicles and energy carriers as well as *logistics* measures that improve the efficiency of the logistics organization ((TNO, 2017); (TNO, 2019)). The primary focus of this exploration, however, is to assess the impact of logistics measures (e.g. load consolidation, modal shift, improved network).

As NO_x emissions have also received increasing attention, especially due to their harmful impact on nature, these type of emissions are also included in this study. EU directives such as the Habitats Directive, as well as the Dutch Clean Air Agreement (*Schone Lucht Akkoord)* impose the necessity of reducing NO_x emissions. The targets for the transport sector in terms of NO_x reduction are, however, less defined than for CO_2. The Clean Air Agreement, for example, aims to achieve 71% less health damage caused by traffic emissions in 2030 compared to 2016, which is partly pursued by the measures outlined in the Climate Agreement.

How this specifically translates to NO_x reduction in the transport sector is unclear. Note that the logistics measures that are considered in this study are not specifically tailored at reducing NO_x. Instead, therefore, the study assesses the potential NO_x reduction as an additional benefit of the included decarbonisation measures.

We aim to identify both the direct individual effect of a specific measure on reducing emissions and the combined effect with other measures. Where possible, the exploration includes feasibility and effectiveness of measures, potential barriers to be overcome and the possible interaction between measures. Next to that, it is assessed to what extent the zero emissions corridor objective can be achieved by implementing already known technological and logistics measures or whether more (radical) measures are needed to achieve the zero emission target.

1.3 Reading guide

The report adopts the following structure:

- Chapter 2 describes the approach and conceptual model for assessment of the logistics emission reduction measures in scope and an introduction to the scenarios for the quantitative assessment in this study.
- Chapter 3 provides a detailed outline of the logistics measures included in the scenarios.
- Chapter 4 explains the methodology of the impact assessment and examines the composition of the Rotterdam-Venlo corridor in terms of transport volumes and emissions per modality and logistics segment.
- Chapter 5 presents the results focusing on the effects of the logistics measures applied to the Rotterdam-Venlo corridor.
- Chapter 6 describes an approach to accelerate the transition towards zero emissions corridor.
- Chapter 7 concludes with a discussion and recommendations, which can be used to develop a research agenda for future studies.

2 Approach and conceptual framework

This research focuses on the impact of logistics measures on the emissions of CO_2 and NO_x of transport on the Rotterdam-Venlo corridor. Through several consecutive steps, we develop scenarios for logistics measures and ultimately assess the impact of these on achieving the zero emission objective for this particular corridor (see Figure 3). The steps proposed in this chapter will be further elaborated on and discussed throughout the following chapters.

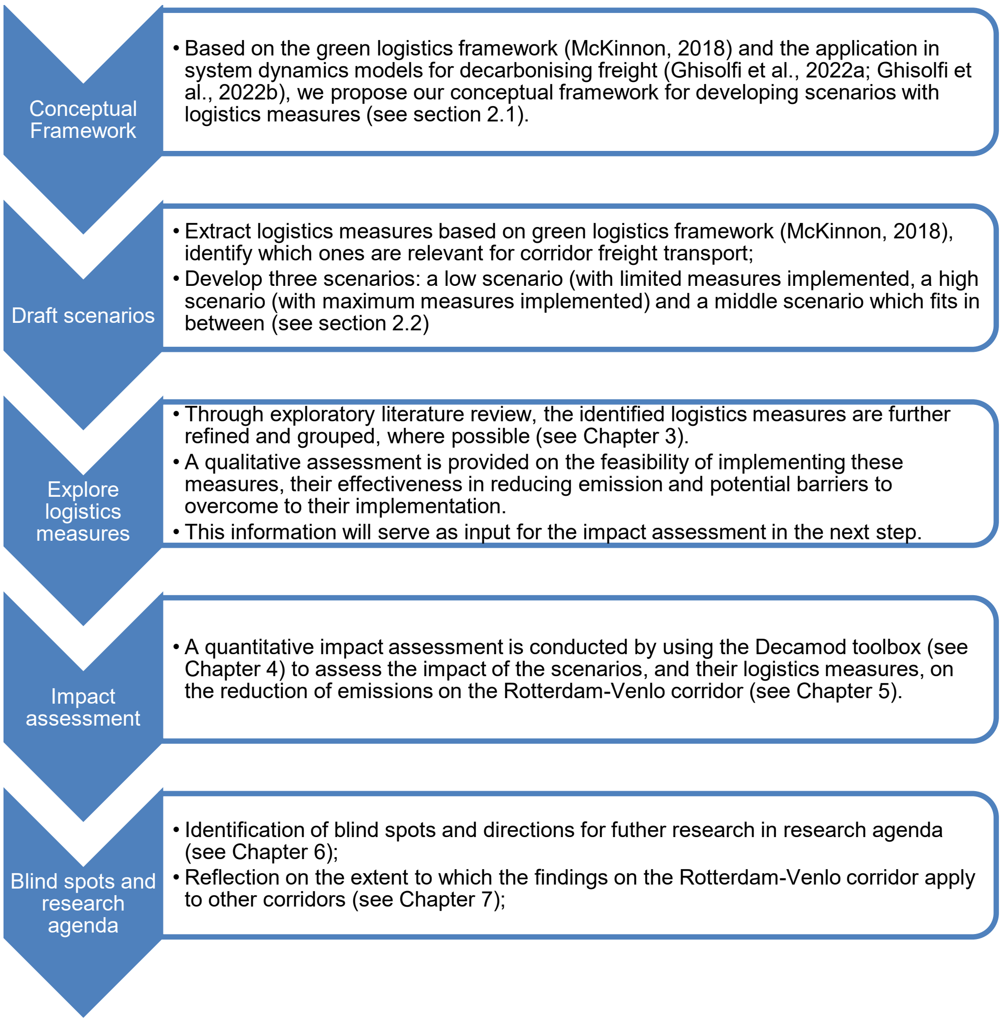


Figure 3: General approach for stepwise scenario development of logistics measures on the Rotterdam-Venlo corridor

2.1 Conceptual framework for developing logistics measures scenarios

In developing the conceptual framework, which prepares for drafting the scenarios in the next step, we build further on the Green Logistics Framework (McKinnon A. , 2018).

This framework describes five broad strategies that stakeholders in the logistics sector can follow to decarbonise transport (see Figure 4):

I. Managing (reducing) freight demand growth;
II. Shifting freight to low-carbon intensity modes;
III. Optimising use of assets and vehicle loading;
IV. Increasing energy efficiency of freight vehicles;
V. Reducing the carbon footprint of energy used.

Within these strategies a broad set of measures can be identified, which will be elaborated on in section 2.3.

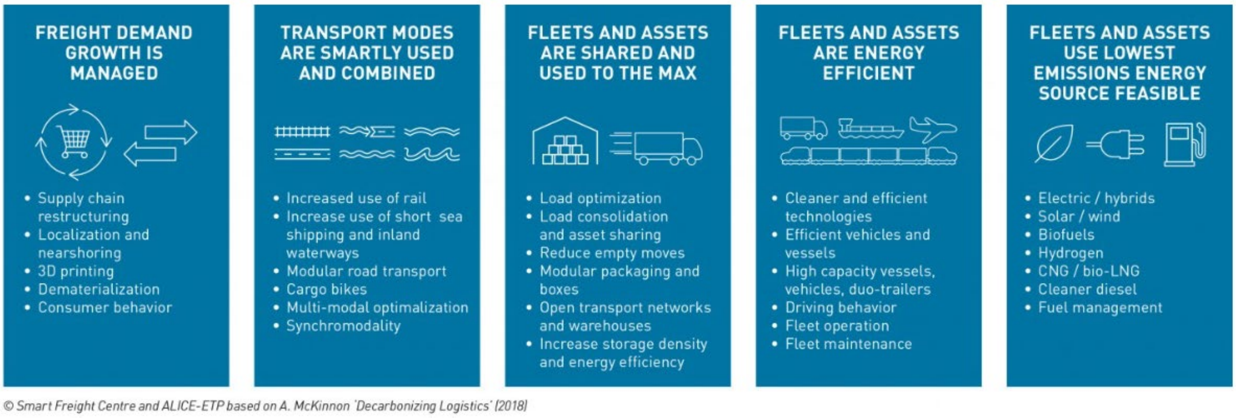


Figure 4: Green Logistics Framework (McKinnon, 2018)

These measures will have an impact on amongst others the number of trips, kilometres travelled, and/or emissions. Logistics stakeholders will not adopt these strategies in isolation. Rather, these follow from their preferences, decisions and behavioural reaction to external factors (Ghisolfi et al., 2022a). The first three strategies focus on logistics measures, which means that these affect the logistics performance and by that have an impact on emissions (in absolute terms or e.g. per ton or per ton-kilometre). The last two strategies are related to technological measures and affect the emissions per vehicle kilometre. While technological measures are taken into account, they are included implicitly in the autonomous baseline scenario, which will be further explained in section 2.3. The main focus of this research will thus be on the effect of logistics measures. However, it is important to note that if vehicles emit less CO_2 and NO_x per kilometre due to technological adaptations (category IV and V), the possible impact of logistics measures, such as consolidation of goods, will be reduced.

While technological and logistics measures are physical ways of reducing emissions (as discussed in section 1.2), external factors also play a role in the level of emissions. For example, regulations can provide instruments to increase the implementation of physical measures, such as the Heavy Goods Vehicle Charge that encourages the sector to use cleaner and more efficient transport. But also pricing mechanisms could be implemented in order to make sustainable logistics alternatives more attractive. However, it is important to note that this study does not explicitly evaluate the effects of policy measures and other external factors on the implementation or effectiveness of physical measures and the level of emissions.

Moreover, it does not address the specific external factors that could help stimulate the adoption of emission reduction strategies.

2.2 Introduction to the scenarios

As previously mentioned, this study primarily focuses on logistics measures and their impact. While external factors are not within the scope of this study, we recognize their importance in determining the extent to which logistics measures are adopted. To account for this, we develop three scenarios that differ in the degree to which logistics measures have an effect on overall emissions on the corridor: a low, middle and high scenario.

The scenarios developed in this study comprise a mix of logistics measures categorized into strategies I through III, as listed at the beginning of section 2.1. Relevant logistics measures are identified through the following steps:

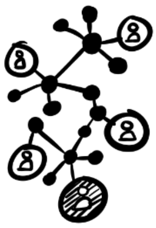
1. A comprehensive list of logistics measures is derived from Punte et al. (2019). These measures are then assigned to the decarbonisation strategies based on the Green Logistics Framework (McKinnon A. , 2018) (see Figure 4).
2. Based on expert opinion it is decided whether these measures are appropriate for long-haul transport and for the Rotterdam-Venlo corridor specifically, and the HCF segments are identified for which they are feasible.
3. Measures that are comparable are consolidated into one category where possible (for clarity reasons).

The three scenarios vary in the extent to which logistics measures are implemented by taking into account two key factors:

1. whether a specific logistics measure is applied in the scenario, based on whether the measure aligns with current decarbonization paradigms or requires increased system thinking and a potential paradigm shift;
2. the effect of the specific logistics measure on emissions reduction. If measures are applied in all scenarios, the extent to which the measure is applied is more widespread in the middle and high scenario.

The descriptions in Table 1 provide an overview of the philosophy of the three resulting scenarios. These scenarios are used to explore the potential outcomes of applying various logistics measures to varying extents. The outcomes are presented as "*what-if*" scenarios and are by no means intended to forecast the future or predict emissions.

Table 1: Scenarios of logistics measures used as input for the emissions assessment

Go solo 	Transporters mainly focus on measures that can be implemented within their own company (no/limited other transport partners / horizontal collaboration required) and some load consolidation or asset sharing might already occur, but only to a limited extent.
Partner up 	Transporters start to look beyond their organization's boundaries and – compared to the *'go solo'* scenario – focus more on load optimisation and consolidation through horizontal collaboration, facilitated by online platforms for example. Also, multi-modal optimisation and synchromodal transport are more and more applied in the logistics and transport sector. Synchromodality in this scenario refers to the extensive cooperation between partners by which real-time mode shifting becomes possible.
All together 	The transport and logistics sector has undergone a paradigm shift whereby focus is on reducing (unnecessary) freight demand by restructuring transport networks and supply chains, reducing bidirectional transport of the same / similar products between regions and influencing customer behaviour. Transport networks are open and connected and synchromodality and asset sharing are at the core (in line with the physical internet concept).

The specific logistics measures included in each of the three scenarios are presented in Table 2. The shades of green indicate the extent to which the measure is applied in each scenario, with darker shades indicating more extensive application. Note that the shading only applies to measures included in all three scenarios.

Chapter 3 will elaborate in more detail on the first three strategies of the Green Logistics Framework and on the specific logistics measures in the scenarios as mentioned in Table 2. Strategies IV and V are equally applied to all scenarios and will be described in more detail in chapter 4.

Table 2: Overview of ZE corridor 2030 scenarios showing decarbonisation strategies and the level of implemented logistics measures (for road, rail and inland shipping) for each scenario (light green: limited application – dark green: extensive application). Note that the shading only applies to measures included in all three scenarios.

<table>
<tr><th rowspan="2"></th><th rowspan="2" colspan="2"></th><th colspan="3">Scenario</th></tr>
<tr><th>Go solo</th><th>Partner up</th><th>All together</th></tr>
<tr><td></td><td colspan="2">Focus on
Decarbonisation strategy</td><td>Logistics measures for lowering emissions, limited load consolidation across organizations</td><td>Increased horizontal collaboration for load optimisation, consolidation and synchromodal transport</td><td>Paradigm shift whereby reducing freight demand growth has a central focus, for example by localisation and nearshoring, and influencing customer behaviour</td></tr>
<tr><td></td><td>I. Managing (reducing) freight demand growth;</td><td>Road, Inland shipping</td><td></td><td></td><td>Supply chain restructuring
Localisation and nearshoring
Decentralisation of production and stockholding
Consumer/ customer behaviour</td></tr>
<tr><td></td><td rowspan="2">II. Shifting freight to low-carbon intensity modes;</td><td>All modes</td><td>Increased use of rail and inland shipping</td><td>+ Multi-modal optimisation
+ Synchromodality</td><td>+ Autonomous transport technologies</td></tr>
<tr><td></td><td>Inland shipping, Rail</td><td>Increased use of rail and inland shipping</td><td>+ Multi-modal optimisation
+ Synchromodality</td><td></td></tr>
<tr><td></td><td rowspan="3">III. Fleets and assets are shared and used to the max;</td><td>Road</td><td>Load optimisation
Load consolidation
Back-hauling</td><td rowspan="2">+ Modular packaging and boxes</td><td rowspan="2">+ Open warehouses and transport networks</td></tr>
<tr><td></td><td>Inland shipping</td><td>Load optimisation
Load consolidation</td></tr>
<tr><td></td><td>Rail</td><td>Load optimisation
Load consolidation</td><td></td><td></td></tr>
<tr><td rowspan="4">Part of baseline scenario</td><td rowspan="2">IV. Fleets and assets are energy efficient;</td><td>Road</td><td colspan="3">Cleaner and efficient technologies</td></tr>
<tr><td>Inland shipping</td><td colspan="3">Rightsizing of engines</td></tr>
<tr><td rowspan="2">V. Fleets and assets use the lowest energy source available</td><td>Road</td><td colspan="3">Optimizing diesel systems
CNG/LNG, Biofuels
Hydrogen, Electric/ hybrid</td></tr>
<tr><td>Inland shipping</td><td colspan="3">Electric/ hybrid shipping
Biofuels</td></tr>
</table>

3 Exploration of logistics measures and their potential impacts

This chapter elaborates further on strategies I to III for reducing emissions of transport and logistics based on the Green Logistics Framework from McKinnon (Figure 4), which are (see section 2.1):

I. Managing (reducing) freight demand growth;
II. Shifting freight to low-carbon intensity modes;
III. Optimising use of assets and vehicle loading.

These specific strategies contain logistics measures rather than technological measures, which aligns with the main focus of this study as discussed in section 1.2. Moreover, through an exploratory literature review, the identified relevant logistics measures for emission reduction on the Rotterdam-Venlo corridor, as part of the scenarios in Table 2, are described in more detail. This chapter provides a qualitative assessment of the feasibility of implementing these measures, their effectiveness in reducing emission and potential barriers to their implementation. The collected information will serve as input for the impact assessment in the next step.

ALICE – the Alliance for Logistics Innovation through Collaboration in Europe – developed the roadmap *Towards zero emission logistics in 2050* (Punte et al., 2019). In this roadmap, the link is made between the decarbonisation strategies of McKinnon (2018) and possible logistics measures. We largely follow the logistics measures described there, supplemented by measures described in the Outlooks Hinterland and Continental Freight (Van der Lande et al., 2018; Otten, et al., 2020). The application potential of each measure is considered by carefully assessing the logistics segments in which they can be effective. In other words, not all measures are applied to all logistics segments.

The following paragraphs provide detailed descriptions of each of the three emission reduction strategies including the specific logistics measures associated with each strategy. Subsequently, based on exploratory literature review, we present the reduction potential for both CO_2 and for NO_x emissions

3.1 Strategy III – Optimising the use of assets and vehicle loading

Current logistics efficiency
Measures that constitute this decarbonisation strategy are mainly concerned with improving the efficiency of logistics by optimizing the load factor of vehicles through load consolidation, asset sharing and back-hauling. These measures are directed at improving the share of total transport capacity (in tonnes or m^3) that is used to actually transport goods, as logistics efficiency decreases when not all load capacity is used or when vehicles / vessels are empty. In line with the above definition, Topsector Logistics currently assumes a transport efficiency of approximately 45% (Ecorys, 2021). This implies that the maximum (theoretical) improvement potential approximates 55% (by which all transport capacity would be utilised).

However, this is only a theoretical improvement potential: in practice a 100% utilisation of transport capacity cannot be reached, amongst others because sometimes volume rather than weight in tons is a limiting factor for vehicle loading, or because there is an uneven spatial and temporal distribution in demand and supply of goods resulting in empty trips (Ecorys, 2021).

Measures to improve logistics efficiency
From a transporter's point of view, logistics efficiency cannot only be achieved by optimizing the own load factors, for example through avoiding empty return trips by backhauling or using advanced planning software for optimizing load, but also by consolidating load with other transporters. The latter is known as horizontal collaboration whereby companies, that are active at the same level of the supply chain, cooperate (Cruijssen, Dullaert, & Fleuren, 2007). In the period 2010-2020 the Dutch Topsector Logistics stimulated horizontal collaboration (in the 4C programme), as in the fragmented transport market in the Netherlands there was quite some efficiency improvement potential (Cruijssen, 2020).

As described in the Outlook HCF 2018 (Van de Lande, et al., 2018) and 2020 (Otten, et al., 2020), sharing of information is required in order to bundle cargo, to reuse empty equipment and to identify cargo flows that can be matched. In the Netherlands, several collaborative transport networks emerged (e.g. Netwerk Benelux, Transmission) and also Cruijssen (2020) identified software providers or Control Tower services that facilitate the matching of transport capacity and demand to improve logistics efficiency. Despite the theoretical potential of horizontal collaboration and best practices that the Topsector Logistics shared, Cruijssen (2020) concludes that not all benefits are realized in practice, as horizontal collaboration can be challenging.

Another logistics measure focused on the further consolidation of goods is modular packaging. By redesigning packaging, boxes and containers for optimal fit to product, modularity allows for more efficient handling, consolidation and loading with goods from other shippers (Punte et al., 2019).

Measure: load optimization, load consolidation and back-hauling
The bandwidth of reduced trips as a result of logistics efficiency that can be realized for road transport between 2011-2050 is estimated to be 4-11% (as compared to reference year 2011), based on a scenario analysis that is conducted in the *Toekomstverkenning Welvaart en Leefomgeving* or WLO 2015 (Romijn, Verstraten, Hilbers, & Brouwers, 2016). Underlying these numbers are estimates of improved average load factor of vehicles / vessels and a reduced percentage of empty trips (Significance, 2019). In order to use the input from the WLO 2015 in our analysis, we interpolated the 4-11% to ensure a match with the base year of the data that is used for the impact assessment (i.e. 2014, see Chapter 4) and 2030. Based on this, potential logistics efficiency savings are estimated to be 2-5.5% (see Table 3).

Measure: modular packaging and boxes
According to Hakimi et al. (2012), applying modular packaging could potentially reduce travel distance by 20% for fast-moving consumer goods. This was established through simulation and by assuming Physical Internet (PI). PI involves encapsulating goods in world-standard, smart and modular containers. PI also exploits the concept of universal interconnectivity of logistics networks and services.

We therefore regard this 20% as the maximum potential. However, due to the short time window until 2030 and minimum influence on international goods which are packed in other countries, we deem achieving a 20% reduction infeasible and therefore adjust the potential effect to 3% in the *partner up* scenario, assuming closed warehouse and transportation networks (i.e. warehouses and modes of transport are not shared). We assume that a quarter of the maximum potential of modular packaging (5%) can be reached in case warehouses and transportation networks are increasingly opened up to other operators. As this measure can potentially be effective for fast-moving consumer goods, in DeCaMod the measure will only be applied to HCF segment *non-perishables.*

Table 3: Summary strategy III (Fleets and assets are shared to the max)

<table>
<tr><th colspan="5">Fleets and assets are shared to the max</th></tr>
<tr><td>Short description of decarbonization strategy</td><td colspan="4">Measures that constitute this decarbonisation strategy are mainly concerned with improving efficiency of logistics by optimizing load factors through load consolidation, asset sharing and back-hauling. In the go solo scenario this is only considered for individual organizations, whereas for the partner up and all together scenario, efficiency improvement can also be achieved by (horizontal) collaboration. In the latter scenario also measures regarding modular packaging are applied.</td></tr>
<tr><th colspan="5">Measure: load optimization, load consolidation and back-hauling</th></tr>
<tr><td>Operationalization of measures for impact assessment</td><td colspan="4">Assumptions
Based on the references used in section 3.1, the lower and upper limit of efficiency savings are 2% and 5.5% respectively. For the partner up scenario an average of these two values is taken;
The effect of the measures (as shown below) are only applied to the following modalities and segments:
For road transport on HCF segments: non-perishables, perishables and semi-finished products
For inland shipping on all container transport.</td></tr>
<tr><td rowspan="2">Estimated impact in the various scenarios on above-mentioned segments</td><td></td><td>Go solo</td><td>Partner up</td><td>All together</td></tr>
<tr><td>vkm/ton[5]</td><td>-2%</td><td>-3.8%</td><td>-5.5%</td></tr>
<tr><th colspan="5">Measure: modular packaging and boxes</th></tr>
<tr><td>Operationalization of measures for impact assessment</td><td colspan="4">Assumptions
This measure is only applied in the partner up and all together scenarios. In the partner up scenario the effect of modular packaging is assumed to be 3%. In the all together scenario the potential effect is estimated to be 5%, where shared used of warehouses and transportation networks is assumed to increase.
As described in Hakimi et al. (2012), modular packaging is mainly applicable to fast-moving consumer goods. This measure is therefore only applied to the following modalities and segments:
For road and inland shipping on segments: non-perishables</td></tr>
<tr><td rowspan="2">Estimated impact in the various scenarios on above-mentioned segments</td><td></td><td>Go Solo</td><td>Partner up</td><td>All together</td></tr>
<tr><td>vkm/ton</td><td>NA</td><td>-3%</td><td>-5%</td></tr>
<tr><th colspan="5">Qualitative assessment of the measures</th></tr>
</table>

[5] Vkm stands for *vehicle kilometres driven*. Note that origin and destination are set fixed for the scope of this analysis, hence vkm/ton.kmGCD (kilometres in Great Circle Distance) does not change.

Confidence on impact estimation[6]		Low / **Medium** / High The measures load optimization, consolidation and back-hauling were combined and impact effects were assigned based on the WLO 2015. No specific estimates could be retrieved for the corridor. Regarding modular packaging a rough estimate was made due to limited availability of studies that assess the potential effect of the measure.
Boundary conditions		The projected efficiency improvements cannot be achieved by solely optimizing one's own operations. Collaboration among several actors is required. This demands a different mindset involving **social innovation**, **information sharing**, and a new approach of organization or **governance**.
Feasibility of implementing measures		Low / **Medium** / High Improving logistics efficiency is no new measure to the sector. Amongst others, the Topsector Logistics stimulated horizontal collaboration in the period 2010-2020, but not all theoretical benefits were realized in practice (Cruijssen, 2020). Thus far, collaboration and efficiency improvement efforts have been voluntary and non-binding. In order to achieve the projected efficiency savings, increased and binding efforts will be necessary. However, since most measures are not new we estimate the feasibility for implementation to be **moderate**.
Required stakeholders		• Shippers: stimulate their transporters to work in an efficient way, contribute to modular packaging. • Transporters: engage in optimizing logistics beyond organization boundaries. • IT-providers / neutral third parties: facilitating information sharing and governance. • Topsector Logistics, Lean&Green Off-road, Sector organizations (e.g. TLN, Evofenedex): sharing best practices.

3.2 Strategy II - Shifting freight to low-carbon intensity modes

Modal shift: from road to rail and inland shipping

By shifting transport from higher pollutant modalities (road) to modalities that pollute less per ton-kilometre, specifically inland shipping and rail, CO_2 and NO_x emissions potentially can be reduced. Earlier research has shown that the potential of goods which could be shifted to rail, however, is limited (TNO, 2017). The upper-level of this potential is expected to be 4% of all piece goods. This is seen as a maximum potential because this analysis was only based on a costs comparison; capacity on the rail network was not taken into account for example. Therefore the share of modal shift is varied between 1 and 4% to both rail and inland shipping. The maximum modal shift is achieved in the scenario were synchromodality takes place, as discussed below.[7]

[6] The paragraphs 3.1-3.3 provide an overview of the three different decarbonization strategies that involve logistics measures and their potential impacts. In the course of gathering the required information, we observed that not all information was readily available. Therefore, in order to be transparent about how we arrived at the figures used in this study, Table 3 and Table 5 include a qualitative assessment by the authors on the *confidence of the estimated impacts* of the logistics measures on improving logistic efficiency in vkm/ton (varying from low-medium-high).

[7] Note that this modal shift effect of 4% is based on a study which looks into the overall potential for modal shift in the Netherlands. This potential could be different (and thus also potentially higher) for transport between Rotterdam and Venlo specifically.

Additional efficiency improvements: synchromodality
In the WLO 2015 scenario analysis a qualitative exploration of the impact of synchromodal transport on logistics concepts and logistics efficiency is discussed. Potentially, synchromodal transport or a-modal booking by shippers can contribute to a more efficient and reliable logistics system as logistics service providers can flexibly choose the optimal transport mode (instead of shippers determining the transport mode in advance). When synchromodal transport is broadly adopted, it can be expected that efficiency gains will be above the upper limit of the presented bandwidth. Important boundary conditions are the availability of integrated supply chain information and standardisation of loading units (Tavasszy et al., 2010).

Measure: Autonomous vehicle technologies[8]
For road transport, for a small percentage of the fleet the use of autonomous vehicle technologies was assumed in the *all together* scenario. The effect of the measure was based on a study by TNO (2021b), which evaluated the effect of truck driving with Adaptive Cruise Control on fuel consumption. As such, for the *all together* scenario a potential reduction in CO_2 per kilometre of 4% was assumed. However, it should be noted that this measure was only applied to 1% of the truck fleet as the use of autonomous technologies by 2030 is expected to remain limited due to complexity in regulations.

Table 4: Summary strategy II (Shifting freight to low-carbon intensity modes)

Shifting freight to low-carbon intensity modes					
Short description of decarbonization strategy		Increased use of rail and inland shipping, multimodal optimization and synchromodality as well as implementation of autonomous technologies in road transport.			
Operationalization of measures in DecaMod		*Assumptions* • Based on the references used in section 3.2, the lower and upper potential of modal shift from road to rail and inland shipping, and multimodal optimization are 1% and 4% respectively. For the partner up scenario we averaged these two values; The modal shift measure is only applied to the following modalities and segments: - Shift from road to rail and inland shipping on all container transport. • The use of autonomous vehicle technologies was only applied to 1% of road transport with an estimated CO_2 reduction per kilometre of 4% in the *all together* scenarios. In the other two scenarios, the use of autonomous technologies is not included.			
Estimated impact in the various scenarios for above-mentioned segments			*Go Solo*	*Partner up*	*All together*
		Modal shift in tonnage from road to inland shipping and rail	-1%	-2%	-4%
		Autonomous technologies on CO_2/vkm for road transport			-4% (for 1% of the fleet)
		Low	Medium		High

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[8] In essence, the use of autonomous vehicle technologies is not considered a logistics measure. However, we found this to be a noteworthy measure to take into account above the effect of more conventional technological measures (such as improve motor efficiency) as a result of regulations.

Confidence on impact estimation		As discussed in the report, the possible effects of the modal shift measures are not tailored to the corridor specifically.		
Boundary conditions				
Feasibility of implementing measures		Low	Medium	High
		The feasibility varies on the specific local context of the corridor and may require investments to realize changes in infrastructure and supply chains.		
Required stakeholders		• Governments: to promote modal shift and autonomous technologies through policy interventions. • Logistics service providers: to facilitate modal shift by providing reliable and efficient transport services. • Shippers: to demand services (mode of transports) that align with sustainability goals. • Technology providers: to develop and deploy innovative solution that support smart choices in terms of transport modalities used.		

3.3 Strategy I - Managing (reducing) freight demand growth

Measures to manage freight demand growth
According to McKinnon's decarbonization framework, achieving zero emission logistics before 2050 is more difficult if freight keeps growing according to current predictions (McKinnon, 2022). Especially in view of the stringent need, following from the 1.5 degree target, to limit the cumulative CO_2 emissions on the way to 2050, it will be necessary to also manage (the growth of) demand for freight transport.

Although there are uncertainties regarding the magnitude of effects, one way to manage freight demand is by restructuring supply chains (McKinnon, 2007). This can be achieved by returning to more decentralized logistics systems through localization, which involves bringing production closer to consumption, and by nearshoring, which involves sourcing materials closer to manufacturing when possible. These measures are expected to reduce global, regional and national freight movements, but may result in increased carbon emissions in other sectors due to the loss of economies of scale (McKinnon, 2022). It should also be noted that localization and nearshoring might not necessarily lead to less transport movement on specific corridors, because despite bringing the production location closer to consumption, the use of main ports such as Rotterdam might still be necessary.

It is proposed that managing freight demand growth also involves reducing the amount of goods that needs to be moved by adopting more sustainable patterns of consumption. This can be achieved by influencing consumer behaviour and implementing measures such as downsizing, lightweighting, digitization of products, product lifetime extension and avoidance of current product and packaging waste (McKinnon, 2022). Influencing consumer behaviour could be achieved through awareness-raising and education on their purchasing habits and encouraging or even regulating re-use, refurbishements, remanufacturing and recycling.

Managing and reducing freight demand growth (partly) aligns with the broader *degrowth* paradigm that advocates a planned, coherent policy to reduce ecological impact by reducing growth (in classic GDP terms) and inequality, while improving well-being (Hickel, 2021).

Freight demand reduction potential
To our knowledge, no studies have been performed yet that explore the effect of one (or more) of the abovementioned measures aimed at managing freight demand growth. As such we will work with the assumption that the maximum reduction potential is 5%.

Table 5: Summary strategy I (Managing (reducing) freight demand growth)

<table>
<tr><th colspan="5">Managing (reducing) freight demand growth</th></tr>
<tr><td>Short description of decarbonization strategy</td><td colspan="4">The distance travelled for freight transportation can be reduced by restructuring supply chains through measures such as decentralization and nearshoring. Additionally, demand for freight transportation can be decreased by influencing consumer behaviour as well as downsizing, light weighting, digitization of products and the avoidance of excessive product and packaging waste.</td></tr>
<tr><td>Operationalization of measures for impact assessment</td><td colspan="4">Assumptions
The effect of managing (reducing) freight demand growth is assumed to be 5%.
The measures are applied to the HCF segments: non-perishables, perishables and semi-finished products</td></tr>
<tr><td rowspan="2">Estimated impact in the various scenarios on above-mentioned segments</td><td colspan="2">Go Solo</td><td>Partner up</td><td>All together</td></tr>
<tr><td>vkm/ton</td><td>NA</td><td>NA</td><td>-5%</td></tr>
<tr><td rowspan="2">Confidence on impact estimation</td><td>Low</td><td>Moderate</td><td colspan="2">High</td></tr>
<tr><td colspan="4">In the exploratory literature search, no figures were found that could be applied. For this reason a rough assumption was made and the confidence on impact estimation is low.</td></tr>
<tr><td>Boundary conditions</td><td colspan="4">Mental shift – rethinking of supply chains and consumption patterns is required
Redesign of existing business models
Creating suitable infrastructure (may involve building new facilities or adjusting current ones (warehouses, ports, etc.) to accommodate changing demands)</td></tr>
<tr><td rowspan="2">Feasibility of implementing measures</td><td colspan="2">Low</td><td>Moderate</td><td>High</td></tr>
<tr><td colspan="4">From today until 2030, only a limited timeframe remains to radically redesign our supply chains and consumption patterns. Given the challenges of overcoming existing business models, infrastructure and social barriers in a short amount of time, the estimated feasibility of implementing these measures is low.</td></tr>
<tr><td>Required stakeholders</td><td colspan="4">Manufacturers: they may shift production to locations closer to end markets allowing for reduced transport demands (distances) and adjust their products and packaging (e.g. by downsizing);
Retailers: the may redesign their supply chain and business models by moving to more localized supply chains and sourcing products from nearby manufacturers and distributors.
Logistics service providers: this group can support other stakeholder groups in helping them implement changes to their supply chain by altering their operations to support more decentralized supply chains;
Policy makers: can play a role by investing in infrastructure to support new practices;
Consumers: through their purchasing choices they can have an influence on driving demand for sustainable logistics patterns.</td></tr>
</table>

4 Approach to quantitative impact assessment

Having described the scenarios, logistics measures and their corresponding effects, this chapter will explain how the impact of these scenarios and measures is calculated for the Rotterdam-Venlo corridor, and how impacts on ton-kilometres and vehicle kilometres are translated to impacts on CO_2 and NO_x emissions. To assess the impact of the scenarios on emissions on the Rotterdam-Venlo corridor, DeCaMod (Decarbonization model) developed by TNO (2020) is used. DeCaMod is an emissions accounting model which aims to provide insights into the potential impact of logistics measures on reducing emissions. Section 4.1 will first describe DeCaMod's general usage and capabilities. In section 4.2 it is explained how DeCaMod is used to gain an overview of the emissions on the corridor Rotterdam-Venlo specifically and how the impact of emission reduction measures is calculated. To conclude, section 4.3 will provide an overview of the current emissions on the corridor.

4.1 DeCaMod: a valuable tool for assessing the impact of emission reduction measures in the Dutch logistics sector

DeCaMod is a tool that provides valuable insights into the total emissions of CO_2 and NO_x that are generated by various modes of transport (road, inland shipping and rail) on Dutch soil, both in the present and for future years. By utilizing detailed data on transport flows in the Netherlands, DeCaMod helps to gain a better understanding of emissions distribution across different logistics segments, type of goods, modalities and specific origin-destination pairs. With this knowledge, DeCaMod assists in pinpointing areas where emission reduction measures can potentially have large impact.

One of DeCaMod's primary strengths lies in its ability to conduct scenario modelling. By exploring "what-if" situations to assess the potential impact of different logistics and technological measures and strategies, various sustainability scenarios can be compared. The outcomes facilitate informed decision-making, allowing policymakers and other stakeholders to identify the most effective approaches for reducing emissions in the logistics sector.

DeCaMod further offers a flexible and tailored approach by having the ability to customize the extent of measures based on the specific characteristics of logistics segments, modalities, vehicle types, type of goods, and origin-destination pair(s). This adaptability ensures that emission reduction measures can be fine-tuned to the unique context of each logistics subsegment. DeCaMod can hence calculate targeted scenarios that address specific emission reduction challenges and opportunities of different logistics segments.

Overall, DeCaMod combines detailed data on the transport flows in the Netherlands and customized scenario modelling to provide insights into the emissions in the logistics sector. It serves as a useful tool for policymakers and other stakeholders to make informed decisions, identify emission reduction opportunities and define targeted action to lower emissions in the logistics sector and achieve climate goals.

4.2 Impact assessment by using DeCaMod

This section addresses how DeCaMod is used for calculating the impact of emission reduction scenarios on the Rotterdam-Venlo corridor specifically. It begins by providing an explanation of the data sources utilized by DeCaMod to determine transport flows and emissions on the Rotterdam-Venlo corridor. Furthermore, the DeCaMod methodology for calculating the impact of emission reduction measures is described.

4.2.1 Data sources for determining transport flows and emissions

Transport flows

DeCaMod contains detailed information on freight transport within the Netherlands including freight transport volumes, vehicle kilometres, modal split, and emissions. As input for the flow of goods, DeCaMod utilizes the Basisbestanden Goederenvervoer (BBGV), which also serve as input for the Basismodel Goederenvervoer (base model for freight, BasGoed) of PBL (Planbureau voor de Leefomgeving). The BBGV data contains information on transported tonnes of freight, vehicle kilometres driven (vkm) and ton kilometres per modality, vehicle type and type of goods (according to the NST 2007 classification[9]) between specific origins and destinations. These origins and destinations are identified by COROP regions.

The BBGV data used in DeCaMod provide information on freight transport on Dutch soil for the base year 2014. To project the impact of logistics measures on emissions in 2030, a growth scenario was applied in DeCaMod considering autonomous growth of transport demand and technological developments in the vehicle fleet (autonomously + forced by regulation). This scenario aligns with established policies related to sustainability, following the findings of the Klimaat- en Energieverkenning (KEV) (PBL, 2022). The modelling approach builds upon the calculations of the KEV 2019 scenarios using BBGV data, as described in Wesseling et al. (2019). As a result, DeCaMod provides data on transport flows within the Netherlands from 2014 to 2030, while applying linear interpolation for the years between 2014 and 2030. Further details on this can be found in TNO (2020).

To specifically extract transport flows related to the Rotterdam-Venlo corridor, a subset of the national data within DeCaMod is selected based on the COROP regions corresponding to Rotterdam and Venlo. To be specific, Rotterdam is located in COROP region 29 (Groot-Rijnmond) and Venlo is located in COROP region 37 (Noord-Limburg). **Only transportation that has its origin and destination within these regions is included in the selection.** For example, any transport that begins in Rotterdam, has a destination in Germany and passes through Venlo without stopping is not considered. Limiting the scope to this specific selection increases the likelihood of effectively implementing measures as it allows for a targeted strategy that aligns with local needs and resources along the corridor. The measures included in the emission reduction strategies in this study may for example require physical adaptations to facilitate their implementation.

[9] https://www.cbs.nl/en-gb/onze-diensten/methods/definitions/commodity-nomenclature-nst-2007

In this regard, locations such as Rotterdam and Venlo serve as possible locations to support the implementation of these measures, such as to consolidate goods. For direct transport to/from Germany this could be more challenging to realize.

It is also important to note that light-duty transport with vans is excluded from the corridor selection as they are assumed to mainly be part of city logistics, whereas this study focuses on HCF.

Emissions
In DeCaMod, emissions of CO_2 and NO_x are determined based on driven kilometres and detailed emission factors per vehicle kilometre. The following paragraphs will explain how the (prognosis of) emission factors for road, inland shipping and rail were obtained to compute the total emissions on the corridor.
On a general note, the prognosis of the emission factors to 2030 implicitly takes into account measures in Strategy IV (such as more efficient engines and use of biofuels) and Strategy V (zero emission technologies) of McKinnon.

Road
In the corridor selection by DeCaMod several vehicle types are distinguished: medium truck, heavy truck and a heavy tractor-trailers. To derive emissions from road transport, emission factors of the VERSIT+ model were used, which estimates the emissions of vehicles based on their vehicle characteristics while also distinguishing between road type-specific emissions (inner city, regional road, motorway). These emission factors are based on real-world emission measurements and monitoring conducted by TNO over decades. These emission factors are also used for the Dutch national emission totals (Emissieregistratie) and emission predictions (KEV), among other applications.

As detailed insights into vehicle characteristics (such as emission class, construction year or fuel type) specific to the Rotterdam-Venlo corridor were not available, aggregated emission factors were used in line with the available transport data. The emission factors were hence aggregated to vehicle type, namely medium truck, heavy truck and a heavy tractor-trailers. These aggregated emission factors specifically consider emissions on motorways (so excluding inner city and regional roads).

To determine these emission factors, the emissions per kilometre were considered taking into account a fleet composition that includes information on the (current and prognosed) annual vehicle kilometres driven per vehicle class. This composition combines vehicle type, year of construction, emission class and fuel type, and is representative for heavy-duty transport on motorways in the Netherlands.
The vehicle kilometres of the current year are produced by the Taakgroep Verkeer en Vervoer of de Emissieregistratie, while PBL models the fleet composition and corresponding kilometres for future years (for the KEV 2022). The aggregated emission factors used were weighted according to the relative share of each vehicle class in the total number of (current and prognosed) vehicle kilometres within a specific vehicle type. The emission factors assume regular traffic flow conditions.

By incorporating the emission factors and fleet composition specific to motorways, DeCaMod acknowledges the differences in emissions between vehicles operating on motorways and those driving in urban environments due to different driving conditions as well as different vehicle characteristics. As mentioned before, insights into detailed vehicle characteristics on the Rotterdam-Venlo corridor were not available. For a more precise analysis, it could be beneficial to use license plate scans specifically on the motorways within the corridor. These scans would provide insights into the fleet composition allowing for more accurate emission factors.

The resulting aggregated emission factors are multiplied by the number of vehicle kilometres per vehicle type according to the subselection of data in DeCaMod for the corridor (described in Chapter 3), which results in the total annual emissions of transport on the corridor.

Inland shipping
For NO_x, detailed emission factors per kilometre were used, based on the model POTAMIS, which align with the emission factors that are used for inland shipping in the Emissieregistratie and the AERIUS Calculator ((TNO, 2020); (TNO, 2021); (TNO, 2021b)). These are specified to waterway category CEMT Va (corresponding to the CEMT class of the waterways of the corridor) and type of ship. The emission factors also contain a prognosis for 2030.

For CO_2, these detailed emission factors were not available. To deal with this, an overall CO_2 emission factor / ton.km was used based on information from the KEV 2022 on volumes (total ton-kms) and total emissions. An overall emission factor was produced for both 2020 and 2030.

Rail
To determine the emissions of rail transport, emission factors for CO_2 and NO_x per ton-kilometre were determined. These emission factors are based on the total annual number of ton-kilometres in rail transport from the KEV 2022 for 2020 and 2030 as well as on the total rail transport emissions in 2020 and 2030. The emissions in 2030 are based on the Emissieregistratie (ER). In addition, data from the KEV 2022 (PBL, 2022) and LuVo (PBL, 2023) were used to obtain the emissions of rail transport in 2030. It's important to note that emissions for 2030 are an estimate because, in both the KEV 2022 and LuVo, the emissions are not specifically categorized for rail freight transport. Instead, they are combined with other categories, such as passenger transport by rail. To address this, the share of rail freight transport compared to rail passenger transport in 2020, according to the ER database, was assumed to remain the same for 2030. This assumption allows for an estimation of rail freight transport emissions in 2030 based on the known proportions from 2020.

4.2.2 Methodology for calculation of effects

Besides establishing the baseline scenario for the Rotterdam-Venlo corridor, DeCaMod is also used to calculate the impact of the developed scenarios (which were described in section 2.2). The calculation of the impact of measures on emission reduction follows the conceptual representation in Figure 5. This figure show the decomposition of CO_2 emissions of logistic operations into different determinants that act at the levels of fuel, vehicle and road type, logistics efficiency (determined by the logistics and supply chain) and transported weight (determined by the production system (density, product design and packaging, number of products)) (TNO, 2019).

The specific determinant affected by a measure depends on the type of decarbonization measure being implemented. For example, electrification directly impacts the parameter gCO_2/vkm as it reduces the emissions associated with the fuel used per kilometre. On the other hand, if a measure focuses on consolidating goods, it leads to a decrease in the current value of the parameter vkm/ton. This is because fewer vehicle kilometres are required to transport the same amount of goods, resulting in increased transport efficiency. As transport efficiency improves, there is a corresponding reduction in emissions. TNO (2020) describes the DeCaMod calculation in more detail.

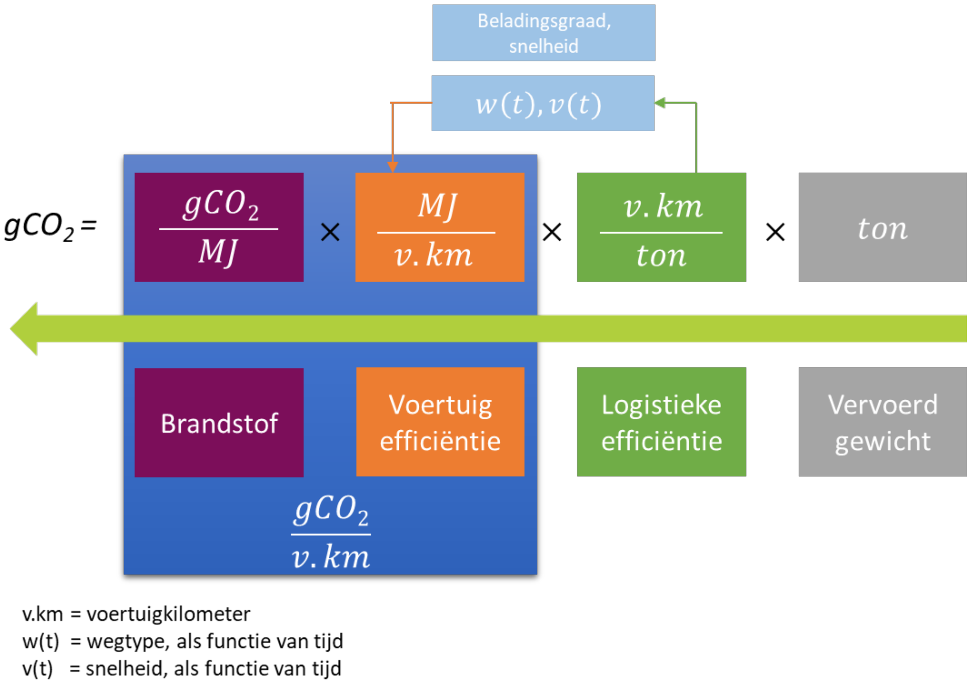

Figure 5: Impact assessment method in Decamod, based on TNO (2019).

By incorporating measures and their corresponding effects into DeCaMod, it is evaluated how different scenarios impact key parameters related to transport efficiency and emissions. DeCaMod takes into account specific details such as modality, vehicle type and type of goods when determining the values of these parameters to ensure that the calculations accurately reflect the specific characteristics of logistic segments. Related to this, DeCaMod adjusts the parameters affected by a measure based on the measure's specific implementation with the transport system. For example, the adjustments are made selectively for particular logistics segments or modalities, rather than applying the measure uniformly across the entire transport system. This level of granularity allows for a more tailored approach in calculating the impact of measures on emissions

Now it has been explained how DeCaMod calculates the impact of measures, Section 4.3 will present the estimated emissions of the Rotterdam-Venlo corridor (as calculated by DeCaMod) in 2020 and provide an overview of how these emissions are distributed across different modalities and segments. Moving forward to Chapter 5, the outcomes of the scenario analysis by DeCaMod will be described.

4.3 Baseline scenario: 2020 emissions on Rotterdam-Venlo corridor

4.3.1 Current situation logistics sector

In this study the baseline year is set on 2020. We first analyse this situation by looking at the transported tonnes and emissions of CO_2 and NO_x differentiated per transport mode. In order to get an idea of magnitudes, the transported volumes on the corridor Rotterdam-Venlo are compared with all freight transport in the Netherlands in Table 6. In terms of weight, the majority of freight on this corridor is transported by inland shipping followed by road and rail. Freight transport in the Netherlands is primarily dominated by road transport.

Table 6: Total volume on the corridor per modality in comparison to total transport volume in the Netherlands.

Volume (million tonnes) - 2020			
Modality	**Corridor**	**Total NL**	**Share corridor in total transport in NL**
Inland shipping	1.9	379	0.5%
Rail	1.2	49	2.4%
Road	1.3	1231	0.1%
Total	**4.3**	**1659**	**0.26%**

Figure 6 shows the projected growth in transported volumes per modality on the corridor until 2030. Transport by rail increases by 39%, while the volumes transported by road decrease by about 4%. This change in modal split can be attributed to various local measures that were included in the growth scenario by Significance (2019), such as local agreements between the Port of Rotterdam and companies on the Maasvlakte. Also, the introduction of the Heavy Goods Vehicle Charge is assumed. These measures likely play a role in the projected change in modal split.

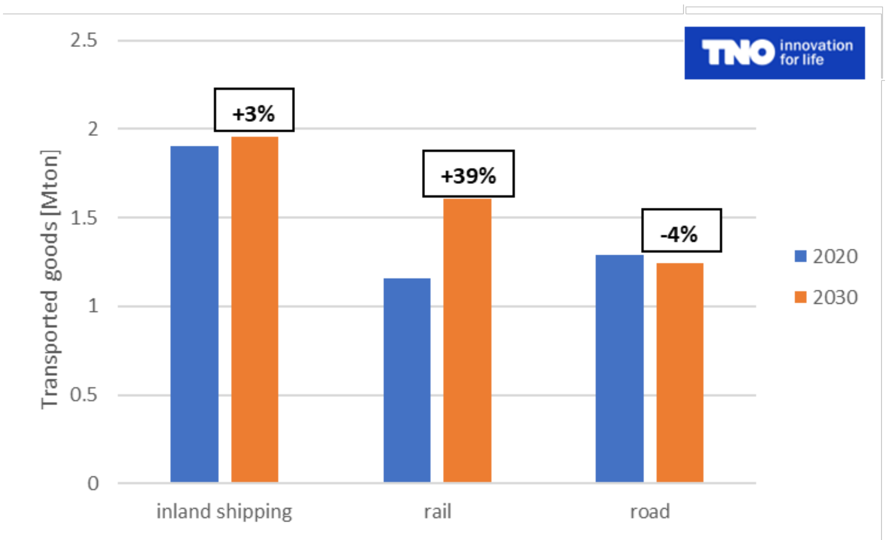

Figure 6: Growth scenarios on the corridor Rotterdam-Venlo towards 2030 per modality.

Table 7 illustrates the total CO_2 and NO_x emissions on the corridor in absolute numbers for 2020 and 2030 with autonomous growth. Road transport is the largest contributor to CO_2 emissions, accounting for about 60% of the total, followed by inland shipping. In NO_x emissions, inland shipping is dominant and responsible for about 75% of the total emissions. As can be seen, the CO_2 emissions of inland shipping slightly increase towards 2030, while a significant decrease in NO_x emissions is visible. This can be attributed to the fleet renewal, which has a more significant impact on reducing NO_x emissions due to the use of cleaner diesel engines.

Table 7: Total emissions of CO_2 and NO_x on the corridor Rotterdam-Venlo (transports with origin and destination in COROP regions in which Rotterdam and Venlo are located) in 2020 and 2030 with autonomous growth.

	CO_2 (kton, TTW)		NO_x (ton, TTW)	
	2020	**2030**	**2020**	**2030**
Inland shipping	7.6	7.7	223	185
Rail	1.3	0.9	29	33
Road	14.8	13.3	38	33

The next figure differentiates the CO_2 emissions per HCF segment and per modality. This shows that, for example, about 20% of the CO_2 emissions on this corridor are emitted by inland shipping transporting containers, while about 30% is caused by trucks carrying containers (as mentioned before, note that this only involves transports with origin and destination in Rotterdam and Venlo). This is as expected, because Venlo is a strategically located inland logistics hub within the corridor of the Port of Rotterdam and hence the selected corridor in this study involves an important route for container transportation. In total 55% of the CO_2 emissions on this corridor are associated with container transport. Emissions by road transport account for more than 60% of the total CO_2 emissions.

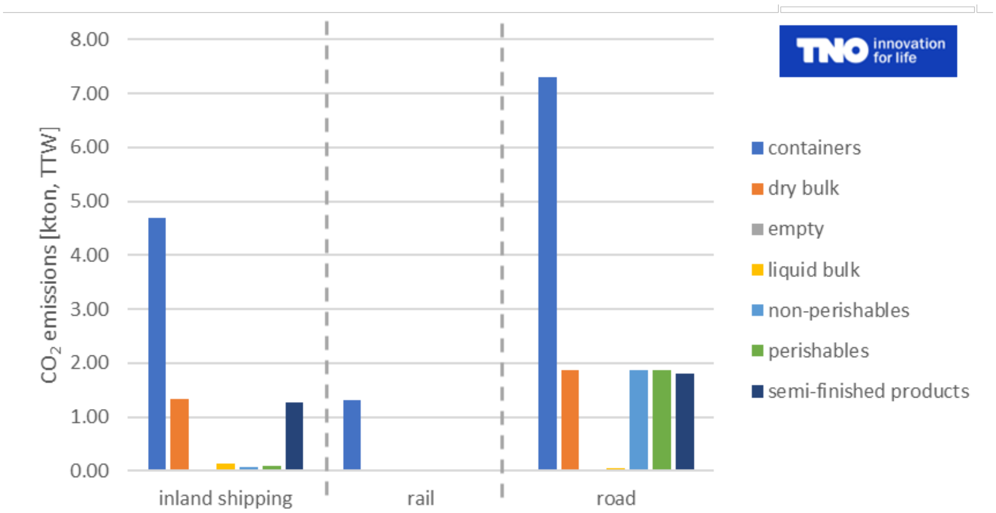

Figure 7: CO_2 emissions per modality per segment.

Also for NO_x emissions the largest amount is emitted by transporting containers, but in this case the contribution from inland shipping is ten times higher than from trucks. Nearly 80% of the NO_x emissions are a result of inland shipping.[10]

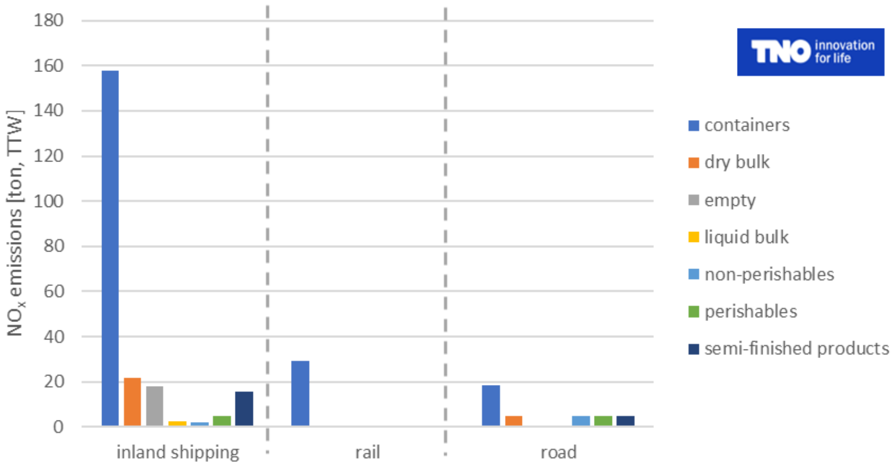

Figure 8: NO_x emissions per modality per segment

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[10] For inland shipping the relative contribution of segments to emissions differs between CO_2 and NO_x due to a different approach of calculating emissions. For CO_2 an emission factor per ton-kilometre was used whereas for NO_x an emission factor per vehicle kilometre. In section 4.2.1 this was described in more detail.

5 Zero Emission corridor 2030: scenario analysis of logistics measures

This chapter analyses the effect of logistic measures on emissions of CO_2 and NO_x on the corridor Rotterdam-Venlo for 2030. Effects are calculated with Decamod for different scenarios, as was elaborated on in the previous chapters. This involves three scenarios, which were described in detail in chapter 2: *go solo*, *partner up* and *all together*.

5.1 Analysis of logistics measures

Figure 9 shows the impact on CO_2 emissions of the scenarios with logistics measures on the Rotterdam-Venlo corridor. Based on Decamod, the emissions from transport on the corridor in the *reference* scenario (in 2030) is 24.0 kton CO_2. In case of autonomous growth, which takes into account *technological measures*, emissions decrease by 9% compared to the 2030 situation without increased use of clean and zero emission technologies (referred to as *reference* in Figure 9). The logistics scenarios demonstrate that on top of emission reduction by technological measures, 2 – 7% extra emissions can be reduced by logistics measures by 2030 according to the scenario calculations. Especially, measures in categories **II** and **III**, which focus on shifting freight to modalities with a lower carbon intensity and shared use of fleet and assets, have a great share in the additional reduction potential. Figure 9 shows that relying solely on clean and zero emission technologies is insufficient for achieving CO_2 reduction goals. It also show that by taking logistics measures the reduction potential is increased, but that more actions are needed to increase the reduction potential.

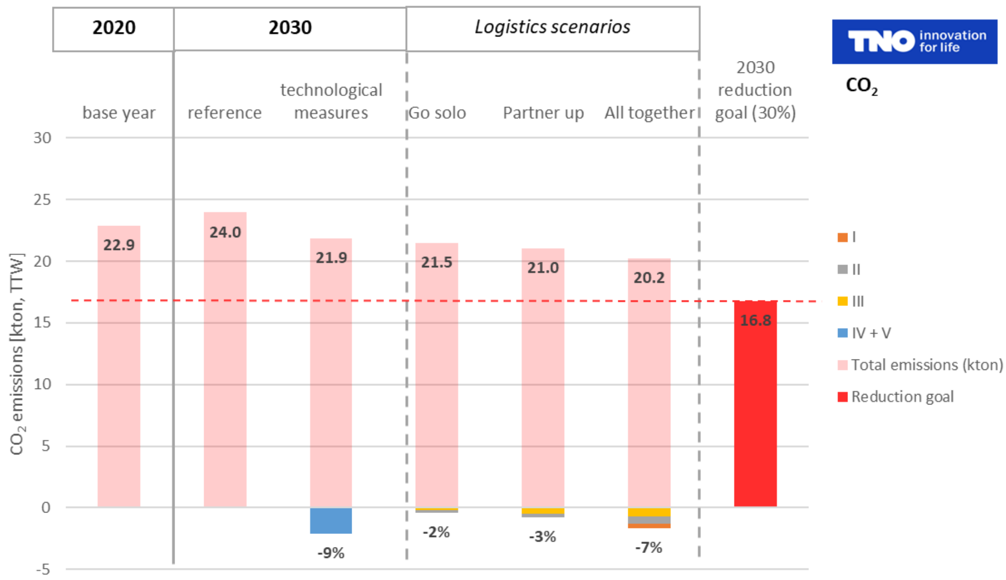

Figure 9: Total emissions of CO_2 (all modalities included) on the corridor Rotterdam-Venlo in 2020 and 2030 for different scenarios.

Figure 10 shows the effect of the different type of measures for the modality *road* on CO_2 emissions. While about 7% of the emissions are reduced due to *technological measures* compared to the 2030 situation in which no technological improvements took place (*reference)*, an additional reduction of about 11 percentage point can potentially be achieved due to logistics measures. This is significant, especially because the CO_2 emissions from road transport have a relatively high share in the total CO_2 emissions on this corridor as Table 7 showed.

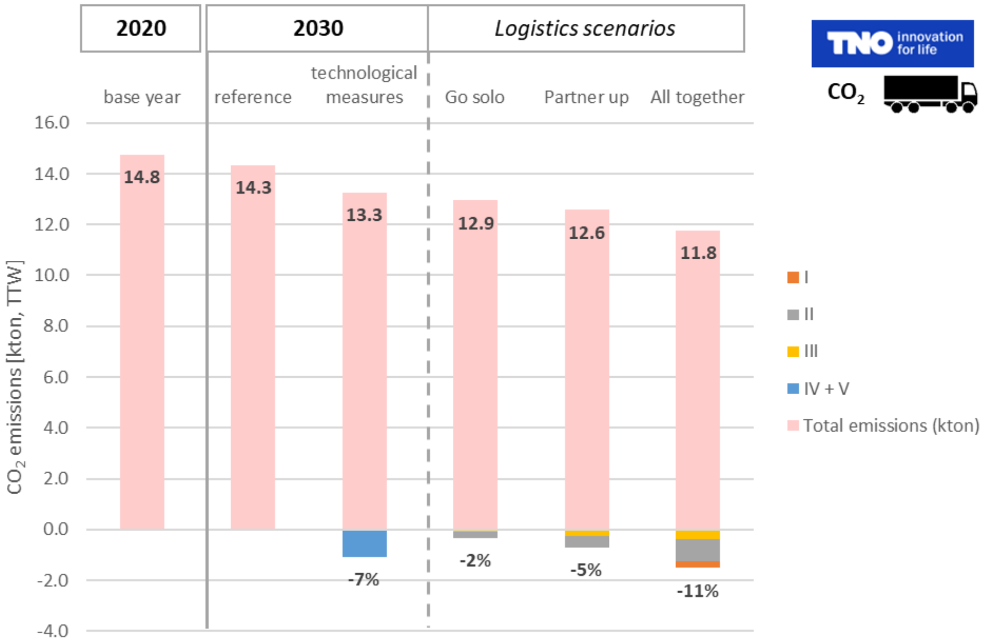

Figure 10: Total emissions of CO_2 for the modality road, on the corridor Rotterdam-Venlo in 2020 and 2030 for different scenarios.

For the modality *inland shipping*, Figure 11 shows that the effect of *technological measures* is limited (1% compared to the *reference* scenario). This is because the fleet renewal of vessels, that is expected to take place in future years, is mainly towards cleaner diesel engines rather than zero emission technologies. The effect of cleaner diesel engines on CO_2 emissions is limited (but does have a considerable effect on other emissions, such as NO_x and particulate matter). Since the effect of technological measures in inland shipping on CO_2 reduction is relatively small, logistics measures can instead potentially have a relatively large impact on reducing emissions. According to the scenario calculations, the impact of logistics measures is around the same order of magnitude as the effect of technological measures in inland shipping, ranging from 1 to 2%. It should be noted that due to modal shift-measures (category II) more tonnage is transported by inland shipping in the three logistics scenarios in Figure 11 in comparison to the 2030 *reference,* 2030 with *technological measures* and *base year* scenarios.

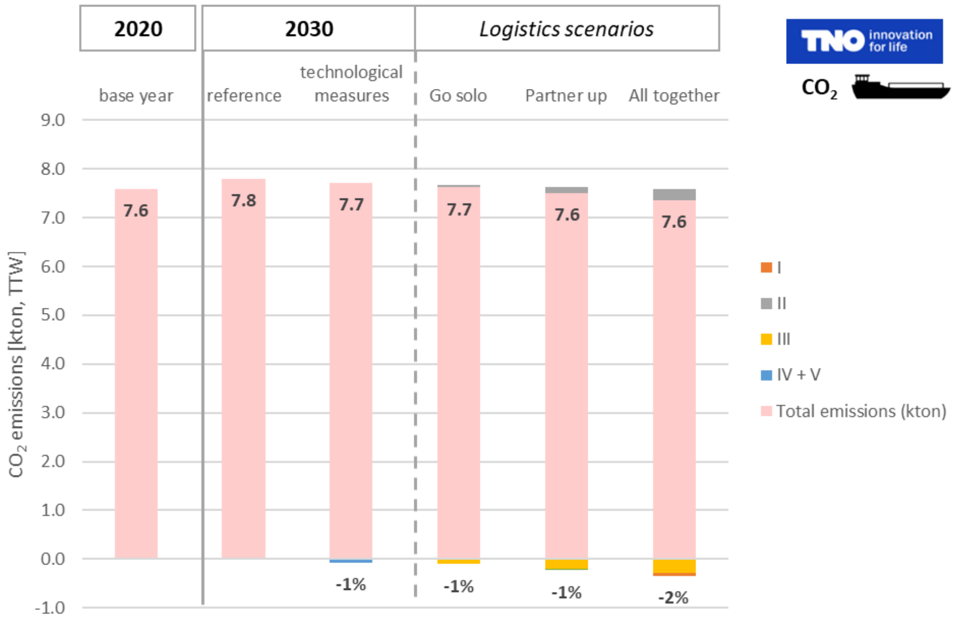

Figure 11: Total emissions of CO_2 for the modality *inland shipping*, on the corridor Rotterdam-Venlo in 2020 and 2030 for different scenarios.

With regards to reducing NO_x emissions, significant results can be achieved on the short term due to *technological measures* (as Figure 12 shows). The reduction in the scenario with *technological measures* is primarily due to the use of cleaner engines that comply with the latest emission standards. The impact of logistics measures is similar to the reduction that was observed in reduction of CO_2 emissions ranging from 1 – 2%. It should be noted that the potential for reducing NO_x emissions as a result of autonomous technological measures is instead of a much higher order of magnitude (around 21%). Because of this, the added potential of logistics measures to reduce NO_x emissions is relatively limited as opposed to the conclusion that was drawn for reduction of CO_2 emissions. In addition to this, a modal shift to inland shipping results into higher NO_x emissions due to the fact that NO_x emissions per ton-kilometre are higher for inland shipping than for road transport.

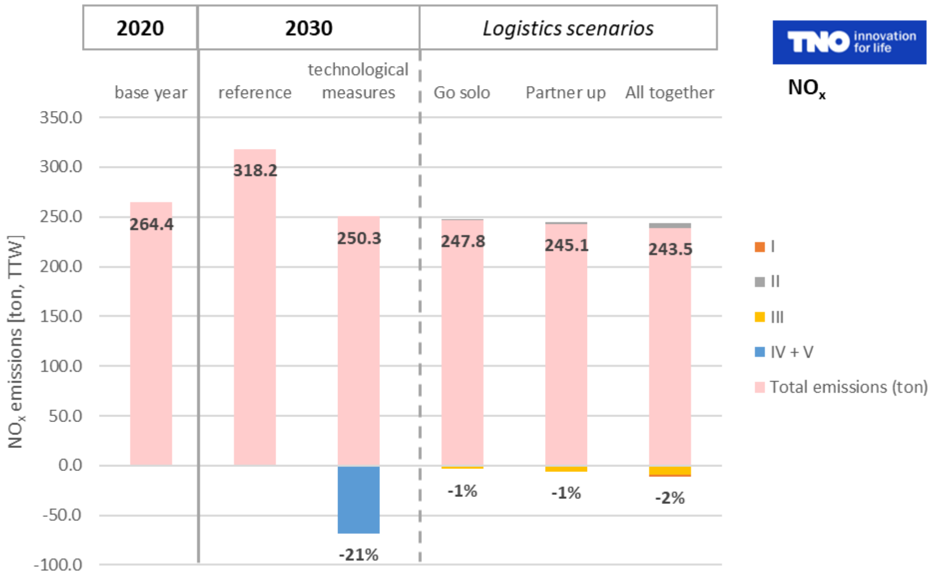

Figure 12: Total emissions of NO_x on the corridor Rotterdam-Venlo in 2020 and 2030 for different scenarios.

By zooming in on the modality road (Figure 13), it shows that logistics measures, as a complement to technological measures, can have a relatively significant effect up to an additional 10 percentage points. This is because there is relatively large room to reduce road kilometres in comparison to reducing kilometres in inland shipping. The potential effect of technological measures in relation to the reference year, on the other hand, is relatively small in comparison to what was observed for inland shipping. The reason for this is that in heavy-duty transport a relatively high share of the fleet currently already has an engine that complies with the latest Euro VI standards. To reduce NO_x emissions, road transport therefore relies more heavily on the implementation of zero emission technologies, leaving more room for logistics measures to make a difference in reducing NO_x emissions while zero emission technologies are not yet widely implemented in the sector. NO_x emissions as a result of road transport have a small share in the total NO_x emissions though, as emissions from the modality inland shipping are dominant. As such, the contribution of measures in road transport to reduce overall NO_x emissions from transport on this corridor is relatively small.

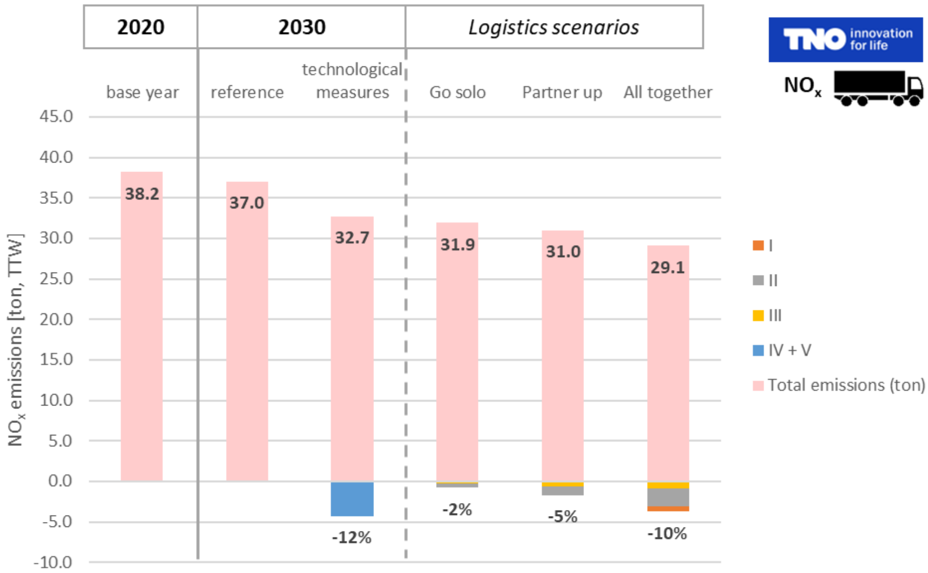

Figure 13: Total emissions of NO_x for the modality *road* on the corridor Rotterdam-Venlo in 2020 and 2030 for different scenarios.

For the modality inland shipping, Figure 14 shows that the fleet renewal which includes technological measures still has a relatively significant impact (23%) on NO_x emissions because there is still a lot of room for improvement in terms of cleaner engines in the upcoming years. Inland shipping therefore relies less heavily on zero emission technologies to reduce NO_x emissions in comparison to road transport. This is due to the longer lifespan of vessels, which means that the rate of fleet renewal is slower and the proportion of vessels that currently meet the latest emission standard (Stage V) is limited. The additional impact of logistics measures is relatively low (1- 2%) as there is little room to reduce kilometres in comparison to road transport. It should be noted that modal shift measures (category II) are included in the logistics scenarios. This results in an increase in emissions from this modality due to higher NO_x emission per ton-kilometre in comparison to road transport.

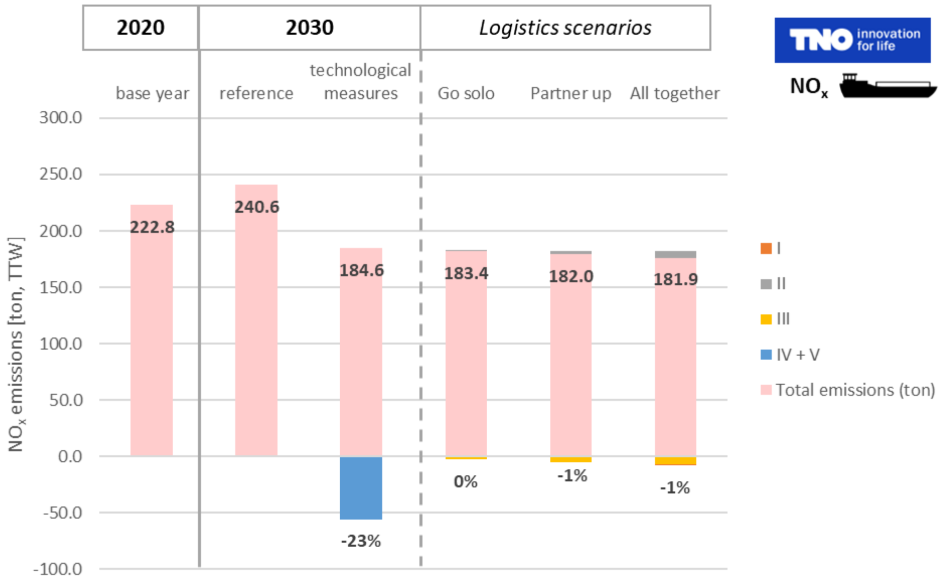

Figure 14: Total emissions of NO_x for the modality *inland shipping* on the corridor Rotterdam-Venlo in 2020 and 2030 for different scenarios.

In conclusion, the analysis indicates that logistics measures can make a significant contribution to reducing emissions on the Rotterdam-Venlo corridor. This is particularly evident for CO_2 emissions, as (at the current expected rate) technological measures are expected to have a relatively lower impact on reducing emissions of CO_2 by 2030 compared to their impact on other pollutants such as NO_x. In order to also achieve significant reductions in CO_2 emissions through technological measures, a substantial increase in the use of biofuels or zero emission technologies is necessary. However, it is unlikely that these alternatives will be available on a large scale by 2030. Logistics measures can therefore be used as an additional instrument to achieve further reduction in emissions in the short term. Chapter 6 will provide further discussion on this topic.

5.2 Rebound effects

The assessment of impacts of logistics measures in this study focusses on the direct impacts. However, as long as strong pricing measures or regulation of CO_2 emissions have not been introduced, most of these measures will only be taken when they lead to a cost reduction compared to the current way of working. When sustainable logistic measures lead to lower costs, rebound effects may occur leading to a reduced impact of the measures.

In economics, this phenomenon is known as the Jevons paradox. In 1865 the economist Jevons noted that efficiency improvements in the use of coal in Scotland between 1830 and 1863 led to an increase in its demand, not a decrease as was expected.

In transport and logistics, the same effects can be expected. If a logistics measure is taken because the costs are lower than in the existing situation, the transport service becomes more efficient.

In case this efficiency gain leads to a lower price of the transport service, the demand for this transport service will increase. This is known as a direct rebound effect. In case the efficiency gain is not translated into a lower price of the transport service, the transport operator will have higher income that will be used to invest or to consume goods or services in different sectors. This is known as an indirect rebound effect. Due to rebound effects, the net reduction of logistics measures on emissions will be more limited or possibly will be even negative compared to the direct impact of these measures. Both situations are a problem for sustainability measures; in the former case the impact of the measures is limited and not very effective, in the latter case the measures are even counterproductive.

Although the exact size of the impact is hard to determine, many empirical studies conducted since the 1980s have shown there is some rebound effect in many areas fluctuating from low rebounds to extreme backfire (UK Energy Research Centre, 2007).

Given that sustainability measures in logistics might lead to undesired rebound effects, the question arises whether it is a good strategy to encourage sustainability measures in logistics that lead to lower costs of transport services. Therefore, in several studies it has been investigated how to counteract rebound effects (see for instance: (Freire-Gonzalez, 2021).

The two main lines are:

- Public policy interventions. When transport services are perceived as cheaper, artificially increasing the cost of the service could avoid knock-on effects. Potential policy measures to counteract cost reductions include environmental taxation (e.g. the Heavy Goods Vehicle Charge), cap-and-trade systems and energy (or resources) pricing in general and regulations (with sufficiently stringent targets).
- Systemic solutions. This line focusses mainly on reducing the demand for transport instead of limiting the growth of transport.

All of this means there is not only a challenge to develop and implement effective sustainability measures in the logistic chain to reduce emissions of transport (direct impact), but also a challenge to avoid undesired rebound effects. For effective measures it is necessary to investigate what possible rebound effects could result and how to avoid or limit this impact as much as possible.

6 Towards a Zero Emission Corridor

As the analysis in chapter 5 demonstrates (see Figure 9), relying solely on clean and zero emission technologies is insufficient for achieving CO_2 reduction goals. While zero emission technologies are highly effective in reducing emissions, the expected pace of the transition is too slow to be able to reach the targets set for 2030. As concluded by Panteia (2022), transitioning to wide usage of zero emission technologies takes times and is complex due to high (initial) costs, limited availability of zero emission vehicles as well as charging / refuelling infrastructure and operational challenges such as limited driving range and long charging times. Speeding up the reduction of emissions is crucial, though, as the overall reduction target is to limiting global warming to below 1.5 degrees Celsius. The longer countries wait to decarbonise, the higher the level of cumulative emissions that have been released by the time global net zero is achieved and the lower the probability of limiting global warming to 1.5°C. This chapter therefore describes directions that could help to speed up the transition towards a zero emission reduction corridor and hence reducing the cumulative emission between now and 2050.

There are in general two directions to accelerate the reduction of emissions by transport:

1. *Speeding up the uptake of zero emission technologies*

First of all, additional measures can be taken to help decrease the aforementioned challenges with respect to the use of zero emission vehicles.

- **High costs:** To help the sector deal with the high (initial) costs that are associated with zero emission vehicles and ships, subsidies can support logistics companies to cover part of their investments. Previous provisions of subsidies, such as AanZET[11] (for trucks) , SEBA[12] (for vans) and SSEB[13] (for non-road mobile machinery), have already shown to be successful.
- **Limited availability of zero emission vehicles:** Replacing older vehicles with new ones that comply with the latest emission standard significantly reduces NO_x emissions. With sufficiently stringent EU CO_2 standards for heavy-duty vehicles, also CO_2 emissions of new vehicles will be significantly reduced[14]. To reduce CO_2 emissions on the short term, biofuels can be an alternative, especially while zero-emission vehicles remain limited in availability. However, it should be noted that limited availability of biofuels is also a concern. A strategy on the use of biofuels can help to maximize their impact (for example, prevent using biofuels for transport modes that have an adequate zero emission alternative available).

[11] https://www.rvo.nl/subsidies-financiering/aanzet
[12] https://www.rvo.nl/subsidies-financiering/seba
[13] https://www.rvo.nl/subsidies-financiering/sseb
[14] The European Commission has recently proposed to tighten the 2030 target for new vehicles from 30% reduction compared to 2019/20 to 45% reduction and to introduce 65% resp. 90% reduction targets for 2035 and 2040. Stricter standards promote the marketing of zero emission vehicles next to efficiency improvements in conventional trucks.

- **Limited availability of charging infrastructure:** To avoid the lack of charging infrastructure impeding the transition to the use of zero emission technologies, sufficient investment must be made to ensure adequate charging infrastructure. Focussing on logistics corridors and hubs may help to match fleets and infrastructure in order to realize sufficient utilisation of the charging and fuelling infrastructure. However, as battery electric propulsion seems to be the most popular zero emission solution on the short term, net congestion can pose a significant challenge in realizing adequate charging infrastructure. To address this in the short term, mitigation measures can be employed. These include smart charging and smart charging strategies, the use of battery packs to store energy and charging plazas for collective use (CE Delft, 2022).
- **Operational challenges.** To overcome operational challenges associated to zero emission vehicles, smart charging technology and strategies can help minimize disruptions to daily operations. Logistics companies should hence improve their knowledge on what a smart charging strategy is for their operation.

In addition, it should be noted that the report of IBO Klimaat (Rijksoverheid, 2023) suggests measures for the government to consider, which could contribute to achieving the targets set in the Climate Agreement. These proposed measures are primarily focused on implementing regulatory and pricing policies that incentivize sectors to shift towards more sustainable alternatives. For mobility, examples of the proposed measures include expanding the scope of the Heavy Goods Vehicle Charge (expected to be implemented in 2026) and mandating emission monitoring for transport companies.

Specifically in the context of a corridor approach, a close collaboration between logistics companies, shippers, governments, grid operators and ports can help to take effective actions that accelerate adoption of zero emission technologies and to prepare well for additional policies that could be introduced following the IBO Klimaat report. The stakeholders can for example work together on assigning suitable locations for charging infrastructure (energy hubs) and sharing knowledge on smart use of zero emission vehicles.

2. Reduce the number of kilometres

Reducing the number of kilometres driven altogether is the most effective way to reduce emissions quickly.

There are two approaches to this:
- increasing the efficiency of transport and
- reducing demand for transport.

As the outcomes in chapter 5 demonstrate, logistics measures have the potential to significantly reduce emissions in the short term. This initial exploration shows that it is worthwhile to perform a more detailed analysis that considers further specifics of the corridor such as a more detailed fleet composition (including emission classes), a more thorough evaluation of the effects of individual measures and the effect of possible additional innovative measures that can be tailored to this corridor specifically (such as Electric Road Systems (ERS) ((Decisio, EV Consult, Sweco, 2022); (Cornelissen & Francke, 2021); (Movares, 2020); (Taljegard et al., 2016)).

First of all, such an analysis is crucial to increase the validity of the conclusions drawn. Moreover, it will provide valuable insights into what is needed to unlock and increase the potential of logistics measures in different segment, taking into account the input of relevant stakeholders of the corridor.

In conclusion, achieving emission targets set in the Climate Agreements requires a combination of measures. These include technological measures, logistics measures and policy measures (such as pricing or subsidies). Increasing the rate of emission reduction is crucial in order to be able to keep global temperature rise below 1.5°C. As such, collaboration between stakeholders is essential along with a detailed plan for the specific corridor to be able to ensure quick and effective implementation of measures. Overall, an approach that incorporates a wide range of measures and involves close collaboration is key to achieving emission targets.

7 Discussion and recommendations

This chapter reflects on the findings of this study. The results indicate that in the most optimistic scenario defined in this study (the *all together* scenario), the combination of measures – including both technological and logistics measures – add up to a total reduction of almost 16% in CO_2 emissions in 2030 compared to a 2030 situation without these measures. This is shown in the summarising figure below. The CO_2 emission in 2020 (*base year)* and 2030 (*reference,* based on a growth scenario without measures to reduce emissions) are shown on the left in blue. The scenario including only technological measures is shown in dark green and the scenarios including the technological measures and the different levels of logistics measures in light green. At the right the reduction goal is shown in red.

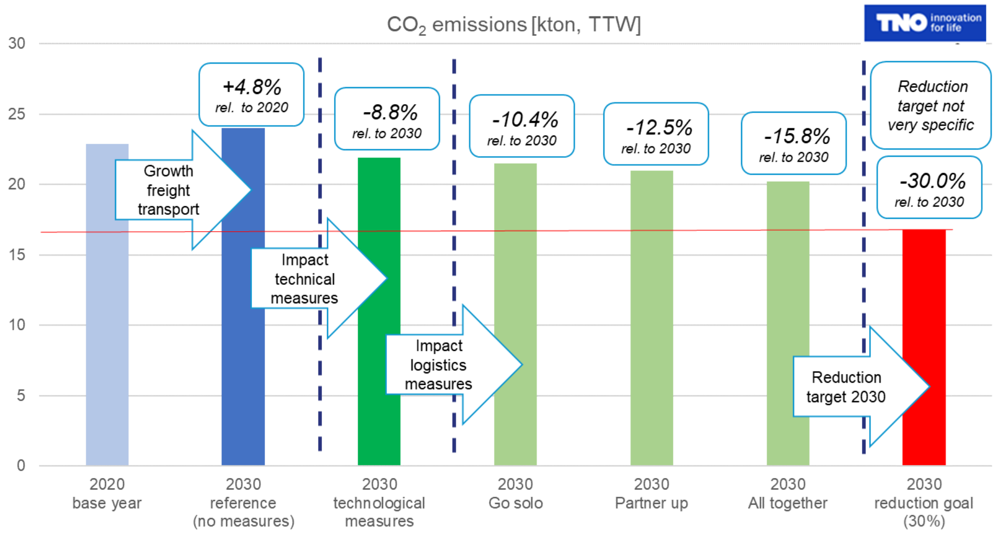

Figure 15: Overview of DeCaMod results: three CO_2 reduction scenarios with logistics measures on the corridor Rotterdam-Venlo.

Approximately 7% of this reduction is attributed to logistics measures in the *all together* scenario. However, compared to the goal set in the Climate Agreement of achieving a 30% reduction in emissions for hinterland and continental freight by 2030, additional action is necessary to accelerate the reduction of emissions. As such, chapter 6 explores what can additionally be done to speed up the reduction of emissions. All in all, the preceding chapters lead to further consideration of several items related to the analysis, which are summarized in section 7.1. This chapter concludes with recommendations for research, the logistics sector and policy makers in section 7.2.

Note that the scope of this analysis was limited to transports with an origin and destination within the COROP regions of Rotterdam and Venlo. Also, the effects of measures as were described in chapter 3, are in most cases only applied to a limited number of segments (for those segments where the measure is expected to have a significant potential) and not to all transports on the corridor.

7.1 Discussion and reflection on the analyses

This study presents an exploration into the potential impacts of logistics measures on reducing emissions, and its findings indicate that logistics measures can make a considerable contribution in this regard, especially for CO_2. In other words, logistics measures do matter. Though technological measures, such as the use of zero emission vehicles, are effective in reducing tail-pipe emissions, the pace of their uptake is expected to be too slow to reach the emission reduction targets that were set for the transport sector in the Climate Agreement. Logistics measures can hence contribute to bridging this gap. It therefore deserves further research to better understand the effects, feasibility and boundary conditions of different measures to ensure targeted and effective implementation of measures. A tailored approach taking into account a more detailed decomposition (logistics segments, type of goods, vehicle types and vehicle technologies) of the corridor is crucial to that aspect.

While most of the logistics measures proposed in this study are not entirely novel to the logistics sector, their successful implementation also hinges on strong collaboration among all relevant stakeholders including carriers, shippers, governments, ports, grid operators and knowledge partners. Transport companies cannot do this solely by themselves. They have limited impact on their own operations as their choices are influenced by other companies' marketing and production decisions, which play a crucial role in supply chain management (Ecorys, 2021). A corridor approach can facilitate collaboration, allowing stakeholders to identify possible barriers and drivers for the implementation of measures, ultimately leading to a more effective reduction of emissions. Moreover, a collaborative mindset can help the stakeholders to expand the scope of measures beyond the conventional ones, such as innovative concepts that may emerge in the coming years and that facilitate faster and more effective adoption of emission reduction measures towards 2030 and beyond.

The quantitative scenario analysis in this study did not consider rebound effects or interaction effects between measures, nor did it take into account indirect effects. It is likely that the impact of logistics measures on emissions reduction may be lower than estimated. In paragraph 5.2, the Jevons paradox was mentioned which suggests that an increase in transport efficiency or lower costs can result in additional activities that generate emissions (possibly even in other industries). To fully understand the impact of logistics measures on emissions reduction, further research is needed to identify potential unintended consequences and explore the effect of potential counteracting measures such as a price policies.

7.2 Recommendations

7.2.1 For further research

This study represents an initial exploratory step. However, additional research is necessary to enhance the assessment of measures which focus on 1. improving the baseline data and 2. increasing insights into the effect of measures.

Baseline data

- It is necessary to update the input data used to more recent years, specifically the Basisbestanden Goederenvervoer (currently base year 2014 was used) and the growth scenario of transport volumes towards 2030.
- To ensure better alignment with the KEV's assessment of measures on total national emissions and the mobility sector specifically, it is essential to take the effect of these measures into account in more detail in the emission factors, especially for modalities *inland shipping* and *rail*.
- To enhance insights into emissions by modalities *inland shipping* and *rail*, it is recommended to conduct real-world emission measurements and collect detailed data on fleet composition.
- To gain a better understanding of the fleet composition and logistics segments on the corridor, the availability of microdata could be explored in collaboration with CBS. Additionally, license plate scans could be used as a tool to gather insights into the fleet composition on the corridor.

Effect of measures

- To improve certainty about the effectiveness of measures, it is necessary to conduct studies that evaluate both the reduction potential and the application potential (extent to which the measure can be applied) of measures. These studies could include simulation and, ideally, pilots or practical implementation.
- This study only focused on transportation that has its origin and destination within the COROP regions of Rotterdam and Venlo. It should be noted that the climate goals for hinterland and continental freight, when applied to the corridor, also entail transports with an origin or destination between Rotterdam and Venlo, and transports beyond Venlo towards Germany. The potential effect of measures will likely be less for international transports as the Netherlands has less influence on those in terms of realizing the potential of measures. Hence, additional efforts are needed to perform a similar analysis and find the potential effect of measures for all transports between Rotterdam an Venlo.
- This study only focused on the Rotterdam-Venlo corridor, which has a relatively high share of container transport. Further analyses are required to assess the impact of logistics measures on other corridors or regions within the Netherlands.
- The scenarios considered in this study do not take into account a circular economy, which will result in a different flow of goods. To assess the long-term effects (2050) and explore the impact of a more circular economy on the type of goods and the transport system, additional research is required.
- With regard to the goal of keeping global temperature rise limited to below 1.5°C, it is important to take measures that have an early effect, as reductions earlier in time contribute more to this goal. It is therefore worthwhile to assess the potential cumulative reductions towards 2050.

7.2.2 *For the logistics sector*

This study's findings, specifically the assessed CO_2 reduction potential of 7% between 2020 and 2030 in the most optimistic scenario, reveal that achieving an annual increase in logistic efficiency of 2%, which was agreed upon as goal by the Dutch transport sector, is not evident. To accelerate progress towards reducing emissions and meeting sector targets by 2030, there is a pressing need for increased efforts to enhance logistics efficiency.

This involves both taking actions that contribute to realizing the potential of measures (in time) as well as taking actions to increase the potential of measures. A detailed plan should be put in place that considers the specific demands of each logistics segment and modality. It is important to note that transport companies cannot achieve this alone. A strong collaboration with other stakeholders such as shippers, governments, grid operators and knowledge partners is crucial as well as cooperation among transport companies. An effective approach to implementing measures on the corridor would involve active participation of all stakeholders in the design, planning and execution of the measures ensuring that they are tailored to the specific needs of each logistics segment and modality.

7.2.3 For policymakers

As was addressed in chapter 1.1, some of the targets outlined in the Dutch Climate Agreement lack clarity on some aspects. However, it is essential that there is a precise understanding of these targets in order to create appropriate urgency and to be able to effectively monitor emissions, compare them with their corresponding targets and take additional/adjust measures if necessary.

According to the analysis in this study, but also according to other studies such as (Panteia, 2022), the transition to cleaner and zero emission vehicle technologies is progressing too slowly to meet the sector targets in the Climate Agreement by 2030. This study highlights the importance of logistics measures complementing technological measures to accelerate progress towards the targets. In fact, logistics measures are necessary to speed up the reduction of emissions and contribute towards keeping the global temperature rise below 1.5 C. The main motivation is that they affect the existing fleet, which still largely runs on fossil fuels, and thus contribute effectively to reducing the cumulative emissions between now and 2050.

While policy measures have been introduced to accelerate the adoption of cleaner vehicle technologies (such as stricter emissions standards, the introduction of zero emission zones, subsidies for zero emission vans and trucks, etc.), there has been less focus on the introduction of measures aimed at enhancing logistics efficiency. Ecorys (2021) emphasizes that concerted efforts are necessary to ensure effective integration of innovative concepts into logistics operations. In other words, the implementation of logistics measures requires effort and cannot be achieved without proper planning and coordination. Therefore, it is recommended to consider ways in which the transport sector can be encouraged or even obliged to take the necessary actions for the implementation of logistics measures as well as considering policy measures that could increase the effectiveness of these measures. Furthermore, it is important to be aware of possible rebound effects and what is needed to reduce rebound effects.

7.2.4 Call to action

This study provides very useful insights in the potential impact of measures to reduce CO_2 emissions on logistic corridors, based on the example of Rotterdam-Venlo. With DeCaMod the impact is shown of both technological measures, several logistics measures and the total if these measures are combined. Besides, impact is shown for several segments such as mode of transport and type of goods for the specific corridor Rotterdam-Venlo. Finally, it is shown that in the most optimistic logistics scenario about half of the climate goal is reached on this corridor (and in the most pessimistic scenario only one third).

On the one hand, this study provides very useful insights and gives a clear overview of the expected situation in 2030 including the challenge to reach the climate goals in 2030. On the other hand, these results also raise many questions. Just to name a few: how to realise the expected impact of the included logistics measures, what additional measures are needed to reach the climate goal in 2030, what are the rebound effects and how can they be avoided, how do these results look like on other corridors with different distributions of freight flows over transport modes and type of goods, what is expected to happen until 2040 and 2050, what is the impact of measures on the cumulative emissions until 2030, 2040 and 2050?

For a number of these questions, ideas and suggestions are already provided in this study. But many of these questions still have to be answered and need further research together with companies, governments and knowledge institutes. In the end, the most important question has to be answered: how to reach the climate goal with effective and feasible measures?

DeCaMod can be used to facilitate fact-based discussions between stakeholders. This study hence provides a very good basis for further action by showing the challenge we have. TNO will discuss these results with several stakeholders and will seek collaborations with companies and government to take up this challenge!

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9 Signature

The Hague, 26 June 2023

TNO

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