Outlook Hinterland and Continental Freight 2018

Top Sector Logistics

Credits

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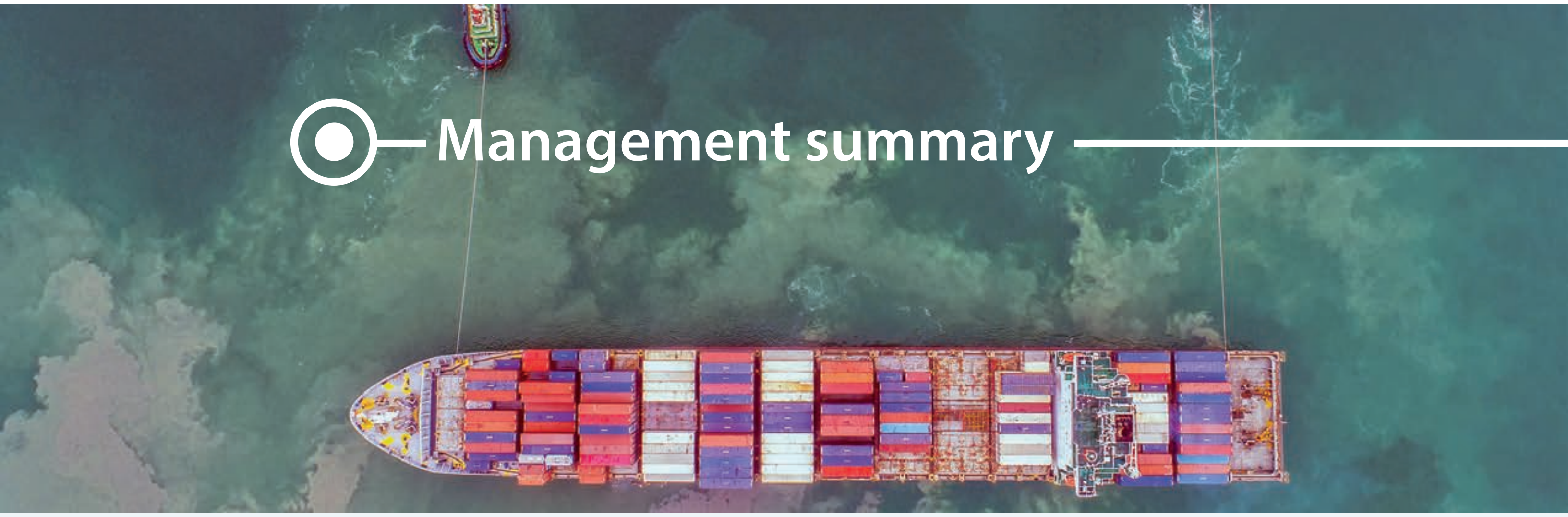


Management summary

Introduction

Driven by world-class seaports, a centrally located airport and an extensive network of roads, rail and inland waterway infrastructure, the Netherlands is a major hub for international logistics. The Netherlands is among the top 10 countries with the highest value of imported and exported goods. In total, almost 1,800 million tonnes per year are transported to and from the Netherlands. A major part of these flows can be considered as hinterland and international continental freight (HCF, for short) flows, using road, inland shipping and rail as transport mode. Including hinterland transport to and from locations in the Netherlands, HCF transport accounts for about 62% of all tonnes shipped within the Dutch borders, illustrating the major role of HCF transport.

Outlook objective and scope

The transport and logistics sector depends to a large extent on fossil fuels. Its CO_2 emissions are significant, which imposes a giant challenge to meet the Paris climate objectives of limiting the average temperature increase to a maximum of 2.0°C. Meeting the Paris goals implies improving the carbon productivity of transport and logistics drastically. The concept of 'Factor 6' was introduced in order to illustrate the challenge that lies ahead: taking into account the ongoing growth of production and consumption, and the related transport movements, the logistics sector needs to decrease its emissions by at least a Factor 6 to reach the Paris goals.

The Topsector Logistics has started working on developing plausible reference scenarios to illustrate the way forward for the Dutch logistics sector. To present the results of these investigations in an accessible way, Connekt, TNO and CE Delft have developed the so-called Outlook format. The City Logistics Outlook 2017 was the first of an ongoing series, presenting an overview of decarbonization paths for city distribution in various segments. This Outlook on Hinterland and Continental Freight focuses on the other major component of CO_2 emissions: those associated with the large volumes of goods transported to and from the mainports (62% of tonnes), the large volumes of other import and export (28%) and the transit of goods (10%).

The aggregate annual CO_2 emissions associated with HCF transport and logistics on Dutch territory amount to 7.0 megatonnes, with transport accounting for approximately 89% (6.3 Mt) and the logistics functions of storage and transhipment for 11% (0.8 Mt). If also the emissions beyond the Dutch border of the same HCF logistics chains starting or arriving in the Netherlands are taken into account, the emissions amount to 20 Mt.

Drivers

Population growth, the general increase of wealth and low-friction international trade are the main drivers for more demand for (international) freight transport. Although more protectionist tendencies are visible lately, it is assumed that the benefits of low-friction international trade will continue to prevail.

Population growth in North America, Western Europe and Japan has been declining over the years, and growth has shifted to other parts of the world. Immigration flows will not change that trend, resulting in a lower demand growth for freight to and from Western Europe.

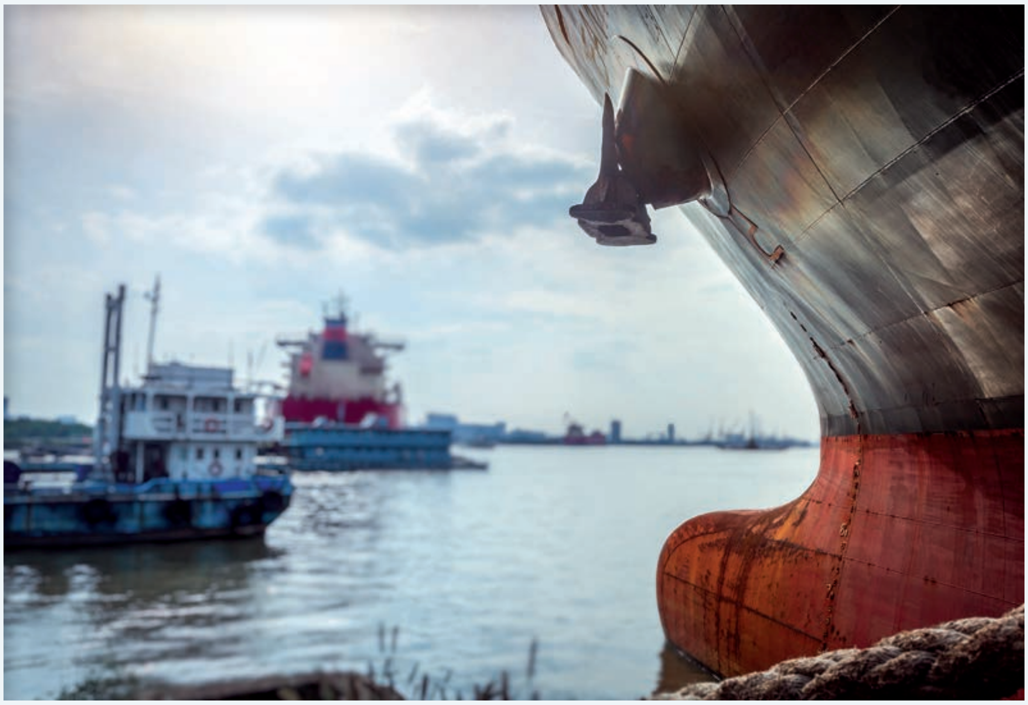
Wealth increase in highly developed economies tend to be more focused on services, higher quality/luxury products and intangibles as software, and less on physical goods. As a result, this Outlook assumes a moderate overall growth of HCF goods transport.

There are some notable exceptions, impacting the HCF flows to and from the Netherlands. Climate policies aimed at reducing CO_2 emissions will reduce the flow of fossil fuels, especially coal and mineral oils. Biobased alternatives will not be nearly as large in transport volume. The shift to electricity and hydrogen as energy carriers will reduce the demand for vessels and trucks for transport of fossil fuels.

The dry bulk transport volume of agrobulk feedstock for animals may be impacted if the attitude towards meat-production and consumption changes.

The result is an expected reduction of more than 25% of the dry and liquid bulk transport market, while maintaining a moderate growth for the non-bulk market segments.

Rail transport and inland barge transport will feel most of the effects. Dry bulk barges have the option to shift to container transport, possibly creating competition on price that will hinder investments in lower-emission technology. If the worldwide pressure to create low/zero-emission trucks which are highly automated (platooning, autonomous) accelerates, this may lead to a 'negative modal shift' to road transport using capacity in the night. Such a scenario may lead to significant additional infrastructure costs and capacity challenges on the motorways network.



Outlook per market segment

Taking Factor 6 as its main goal, this Outlook defines pathways for five different HCF segments: dry bulk, liquid bulk, perishables, non-perishable consumer goods and semi-finished products. This is done on the basis of trends, segment-specific characteristics and detailed assumptions on the potential of identified decarbonization measures, which are used for back-casting from 2050. The results are summarized in 'cascade graphs' that combine the timing and impact of each proposed measure in a single view.

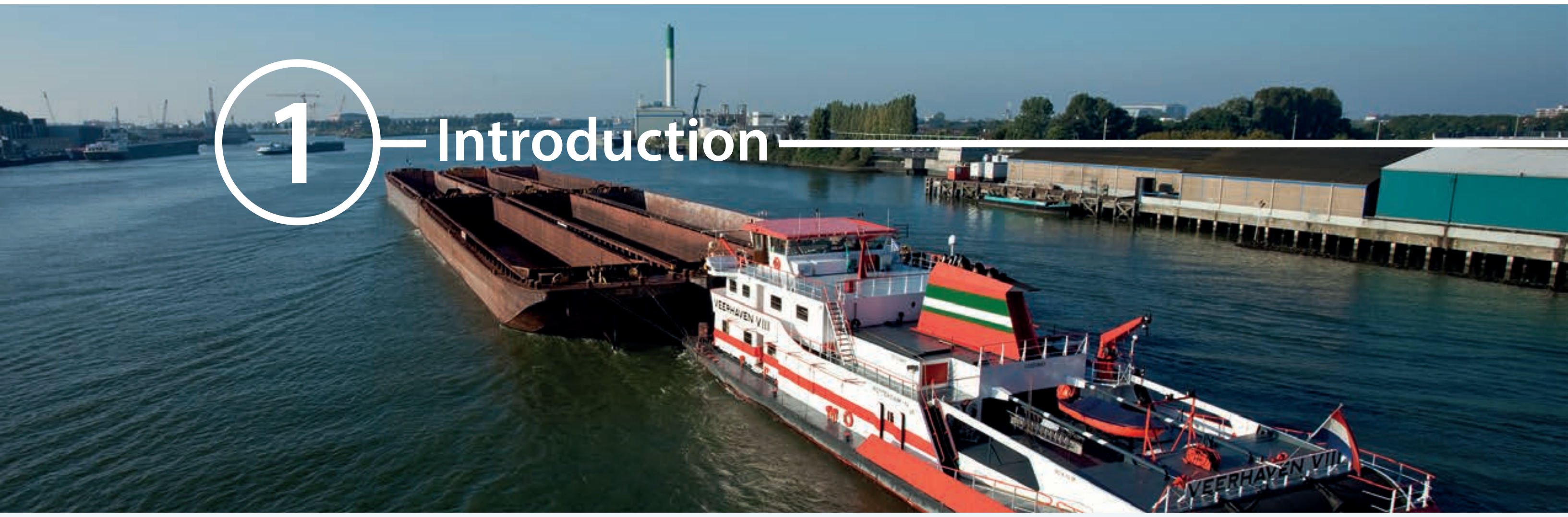
The reduction of transport emissions of bulk segments will rely particularly on zero-emission energy carriers, such as electricity and hydrogen, whereas the non-bulk segments will also be able to introduce more energy-efficient logistics concepts, mainly due to network optimization. The supply chains of these segments are generally more complex, with larger numbers of links, logistics activities and actors. The contribution of sustainable, energy-efficient transhipment and storage is low in all segments except for perishables. The expected contribution of vehicle and vessel technologies, autonomous driving and ITS is more or less similar for all segments, while the impact of logistics measures, including modal shift, is far more important for the non-bulk segments.

Consumer and investor pressure will push leading companies in markets close to consumers (B2C) towards implementation of zero-emission technologies and more efficient logistics. Together with governments, these companies will act as frontrunners and lead the followers in the market. This requires new and optimized business models using vertical integration, better utilization of equipment and investing in advanced low/zero-emission technologies.

On a system level, reaching a Factor 6 improvement in carbon productivity and, thus, the Paris goals seems possible without impacting the competiveness of the logistics sector and the prices of products shipped. The transition will, however, require (small and large) changes to the current structure of how logistics is organized, affecting individual interests and parties.

The speed of the transition and its impact on CO_2 emissions will depend partly on how governments will implement policies such as standards and financial incentives to create the required level playing field for zero-emission technologies, while helping to accelerate large-scale implementation.

For the Netherlands, maintaining the position of the mainports is a key driver also in the interest of, for example, the perishable food sector. The non-road modes will be kept competitive in order to maintain the advantage of the multimodal hinterland network that has provided the Dutch mainports its competitive position in the past.



1 Introduction

International trade, transport and logistics are a significant part of the Dutch economy. The Netherlands is among the top 10 countries with the highest value of imported and exported goods. The value of the import and export combined is about 1.5 times the country's GDP, which is high compared to many other countries in the world (CIA, 2017). The mainports Rotterdam and Schiphol are European gateways.

This large volume of trade and transport generates a vast number of freight movements and consequently substantial CO_2 emissions. Transport accounts for 24% of total domestic CO_2 emissions in the Netherlands[1].

With the Paris declaration (Paris Climate Summit 2015), the majority of the world's countries have agreed to reduce their CO_2 emissions in order to limit the average temperature increase to a maximum of 2.0°C. Every economic sector needs to reduce its (cumulative)[2] emissions drastically, implying a target for freight transport in the Netherlands, too. The sector needs to radically increase its 'carbon productivity'[3].

The Topsector Logistics has started work on developing plausible scenarios to achieve such goals for the Dutch logistics sector. To present the results of these investigations in an accessible way, Connekt, TNO and CE Delft have developed the so-called Outlook format. The City Logistics Outlook 2017 was the first of an ongoing series, presenting an overview of decarbonization paths for freight distribution in various segments.

This Outlook on Hinterland and Continental Freight (Outlook on HCF, for short) focuses on the other major component of CO_2 emissions: those associated with the large volumes of goods transported to and from the mainports and the large volumes of import, export and transit of goods.

1.1 Why this Outlook?

Transport and logistics can be seen as services in a very competitive market, driven by the demands of shippers and customers. Logistics is, in other words, a derivative of economic activity.

1 This excludes external CO_2 emissions from maritime transport and air transport (ECN, 2016, p. 151).
2 Although reduction targets are often set for a given year, the real target is a reduction in cumulative emissions.
3 Carbon productivity is defined as useful transport of goods (tonne-km) per kg CO_2 emitted.

Providers of transport and logistics services and their subcontractors fulfil that demand within the limitations set by the available infrastructure, i.e. the available capacity and capability of roads, bridges, waterways, harbours, railways, terminals and the like, and regulatory constraints with respect to health and safety, taxes, imports, emissions and so on. (Public) infrastructure and regulatory constraints are by definition not a differentiator available for individual companies to create a competitive advantage per se. Infrastructure and trade associations can, however, act as differentiators for a geographic region, as can be observed in the Netherlands.

Most transport and logistics equipment are standardized, developed and supplied by large OEMs[4], mostly residing in other (EU) countries. Energy and fuel, too, is standardized and supplied through infrastructure owned by third parties or governments. The volume of these commoditized inputs is such that no single party can become a large buyer able to influence their purchasing price substantially by sheer volume.

The service of transport and logistics is by and large a commodity itself, making it easy for shippers to switch transport providers. This creates a highly competitive market with a high price elasticity from the perspective of the transport provider: there is very little room for price differentiation, or business is shifted to competitors. For the market as a whole, however, lower price elasticity can be observed: the total demand for transport is relatively insensitive to price changes in transport, although this differs significantly between transport modes and types of goods. In storage, there are some notable exceptions. The mainports themselves are difficult to replace or move. In rail cargo, the influence of governments is large.

Compared with other sectors, the commoditized inputs and the race to the lowest possible price in larger geographical markets creates companies with relatively little room to invest in change. Investing in new, innovative (risky), sustainable equipment before everyone is forced by regulations and without the (financial or long-term business) support of their customers is a risk very few are able or willing to take.

While in City Logistics the pressure to reduce emissions by the final customer (consumer and citizen) and by local authorities is a major factor in driving change, this is hardly the case in HCF: only certain brand-sensitive FMCG-shippers[5] see the writing on the wall and take steps to achieve deep decarbonization before they are forced to do so by their customers or by government. As most flows of goods in HCF go unnoticed as far as the final customer is concerned, price and costs are the dominant deciding factor in transport purchasing choices, rather than emissions (unless forced by regulation).

Currently, most sustainable technological options for powering heavy-duty trucks, barges and ships are not yet commercially available, limited in operational usefulness and/or much more expensive than commoditized fossil-fuel and internal combustion engines. The economic structure and conservative character of the transport market, with many small and medium-sized companies, hinders innovation and large-scale introduction of new technologies.

Infrastructure investments for transport are large, expensive (public) projects and take a long time to plan and execute in a densely populated area like the Netherlands. Space is a premium and scarce good, and many citizens do not want to have transport in their backyard.

4 Inland waterway barges are an exception. These are often one-off, custom-made capital goods. OEM = Original Equipment Manufacturer.

5 Fast Moving Consumer Goods, such as Heineken, for example.

The payback time is decades, so infrastructure decisions are difficult long-term bets in a fast-changing landscape. This makes adapting infrastructure to a new transport system very hard as long as uncertainty is high, creating a self-fulfilling prophecy.

Roads and railways are dual-use: people and goods compete for the available and limited capacity. Growth and concentration of demand will, unfortunately, soon catch up with any increase in capacity, creating congestion, decreasing the reliability of supply chains and therefore the attractiveness of a mainport or location for trade.

The abundance of waterways in the Netherlands with connection to main markets in nearby countries has created a third option to bypass the limitations and congestion of rail and road infrastructure for transporting large (bulk) volumes of goods: inland barges. Unfortunately, the market structure, ownership structure (barges are often family-owned) and extremely long[6] technical life of hulls and engines are a major barrier to conversion of the fleet to low- or zero-emission barges.

The call to decarbonize transport will reach HCF flows of goods, and it will not stop for barges. If such a demand were to suddenly become far more urgent in the future, thereby influencing shippers' decisions, barges could become unattractive. Even if this held solely for containers, a shift from barge back to road would create major capacity problems for the road infrastructure.

Last but not least, there is uncertainty about the future volume of certain goods. The volume of coal and other fossil fuels handled and transported to the hinterland is obviously set to decrease over time, given the pan-European desire to reduce emissions. Will biomass replace that volume or not? Will the changes in production locations create different flows of goods across the world? Will rail capacity from China and other countries increase to a level that influences flows of goods through the mainports?

These factors make it hard for all stakeholders to envision the most likely path or paths to deep decarbonization. The challenge of this Outlook is to investigate:

- the available facts and data;
- the external trends, including regulation, that are most likely to influence the demand and the competitive environment;
- the technological options for energy and propulsion, and their economic impact;
- the new options created by automation and ICT.

This is combined with explicit assumptions to create a likely path to securing the Paris goals, offering a perspective for action for all parties involved. The value of this exercise lies not in whether this particular path is the right one, but in the explicit reasoning, based on assumptions, that can be debated and shared and improved upon, in order to come to a shared vision on the route towards decarbonized freight transport.

The Outlook shows how, based on these assumptions, the sustainability of hinterland and continental transport and logistics can be improved. This involves explicitly looking beyond current logistics concepts, with a typical time horizon of 2050 and taking 2030 as an intermediate target.

6 Barges have a typical lifetime of 40 years or more. See Addendum F for a breakdown of the current Dutch fleet.

1.2 Approach

The main assumption in developing this Outlook is the non-negotiability of the target of drastically improving the carbon productivity of transport and logistics, as imposed by the Paris agreement. For the transport and logistics sector this agreement translates into the challenge of achieving a 6-fold increase in carbon efficiency. This challenge, referred to as the 'Factor 6' challenge, is further exemplified in the next chapter. Taking Factor 6 as its main goal, the Outlook sets out pathways to this end for five different HCF segments: dry bulk, liquid bulk, perishables, non-perishable consumer goods and semi-finished products. This is done on the basis of detailed assumptions on decarbonization measures and potential, which are used for backcasting from 2050. The results are summarized in 'cascade graphs' that combine the timing and impact of each proposed measure in a single view.

In order to identify the decarbonization potential of the hinterland and continental transport segments and to establish the routes towards realizing the Paris objectives, the involvement of the transport and logistics sector is of vital importance. In this perspective, interviews with numerous key stakeholders were held to validate the expert opinions and assumptions made in the Outlook.

This Outlook is the first of three editions aiming to iteratively develop a vision for each HCF segment along one or more feasible paths to decarbonize freight transport. A vision is not a prediction of the future, nor a prescription of actions and tasks. As stated, the goal is to provide a baseline that can be shared, debated and improved, to structure discussions among stakeholders, to allow anyone to test their own scenarios, to make it easier for all involved to check all dependencies and to facilitate identification of essential dependencies in actions. As such, this first version is an invitation to contribute, an invitation to add improvements and an invitation to share it widely.

1.3 Reading guide

First, Chapter 2 demonstrates the challenge of 'Factor 6': the target derived from the Paris agreements on reducing GHG emissions. Chapter 3 provides a definition of HCF transport and logistics in the Netherlands and a division into the five most relevant segments in international hinterland and continental freight transport. HCF is quantified in terms of tonnes and tonne-kilometres and the associated CO_2 emissions. Next, Chapter 4 gives an overview of the trends and developments relevant to HCF, which form the basis of the Factor 6 challenge. Chapter 5 then sketches the Factor 6 decarbonization paths per segment. It defines the so-called 'decarbonization concepts', or options for reducing the sector's carbon footprint, and provides the perspective for action. Proceeding from the expected uptake of the decarbonization options, a timeline is proposed for fulfilling the Paris climate goals. The chapter closes by presenting the overall conclusions on the decarbonization of hinterland and continental freight in the Netherlands.

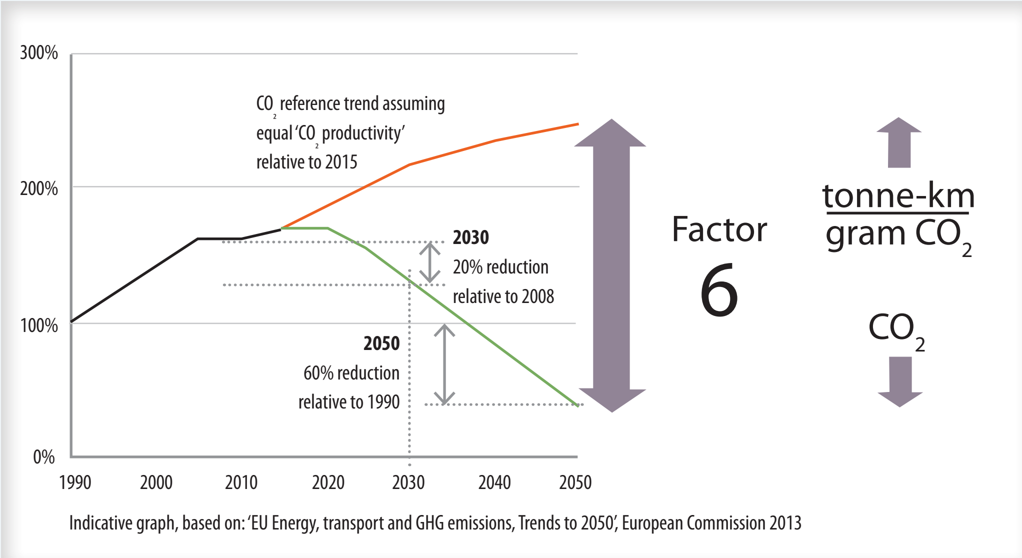
2 The challenge of Factor 6

The EU has set itself a long-term goal of limiting global warming to 1.5-2 degrees Celsius. The 2.0 degree target translates into reducing greenhouse gas emissions by 80-95% in 2050 compared with 1990 levels. To achieve this goal, emissions from transport must be reduced to over 60% below 1990 levels by 2050, all assuming a linear decline in emissions over time.

The importance of this assumption is rooted in the difference between rapid versus late reduction of emissions. The basis is a total maximum budget of cumulative CO_2 emissions, calculated to limit atmospheric CO_2 concentrations to the required level: if we achieve fast and early emission cuts, there is less need to achieve the 60% reduction. On the other hand, if reduction is delayed (which appears to be the case), the target moves from a 60% reduction to 80% or more as more of the cumulative budget is consumed.

Any successful policy or action on climate change to secure this goal must support two objectives: reducing CO_2 emissions as soon as possible and maintaining economic growth. Continuous economic growth will lead to a continued increase in freight transport demand. In the Netherlands this assumption means that meeting the 2050 target for transport emissions requires an approximately six-fold increase in 'carbon productivity': the amount of freight transport per unit of carbon dioxide-equivalents emitted, i.e. tonne-km/CO_2e (see Figure 1).

Figure 1
To secure the Paris climate targets, EU freight transport must achieve at least a sixfold increase in CO_2 productivity by 2050.



Note: freight transport reduction target assumed equal to overall 60% reduction target for EU transport sector

To achieve this sixfold increase in carbon productivity requires an integrated approach. This approach should make full use of the opportunities available to cost-effectively increase energy efficiency, decarbonizing energy sources, accelerating the development and deployment of new low-carbon technologies. Futhermore, it should grasp opportunities for optimizing supply chains and logistics operations and changing business and consumer behaviour. CO_2 abatement options are needed at all system levels, i.e. energy carriers, powertrains, vehicles, fleets, logistics operations, behaviours and so on, and in all transport areas and for all transport modes.

Analysis of the Dutch transport sector shows that the required pathway towards the intermediate 2030 target and the ultimate 2050 target is very challenging. Existing and currently planned low-carbon policies and measures will, together, only be able to accommodate emissions from projected growth in transport demand and stabilize emissions at current levels. Analyses also show that there is significant reduction potential available from a wide range of measures. Although achieving the full potential of existing and planned policies and measures will in itself by no means be straightforward, even more complex system innovations and coherent sets of abatement options will be needed to achieve six times more efficient hinterland and continental freight transport.

For HCF as a whole, as well as for the segments distinguished, the same Factor 6 is assumed to be required by 2050. Although growth rates in transport demand may differ from segment to segment over time, the overall long-term challenge will still require a Factor 6 emissions reduction.

3 Hinterland and continental freight transport in the Netherlands

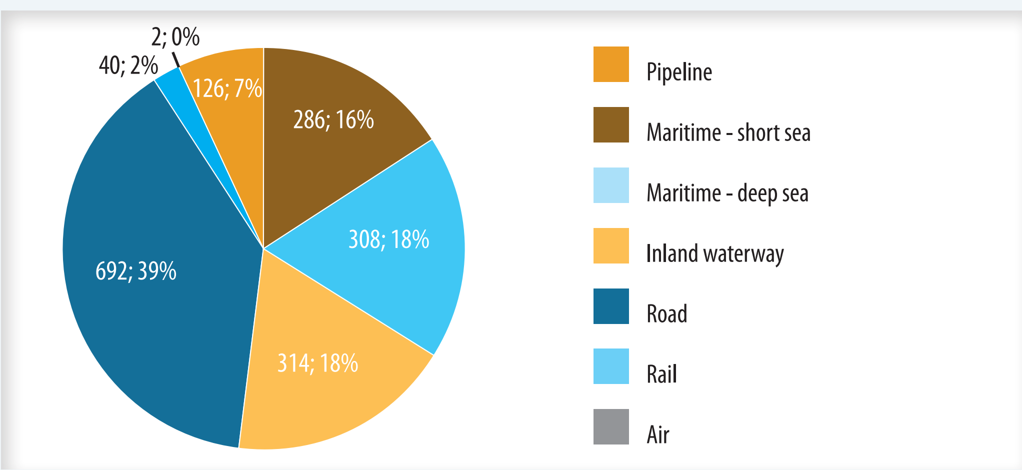
This chapter presents an overview of HCF transport and logistics in the Netherlands. First, in Section 3.1, the scope of the Outlook is explained. Next, Section 3.2 provides an overview of the total freight transport volume in the Netherlands and the share of HCF transport per mode. The transport volumes and CO_2 emissions of the various international transport flows are then presented in Sections 3.3 (total) and 3.4 (per market segment). In Section 3.5, the emissions associated with the logistics activities (storage and transhipment) are presented. Section 3.6 summarizes the main conclusions.

The data presented in this chapter have been produced under cooperation with the Dutch national statistics bureau CBS, that gathers information on transport volumes and fuel sales. For translation of transport performance into CO_2 emissions, CE Delft's STREAM model has been used in addition to statistics. All CO_2 emissions reported are defined as well-to-wheel emissions, including the emissions related to upstream fuel production.

3.1 Scoping: defining hinterland and continental freight in the Netherlands

The freight transport market is an international market. The transition to a single market in the EU has resulted in a huge increase in transport flows between the European countries and a strong internationalization of the freight transport sector itself. Cross-border transport has become increasingly important. This is the case for all transport modes. Figure 2 shows the share of transport volume to and from the Netherlands in megatonnes (Mt) per mode, with a total of 1,768 Mt. The figure covers both import and export, transit is only counted once.

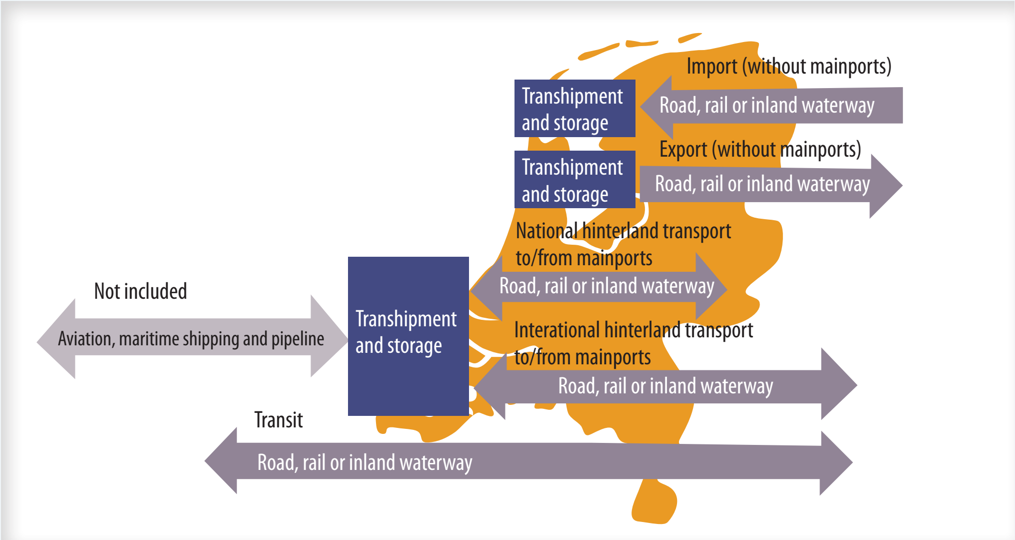
Figure 2
Total shares of freight transport to and from the Netherlands in megatonnes per mode (2015).



This Outlook 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. Pipeline transport is also excluded from this Outlook, since it already has a very high efficiency and specific application.

Figure 3 shows a graphical representation of this Outlook's scope. This figure shows the link between all the hinterland transport, that **is** included in the Outlook. Aviation, maritime (short sea and deep sea) shipping and pipeline transport are **not** covered in this Outlook.

Figure 3
Scope of international transport covered in this Outlook.



3.2 Total freight transport on Dutch territory

Freight transport on Dutch territory comprises both national and HCF transport. To put HCF transport in context, this section provides an overview of the sum total of freight transport in the Netherlands, including HCF.

The total transport volume of all land-based freight transport (road[7], rail and IWT) on Dutch territory is 1,121 Mt (2015 data), of which 44% crosses one of the Dutch borders and is therefore considered as HCF transport. Almost one-third of all the national freight transport is hinterland transport to or from one of the Dutch mainports.

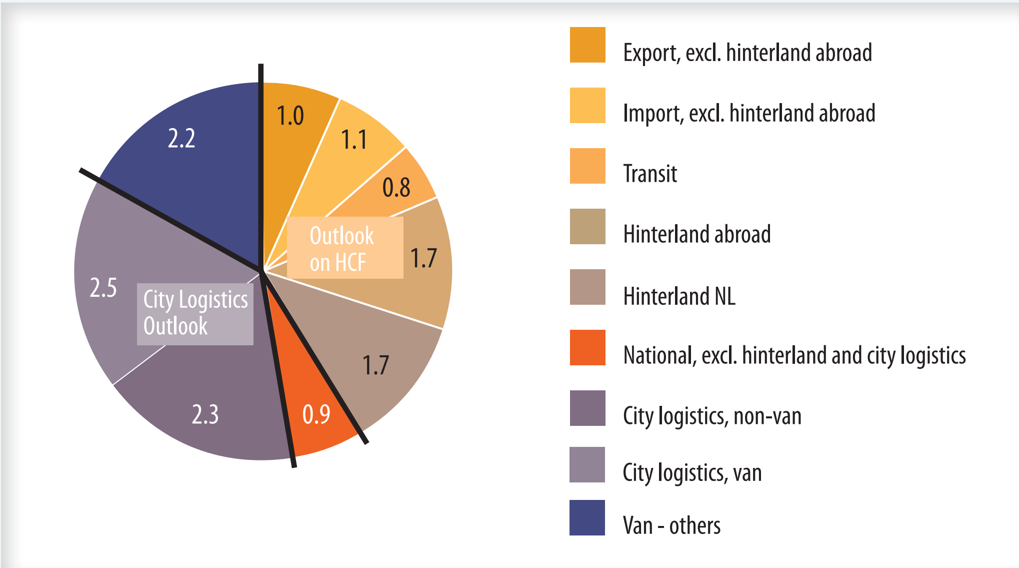
Including hinterland transport to and from locations in the Netherlands, HCF transport accounts for about 62% of all tonnes shipped, illustrating the major role of HCF transport.

7 In this Outlook road freight transport consists of all freight carriage by road truck (>3.5 t); vans are excluded.

Expressed in tonne-kilometres on Dutch territory, the total freight transport volume amounts to 106,780 megaton-kilometres (Mt-km). National transport (including hinterland) has a share of 43%, which is less than the share in Mt. If all hinterland transport is considered as HCF transport, almost three-quarters (74%) of the tonne-kilometres is international transport.

Translating the transport volumes into GHG emissions shows that, although HCF transport constitutes the bulk of transport occurring on Dutch territory, the share in GHG emissions is around 45%. This can be explained by the greater efficiency of HCF transport compared with city logistics. Particularly vans have a relatively modest share in tonne-kilometres, but more than a third in the total CO_2 emissions of freight transport. The vehicles used in HCF are relatively large: the smallest vehicle category used in HCF transport is the largest one used in city logistics.

Figure 4
Total CO_2 emissions on Dutch territory of freight transport, including national transport (Mt in 2015).



The remainder of this chapter focuses on HCF transport.

3.3 Hinterland and continental transport volume and emissions per transport mode

HCF transport comprises various categories, differing in the distance of the logistics chains and the transport modes used:

- Import, export and transit (excluding all hinterland transport to/from destinations/origins outside the Netherlands).
- International HCF transport to/from mainports (differentiated by airport and seaport).
- National HCF transport to/from mainports (differentiated by airport and seaport).

3.3.1 Total volume of HCF transport

For each type of HCF transport mentioned above, Figure 5 shows the total transport volumes - for all three transport modes together. The majority of HCF transport is hinterland transport, with a share of 62%. The HCF transport volume totals 697 Mt.

Figure 5
International freight transport volumes in the Netherlands (Mt in 2015).

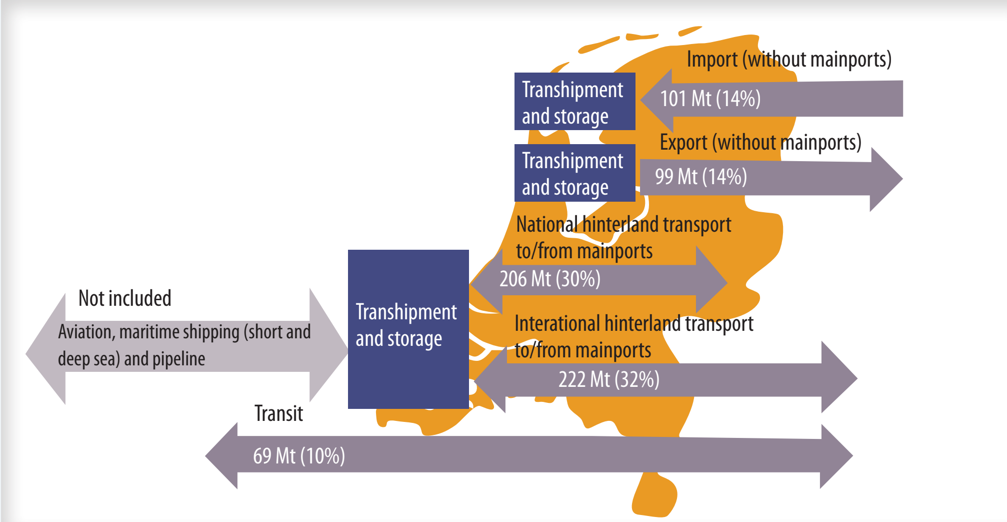
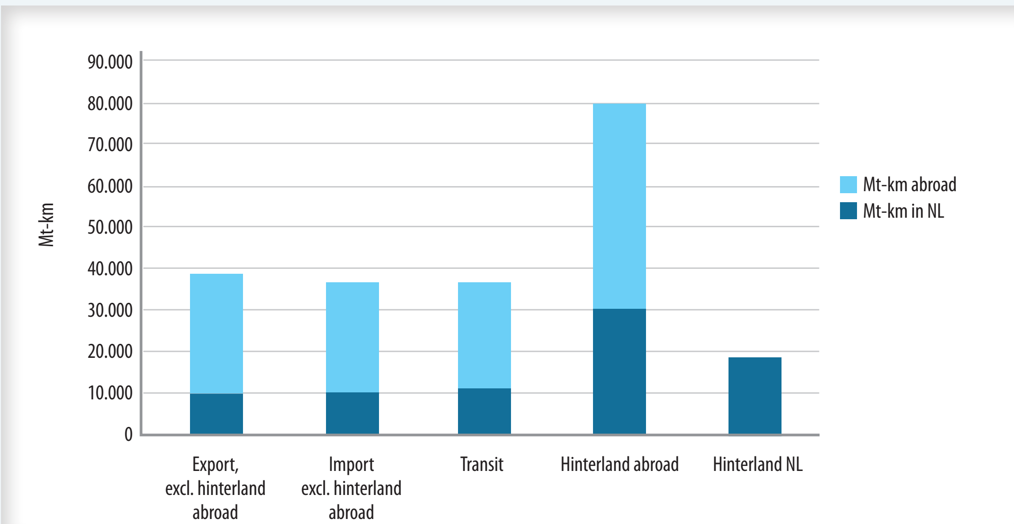


Figure 6 shows the Mt-km (on Dutch territory and abroad) corresponding to the volumes of the international transport flows shown in Figure 5. In terms of tonne-kilometres on Dutch territory, import (12%; excl. international hinterland transport), export (12%; excl. international hinterland transport) and transit (14%) all have a comparable share. National hinterland (23%) and international hinterland transport (38%) are both larger, together accounting for 62% of the international freight transport tonne-kilometres on Dutch territory.

Considering the entire chain, including the transportation occurring abroad, the shares of import (17%; excl. international hinterland transport), export (18%; excl. international hinterland transport) and transit (17%) are all relatively larger than when only transport on Dutch territory is considered. The share of national hinterland (9%) is much smaller, as these transport flows do not cross the border. International hinterland transport (38%) has the largest share.

Figure 6
International freight transport volumes on Dutch territory versus abroad (Mt-km in 2015).



Combining the results on Mt and Mt-km, it can be calculated that the average distance of international transport per chain type (import, export, international hinterland and transit) is about 113 km on Dutch territory and about 301 km in total (on Dutch territory plus the part of the chain that is abroad).

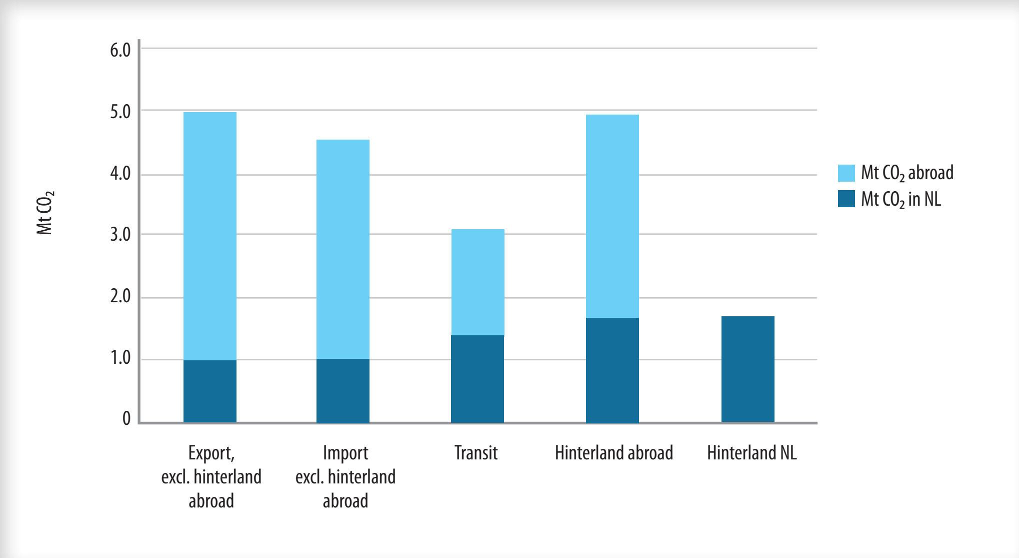
The mainports of Rotterdam and Amsterdam account for respectively 74% and 17% of the hinterland transport volume. Combining this with the data from Figure 5 shows that the Port of Rotterdam alone accounts for 45% of the total international transport volume (in Mt) in the Netherlands, with Rotterdam and Amsterdam together representing 56%.

3.3.2 Total CO_2 emissions of HCF transport

The total CO_2 emissions based on the Mt-km on Dutch territory and abroad of the various international transport flows in the Netherlands are shown in Figure 7. The annual CO_2 emissions of international freight transport amount to about 6.3 Mt if only emissions on Dutch territory are considered and around 19.3 Mt if the entire chains are considered (excluding emissions from aviation and maritime shipping). For comparison, the CO_2 emissions of national freight transport total about 3.6 Mt (excluding hinterland transport and vans).

As with the transport volumes in megatonnes and megatonne-kilometres, hinterland transport accounts for the greatest share of CO_2 emissions from international transport on Dutch territory: 54%, (Figure 7). Considering the entire chains, hinterland transport CO_2 emissions are 34% of the total CO_2 emitted by international transport.

Figure 7
CO_2 emissions of international freight transport on Dutch territory versus abroad (Mt in 2015).



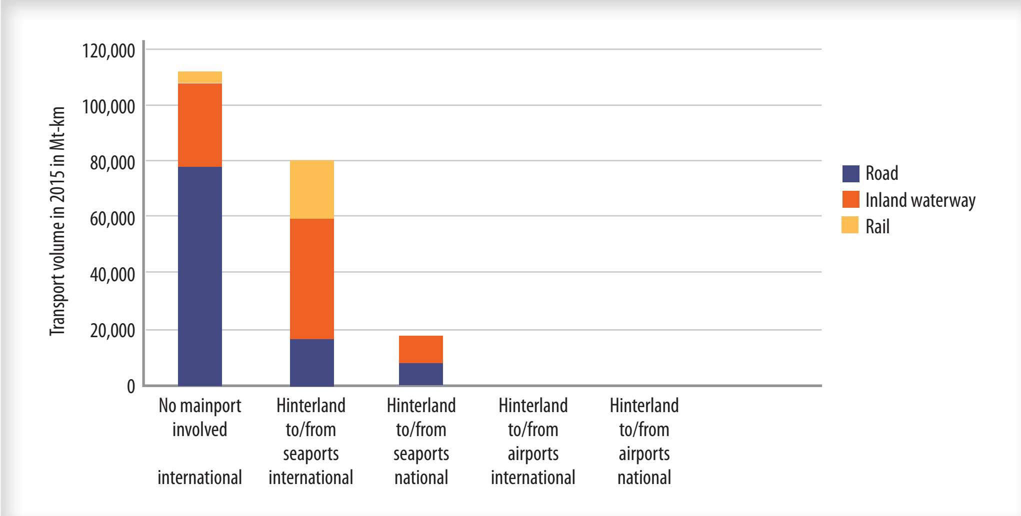
3.3.3 Transport volume of HCF transport per mode

With 6% of the total tonnage of international transport, rail transport represents only a small share of international transport flows compared with inland waterway (47%) and road (also 47%). Road has an especially large share in import (74%), export (75%) and national hinterland transport (61%). Inland waterway has a large share in transit (67%) and international hinterland transport (70%). With a 14% market share, rail is relatively strong in hinterland transport. This represents more than three-quarters of total HCF rail transport in the Netherlands.

According to Figure 8, rail accounts for about 12% of freight Mt-km, compared with 40% for inland waterway and 48% for road. This is due to the average distances for inland waterway (139 km) and rail (157 km) being larger than for road (83 km).

Inland waterway transport (IWT) is particularly strong in hinterland transport from seaports, with a share of half of the Mt-km for both national and international shipments.

Figure 8
Modal split of HCF transport volumes on Dutch territory (Mt-km in 2015).

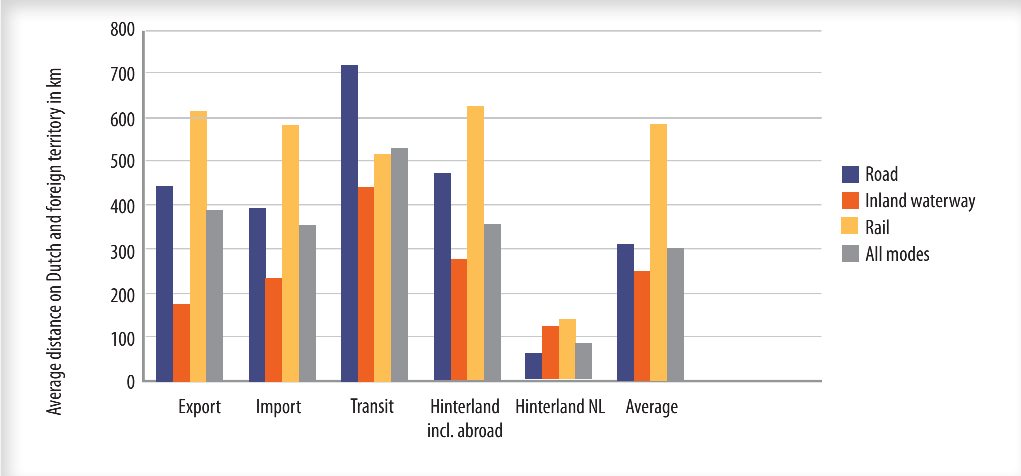


The relatively larger share in Mt-km of rail transport can be explained by the longer average distances for rail (587 km) that are significantly larger than for road (311 km) and inland waterway (255 km).

Average transport distance

Figure 9 shows the average transport distance per mode and type of chain, as well as on overall average. The distances for rail are generally larger than for IWT and road, although there are certain exceptions. The international chain of transit transport by road is longer than for both rail and IWT.

Figure 9
Average transport distance for international freight transport on Dutch territory and abroad (km in 2015).

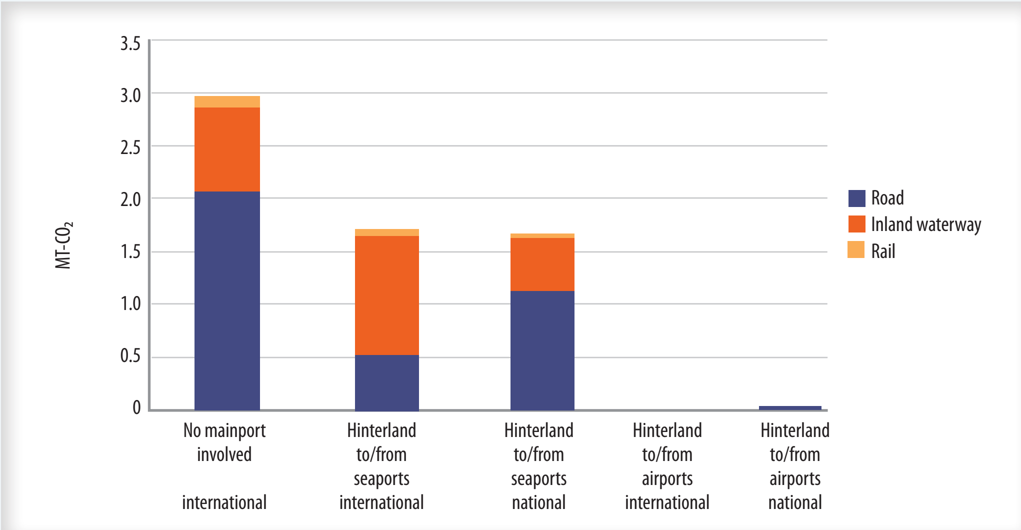


3.3.4 Total CO_2 emissions of HCF transport per mode

Figure 10 shows that, at 61%, road transport accounts for by far the largest share in the CO_2 emissions of HCF transport occurring on Dutch territory. IWT accounts for 38%, while rail is responsible for a mere 1%. If the emissions abroad are included, road transport is responsible for an even larger share of CO_2 emissions, accounting for 75% of the CO_2 emitted as a result of HCF transport. The share of IWT is then 23%, with rail remaining at only 1%.

Figure 10

CO_2 emissions of international freight transport per mode and territory (Mt in 2015).



3.4 HCF transport volume and emissions per segment

In addition to this breakdown according to transport mode and type of cross-border transport flow (import, export, transit and hinterland), it is useful to distinguish between types of freight or goods, as these may be associated with different decarbonization concepts.

Two main categories are identified here, which can be subdivided into two or three sub-categories:

1 Raw materials (liquid bulk versus dry bulk).

2 Consumer and (semi-)finished products (perishable goods, non-perishable consumer goods and semi-finished products, machines, transport and industrial equipment).

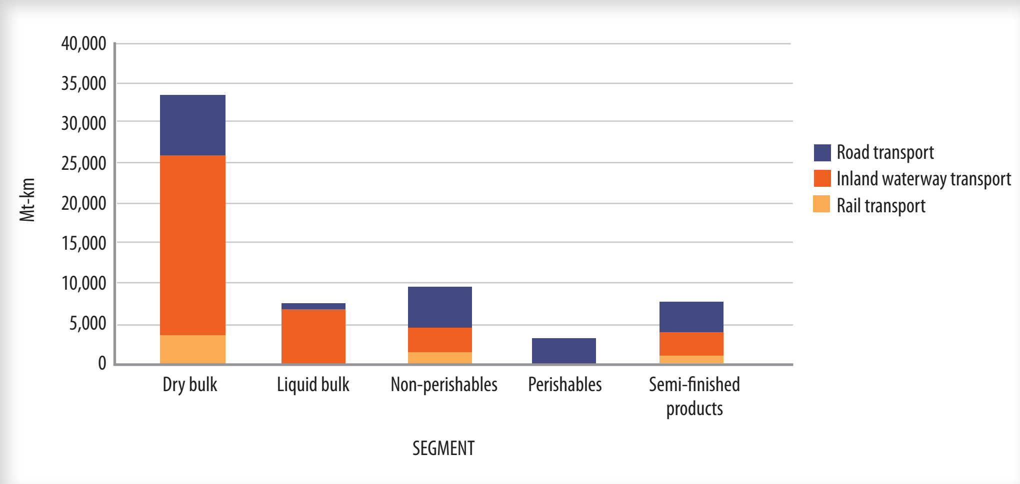
3.4.1Transport volume in megatons and megaton-kilometres per mode and per segment

For each mode Figure 11 shows the transport volume per segment in Mt for international freight transport on Dutch territory.

The dry bulk segment accounts for over half the Mt (53%) and Mt-km (55%) of transported goods. The shares of liquid bulk (11% in Mt, 12% in Mt-km), non-perishables (17% and 16%, respectively), semi-finished products et cetera (13% and 13%, respectively) are much smaller and of comparable size. The perishables segment is the smallest, in both Mt (6%) and Mt-km (4%).

Road transport dominates non-perishables (92% in Mt, 89% in Mt-km), perishables (100% in both cases) and semi-finished products et cetera (61% and 49%, respectively). Inland waterway is dominant in the transportation of dry bulk (60% and 68%, respectively) and liquid bulk especially (92% and 89%, respectively).

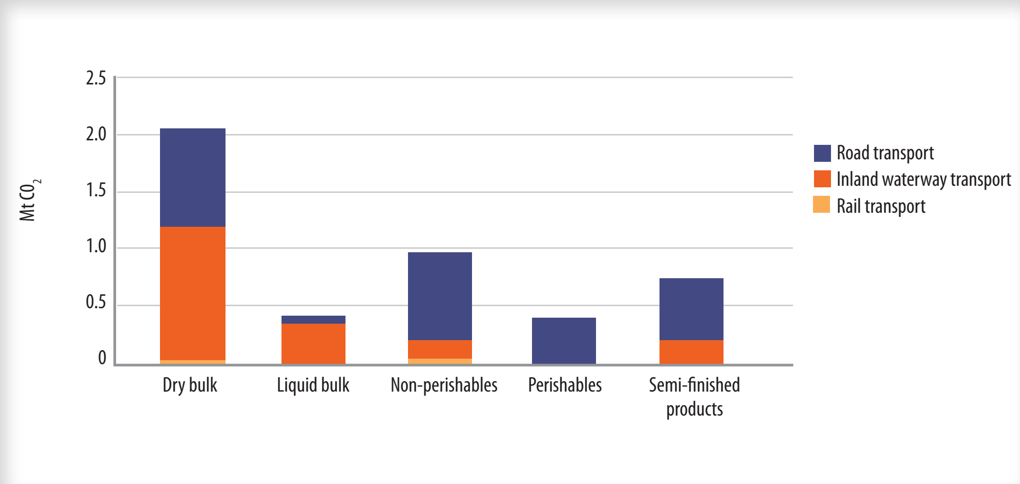
Figure 11
Transport volume per segment of HCF transport on Dutch territory, (Mt-km in 2015).



3.4.2 CO_2 emissions per mode and segment

From the Mt-km data CO_2 emissions were calculated, for logistics chains that start or end in a seaport. Dry bulk accounts for 45% of the total CO_2 emissions of hinterland and continental freight, which is less than its share in Mt and Mt-km. The segments with a large share of transport by road (non-perishables: 21%, semi-finished products: 16% and perishables: 9%) have a larger share in CO_2 emissions compared with their share in Mt and Mt-km. Liquid bulk has a share of 9% in CO_2 emissions.

Figure 12
CO_2 emissions per segment of port-related hinterland and continental freight on Dutch territory (Mt in 2015).



3.5 The logistics function

The two main elements of the logistics function are storage and transhipment. Four storage function categories are distinguished:

1 **Ambient:** general warehousing, including distribution centres (DCs) and cross-dock centres.
2 **Cool-freeze:** warehouses and DCs with conditioned temperatures.
3 **Dry bulk:** outdoor storage of bulk, and partial indoor storage of grain, salt, fertilizers, et cetera.
4 **Liquid bulk:** storage of oil, chemicals and food in silos.

The transhipment function also splits into four categories:

1 **Deep sea container:** transhipment of maritime containers in seaports.
2 **Inland container:** transhipment of maritime and inland containers in inland ports.
3 **Dry bulk:** transhipment of dry bulk cargo in seaports and inland ports.
4 **Liquid bulk:** transhipment of liquid bulk cargo in seaports and inland ports.

To estimate the CO_2 emissions of the logistics functions a two-way approach was adopted: top-down and bottom-up. The top-down approach consisted of analyzing the results of global studies on the carbon footprints of logistics functions and long-term energy agreements on energy savings in specific sectors, while the bottom-up approach was based on energy consumption and emissions data at the company level. These calculations on CO_2 emissions of the logistics function are described in Appendix D. Table 1 provides an overview of the CO_2 emissions of HCF transport and the associated logistics function, as calculated in Appendix D.

Table 1

Overview of CO_2 emissions for international transport and logistics in 2015.

TRANSPORT		**CO_2 (Mt/year)**	**% INT.**	**CO_2 (Mt/year)**	
Land transport	Import	1.054	100%	1.05	
	Export	1.023	100%	1.02	
	Transit	0.809	100%	0.81	
Hinterland from mainports	Netherlands	1.673	100%	1.67	
	International	1.713	100%	1.71	
Total transport emissions (on Dutch territory only)			*6.3*	*89%*	
LOGISTICS		**CO_2 (Mt/year)**	**% INT.**	**CO_2 (Mt/year)**	
Storage	Ambient storage	0.300	40%	0.12	
	Cold storage	0.400	40%	0.16	
	Dry bulk storage	0.030	50%	0.016	
	Liquid bulk storage	0.300	50%	0.15	
Total storage				0.45	
Transhipment	Deep-sea container	0.150	100%	0.15	
	Inland container	0.030	100%	0.03	
	Dry bulk	0.190	50%	0.10	
	Liquid bulk	0.110	50%	0.06	
Total transhipment				0.30	
Total logistics				*0.75*	*11%*
Total transport and logistics (on Dutch territory only)				**7.0**	**100%**

The aggregate annual CO_2 emissions associated with HCF transport and logistics on Dutch territory amount to 7.0 Megatonnes, with transport accounting for approximately 89% (6.3 Mt) and the logistics functions of storage and transhipment for 11% (0.8 Mt).

3.6 Conclusions and synthesis

From the foregoing analysis the following conclusions can be drawn:

- The total annual CO_2 emissions of HCF transport within the Netherlands are about 6.3 Mt when only emissions on Dutch territory are considered. When the entire chains are considered (excluding aviation and maritime shipping), HCF CO_2 emissions total 19.3 megatons. Including logistics and transhipment, which represent 11% of the total emissions, these figures increase to 7.0 and 20.0 Mt, respectively.

- The emissions occurring on Dutch territory amount to about one-fifth of the total CO_2 emitted by transport in the Netherlands (PBL, 2016).

- Road transport accounts for the largest share of HCF transport CO_2 emissions: 61% of the emissions on Dutch territory and even 76% when the whole chain is considered, illustrating the pressing need for decarbonizing this transport mode. IWT also has a significant share in CO_2 emissions: 38% (emissions on national territory) and 23% (entire chains), while rail has a very small share of 1% (emissions on national territory) and 1% (entire chains).

- Hinterland transport accounts for about 54% of HCF transport CO_2 emissions on Dutch territory, illustrating the relative importance of ports as nodes where transport begins or ends. Taking the entire logistics chains into account reduces this share to 34%.

- Considering the various types of goods, dry bulk proves to account for 45% of CO_2 emissions, with the share of road transport noteworthy. While inland navigation is used mainly for large-scale bulk transport, road transport still plays an important role in the transport of mainly smaller batches (e.g. agricultural produce).

- Together, dry and liquid bulk account for over half the emissions. In the transition to sustainability, both categories are likely to become smaller, however, as transport of coal and oil derivatives will clearly decline. At the same time, though, it is as yet unclear whether alternatives will come into the picture.

- At 61%, the share of road transport in CO_2 emissions is already high. Moreover, this share is expected to rise further in the coming years.

- Owing to its small carbon footprint, rail transport has only a tiny share in overall emissions. With 6% on Dutch territory, in terms of tonne-km, too, the share of rail is small.

- When the total transport chains - including those abroad - are considered, the share of rail transport is somewhat larger but still small, about 12%, compared with 40% for inland waterway and 49% for road. Average distances for rail (587 km) are significantly longer than road (311 km) and inland waterway (255 km). These distances are also significantly longer than the distances typically covered in the Netherlands - approximately 150 km - implying that solutions to decarbonization must be international in nature.

4 Current and future trends and drivers

Based on interviews, literature and workshops we have identified the primary external drivers in society, technology, logistics and policy that will have the most significant influence on HCF logistics over the coming decades. We have identified the trends and developments that will have an overall impact, as well as those likely to have a specific (and sometimes different) effect on a specific segment.

4.1 Drivers influencing HCF logistics

Over the last few decades, international trade has grown rapidly owing to globalization and dominance of the industrialized world. The rise of Asian economies, providing cheap consumer goods for developed economies, and trade liberalization policies have fostered international trade and the development of ports like Rotterdam and Amsterdam. Globalization has resulted in common standards (e.g. maritime containers), removal of trade barriers and massive demand for transport, resulting in scale advantages and subsequently in cost reductions. Global sourcing and regional specialization is still developing, with a focus on high-value goods production in the Netherlands.

Logistics does not take place in isolation and the past growth of logistics resulting from the rise of Asian economies will not automatically continue. Many external factors will affect HCF or even define the boundaries in which its operations are organized in the future. The current and future trends and drivers have been grouped into:

- Demand and supply trends.
- Transport of fuels and energy carriers in a decarbonised economy.
- Fuels and energy carriers used in decarbonized HCF transport.
- Societal pressure.
- Government policy.

The following section introduces for these categories the relevant trends and drivers and specifies them for the various market segments up to 2050. The impact of the trends and drivers on the distinguished HCF market segments is presented in section 4.3.

4.1.1 Demand and supply trends

Population size and per capita income are key indicators for logistics growth. A further-growing world population and a growing middle class means a growing base for consumer goods and a growing demand for nutrition.

The world's population is expected to reach 9.7 billion people in 2050, compared with 7.3 billion in 2015. In 2050, there will be one-third more consumers compared with today, especially in Asia and Africa, while Europe's population is expected to decrease by approximately 10% over the decades up to 2050. Global income, consumption and production will therefore spread from the traditional regions of North America, Europe and Japan over the entire world. Developed countries will consequently benefit less from globalization than before, resulting in lower GDP growth and a reduction of import growth. The same is true for export flows, since Asia and Africa will develop their own high-quality production facilities. This will lead to a dispersal of manufacturing across the world.

The central transfer/hub position of the Dutch ports will become less pronounced, since point-to-point trade lanes will gain in importance, not least as a result of investments from the East.

Although the roles of individual regions are likely to change, there is unlikely to be significant reshoring towards Europe. Instead, other regions will take over where cheap labour is available in abundance.

Containerization and the use of reefers for transporting perishables and temperature-controlled goods will increase as a result of globalized production in combination with increased consumption of fresh (exotic) produce.

Port and terminal congestion is a serious problem in container logistics, particularly with respect to handling and hinterland transport by barge. One of the causes is the enormous increase in call and ship sizes. The unpredictability of operations leads to congested terminals and a risk of a reverse modal shift towards road. At the same time road congestion is also increasing, despite huge investments in improving the road network around ports and towards the hinterland.

The capacity of the rail and inland waterway transport (IWT) network is still sufficient and will increase as carbon-based flows (coal, fuels) decrease in the near future. However, the rail and IWT network do not cover all the main corridors. France, Spain and central Europe, in particular, lack good rail and IWT connections, limiting their potential to attract cargo flows.

The circular economy, based on the re-use of discarded products, will seriously impact logistics and increase the number of transport movements. However, the impact on international transport is expected to remain limited, as most of the circular transport flows will be on relatively short distances and remain within the national boundaries.

Technology

In addition, technological advancements will help decarbonize HCF logistics. The transparency of production chains will improve as a result of optimized track-and-trace systems, supported by technological advances. Data exchange between terminals, operators and independent platforms will help optimize logistics networks. This will allow better planning, on the one hand, but will also allow logistics service providers to make more informed decisions along the chain. These developments will play an important role in making logistics chains more efficient, permitting a more effective match of supply and demand, fed by an enormous amount of useful operator data available from connected platforms.

The increase in transparency and reliability of non-road modes will ease modal shift projects and make these modes more competitive. The use of co-modality will increase as just-in-time services can also be offered by rail and inland navigation if these modes are afforded a preferred position on their infrastructure networks. The revival of the old silk road may lead to new trade opportunities since the travel time between Europe and China reduces significantly, the impact on overall trade volumes is limited, however.

While 3D printing is often cited as having a potentially significant influence on future demand for transport, by enabling reshoring of production, the influence will, in fact, remain very limited, since 3D printing is expected to cut costs under specific circumstances only. In particular, it will be used for non-mass-oriented applications (customized products and prototypes) and complex products with high production costs. It should be noted that 3D printing may also be a solution to the timely delivery of long-tail products[8].

Truck platooning and autonomous and assisted driving will reduce the costs of transport and allow operations to be made more efficient and new business models to be introduced by first movers.

The emergence of shared ('dark') warehouses will provide an opportunity to organize logistics networks more efficiently and reduce transport distances, especially for e.g. consumer goods not requiring any post-logistics processing steps but merely stored before being sent out for purchase.

4.1.2 Transport of fuels and energy carriers in a decarbonized economy

Decarbonisation of the economy as a whole will cause an enormous change in the use of energy carriers by all sectors. The mainly fossil-based energy carriers in use today will be replaced by carbon neutral alternatives. The phase-in of carbon-neutral energy chains will impact both the volume and the structure of HCF logistics.

The use of coal for power generation will be phased out, drastically reducing the need for hinterland transport of coal, which comprises 10% of hinterland transport from ports. The closure of coal-fired power plants has already started in the Netherlands, supported by a sharp decline in the costs of sustainable power generation. Germany, a major market for coal is expected to close down coal plants as well. It will take longer to replace cokes for steel production, but eventually a less polluting alternative will be introduced. Coal and cokes are transported predominantly by rail and by specialized bulk push barges.

Biomass - possibly in combination with CCS/CCU[9] and in cascade with the production of high value energy products[10] - is one of the candidates to replace coal as an energy source, but it is likely to play only a minor role due to limited availability of sustainably grown feedstocks. A precondition for use of biomass as fuel is a short term CO_2 cycle of harvesting it, burning it for energy and growing new biomass, requiring stringent certification schemes. Biomass logistics will replace coal transport, while the push barges can be easily modified for biomass transport.

8 Less popular goods in lower demand.
9 Carbon capture and storage / carbon capture and use.
10 Cascading implies using individual component for the most valuable application.

Steel production, also requiring large amounts of coal, is expected to continue the use of coal as a carbon and energy source in the next decades. The production process will be made more efficient, but the replacement of coal by hydrogen or electricity is novel, complex and not expected before 2040. Available scenarios assume the use of CCS/CCU to eliminate CO_2 emissions. If coal is phased out from steel production and steel recycling increases, the fall in demand will automatically lead to a reduction in carrying capacity.

Fossil liquid fuels used in transport will be phased out. Today 95% of mineral oil imports are used to produce transportation fuels. This demand will be reduced, as in all probability passenger cars and light trucks will be electrified. For freight transport, the ultimate solution is not yet clear and will depend on technological developments in the coming decade. What is clear, though, is that fossil fuels will no longer be able to be used to power large trucks and inland vessels. The drop in demand for tanker capacity (road, rail, barge) will be significant, even if heavy-duty transport comes to rely partly on biofuels.

Solar fuel or, more generally, power-to-X (PTX) fuel is a black swan, leaving fuel logistics relatively unchanged. It can theoretically be produced by using (cheap) renewable energy in areas with abundant space and wind or sunshine, taking water to produce H_2. Hydrogen can be bound to heavier atoms like nitrogen to generate a gas or liquid, or even to generate hydrocarbons in a reaction with CO_2. If, due to innovation, costs drop to a competitive level, it might be possible that energy producing countries start to evolve using this process, generating new liquid fuel flows to Rotterdam. At a more limited scale the production of PTX fuels can also play a role in the Netherlands for balancing the varying supply of renewable energy to the demand.

The same can be said for negative CO_2 factories, such as piloted by start-ups as Global Thermostat[11], that removes CO_2 from ambient air. If the cost curve of this process (using renewable energy inputs) drops to a level where it can compete with other solutions, it may become of interest to oil producing countries to sell mineral oils with the guarantee that the emitted CO_2 is compensated.

Hydrogen may play a role as a buffer for excess renewable energy. Although the market price may be low (and at times even negative), this does not mean that hydrogen produced from excess electricity will be cheap. This will depend on the net capital costs of the electrolysis facilities that will be on-stream only part of the day. Furthermore, the future availability of excess electricity for hydrogen production should not be overestimated, as this will be reduced by effective demand management in smart grids and/or by storage in alternative stationary options with possibly lower costs.

4.1.3 Fuels and energy carriers used in decarbonized HCF transport

Decarbonisation of the logistics sector (Factor 6) will drastically change the energy carriers and propulsion technologies used in freight transport.

Electricity and hydrogen

Large trucks and inland vessels will use electricity or hydrogen for propulsion, supported by improved technologies and reduced costs. HCF transport equipment will benefit from developments in passenger cars and city logistics, where the transition has already started. The energy will be stored on-board in a battery, taken from an overhead wire, or produced on-board from sustainably produced hydrogen stored in a tank.

11 https://globalthermostat.com/

Fuel-cell vehicles running on hydrogen are technically nearing maturity. They combine some of the superior driving characteristics of electric vehicles with a longer range, a short refuelling time and an energy infrastructure that is more similar to the current system based on petrol stations. These are all important advantages from an end-user perspective. At the current state of technology, however, the energy chain from renewable electricity to the mechanical energy at the wheels involves significant energy losses associated with electrolysis, compression or liquefaction and subsequent transport of hydrogen and conversion back to electricity in the fuel cell on board the vehicle. For a given amount of renewable electricity, e.g. from solar energy (photovoltaics) or wind turbines, a battery electric vehicle can drive at least twice as far as a hydrogen-powered vehicle. As long as renewable energy is not abundantly available at low cost, from an overall energy perspective, hydrogen will be used most in applications where the drawbacks of battery electric vehicles are unacceptable.

As a continuation of the current trend of electrification of locomotives, rail diesel locomotives will be replaced by electric ones and tracks will become increasingly electrified, since the overall operational costs of electric rail transport are lower. Small batteries will be implemented for train operations in yards where transhipment operations prevent installation of an overhead wire.

Current developments indicate that inland navigation too will shift towards electric drivetrains, allowed by autonomous driving that require less personnel and changes the business case. New ships will be operated with an electric motor, combined with a diesel engine at first, as financing new old fashioned diesel drivetrains will become complex and second hand sales prices of old-fashioned ships will strongly decline. In the short term a diesel hybrid drive train will result in a 15-20% reduction of fuel consumption. Once the costs for batteries or fuel cells have come down, the diesel engine will be replaced by one of these options.

Battery packs can be used as a buffer in the electricity grid, which allows first movers to buy electricity in periods of oversupply and sell it when the demand is high. When intermediate storage has become a commonality, the benefits of storage will become smaller.
Terminals will electrify in order to maintain a competitive position with respect to the many new electrified terminals under development in China, as well as warehouse terminals becoming green through use of renewable power.

Analysis has shown that producing the sustainable energy carriers required for transport (passengers and freight) from mainly wind and sun is well feasible. Total demand for electricity will increase by 25%, but there are no limitations in terms of the space available for production (CE Delft, 2017). Significant changes to the infrastructure will be required, however.

Biofuels

The advantage of biofuels is that they can be used in the currently available fuel infrastructure and in diesel engines. Future availability is uncertain, however, and depends on development of conversion techniques and availability of surplus land. Current estimates of global biofuel availability in 2050 points to global biomass potential being insufficient to cover demand for transport (PBL, 2018). Moreover, given that other sectors will also express increasing demand for sustainably produced biomass in the coming decades, it is wise to assume that the availability of sustainably produced biofuels for the transport sector will be only sufficient to replace part of current fossil fuel consumption, and that this will be in the most complex sectors to decarbonize: aviation and maritime shipping.

Assuming that passenger car and public transport will become completely electrified, demand for the remaining transport modes in the Netherlands is projected to be around 100 PJ for trucks, 25 PJ for inland navigation and 300 PJ for aviation and maritime shipping (Dutch share based on world GDP) in 2050.

The required biomass for producing this 425 PJ in 2050 will not be available in the Netherlands, nor will it be covered by imports available from Europe. The total supply from Dutch sources will be limited to around 20% of this demand, assuming that current application of biomass remains untouched. Based on an equal amount per European inhabitant, some 40% of demand could be covered by European imports, with another 40% available from imports from outside Europe, using the same allocation method.

Based on the demand from other sectors and the uncertainty of the projections, we assume that biofuel will only be sufficiently available to cover part of the demand in maritime shipping and aviation, and not that of the inland transport modes.

On top of availability, it should be noted that despite a 'closed carbon cycle' the well-to-wheel (WTW) GHG emissions of biofuels are not zero, with GHG emissions occurring in agriculture, fertilizer production and fuel production and distribution. In addition, there are often significant GHG emissions resulting from so-called indirect land-use change (ILUC). As a consequence, the consensus is that biofuels for transport should be reserved for applications where electricity and hydrogen are not viable options, viz. maritime shipping and aviation and niche applications in other modes.

The WTW emissions of methane-powered vehicles can be significantly reduced by using biogas or synthetic gas produced from renewable energy and captured CO_2. The availability for use in transport of biogas with favourable WTW emissions, e.g. from waste or manure, will always be limited for the same reasons as with biofuels. In addition, there is concern about creating a lock-in if there is large-scale use of natural gas as a transition fuel to bridge the gap between diesel vehicles and the future upscaling of alternatives like electric and hydrogen vehicles.

Synthetic fuels
Similar to biofuels, solar or PTX fuels offer the opportunity to continue the use of a liquid or gaseous fuel (e.g. methanol or ammonia), but the energy chain is less efficient than for electric propulsion and some require CO_2 as a source and are therefore also criticised. As carbon will be a scarce material in the future, it is not yet clear to what extent it will be available for transport, and against which price.

Different energy carriers for different applications
All options have their specific advantages, drawbacks and limitations, leading to the conclusion that it is likely that the future HCF transport system will contain a mix of all of these technologies, with each technology applied in specific (sub)sectors or niches where the benefits of the technology outweigh the disadvantages. It is at this stage not possible, and also not constructive to the transition, to make a blueprint indicating which technology will 'win' in which application.

4.1.4 Societal pressure

In the years ahead, a clearer view on the impacts of climate change and the Paris agreement will increasingly raise the awareness of customers. As such, societal pressure is paramount to changes in logistics. Analogously to the improved chain transparency for clothing, meat and chocolate, the impacts of production and logistics will become more and more transparent. There will be reduced acceptance of consuming short-lifetime consumer goods associated with long logistics chains with high emissions and operators will be forced to use more efficient equipment. Increased supervision of logistics and data transparency will allow detailed monitoring and labelling of operations, which may also result in a reduced consumption of these consumer goods and reshoring of production.

Supported by improved awareness, the shift to 'local-for-local' will intensify. It may lead to less imports, but the risk of increased national small-scale transport needs to be taken seriously. Since local-for-local requires a lot of space around cities that is not available, it is not likely to have a strong impact on world trade and Dutch imports.

Additionally, the shift from products and ownership to the use of services will intensify, increasing the potential for circularity since manufacturers then have more control over their products and end-of-life processes. As part of the energy and climate transition, the economy will become more and more circular in general. The more fossil fuels are kept underground, the more carbon will become a scarce good. This will lead to a situation in which there is re-use not only of building materials and suchlike, but also of other carbon-containing materials, as this will reduce the need for biogenic carbon from scarce biomass.

Meat and dairy production are a major contributor to global GHG emissions, on a scale comparable with that of transport. In the coming years the GHG emissions of dairy and meat production will be increasingly debated and agriculture pressurized to increase the efficiency of farmland use and protein production and improve animal welfare. The extent to which people's diet will shift from animal to vegetable proteins is as yet unclear, especially outside Europe, where meat consumption is still growing. A substantial share of dry bulk imports is feedstock for industrialized meat and dairy production facilities. It is not yet clear whether community scrutiny will lead to lower production volumes in the Netherlands.

The impact of hinterland transport on the road network, especially around port cities, is significant and its presence is perceived as annoying and unhealthy. At the same time, there are physical limitations to the expansion of the road network, resulting in severe congestion. Therefore, ports increasingly start using inland hubs. As part of this concept, deep sea terminals send clients' containers to an inland hub, using rail or inland waterway.

Investors also may contribute towards greening international freight transport. This could be as part of external finance using sustainability criteria for the investment in transport equipment. Current trends of shifting investments from the tobacco industry and nuclear power industry towards most sustainable markets and the recent pressure on the oil companies can be explained as increasing pressure from investors on greening the logistics industry. In addition, the first signals of large shippers taking matters into their own hands can be observed.

4.1.5 Government policy

Government policy is a derivative of societal preferences and required to create a level playing field in the economy, to reduce market barriers and to incentivize individual players to move forward towards the goals set by society. The European regulations phasing out sulphur in fuel and the European emission standards are two examples of how societal pressure was translated into regulations.

As the complexity of various routes towards decarbonization differ, so too does the need for government assistance:

- Relatively simple adaptations within the own organization (modal shift, optimization of individual logistics performance) can be implemented without strong support (level 1).
- More complex adaptations will need government support during start-up (business case development in a complex, multi-partner network, modal shift) (level 2).
- In case of advance investments or barriers to increased efficiency, the level playing field needs to be created and guaranteed (level 3).
- The final category is development of new infrastructure requiring large up-front investments (level 4).

The Paris climate agreement will help bolster the case for various types of policies and regulations that help internalize external effects like GHG emissions. Examples of effective policies include performance standards, fuel regulations, excise duties and distance-based charging schemes. One example of legislation currently under development are the fuel consumption standards for trucks, which aim to turn the potential 40% fuel consumption reduction into reality. This first step will be followed by tax and other incentives for production, marketing and use of zero-emission vehicles.

For the upscaling of zero-emission technologies, targeted subsidies can help generate market volume.

The improvement of the operational carbon footprint will be incentivized by governments, but also by port authorities. Setting a price on carbon is an important element of the policies, but also reducing knowledge barriers are important for transport operators to act. Shippers can take the lead in greening logistics network design.

4.2 Impact of drivers per market segment

4.2.1 Dry and liquid bulk

The major change affecting dry and liquid bulk flows is expected to take place in the energy and transport sectors. The decline of the use of coal for energy production and fossil fuels is likely to have a substantial impact on the size of the flows in the bulk market. Today, 30% of the inland navigation transport performance is linked to the shipment of fossil energy carriers. The containerization rate of bulk flows will increase, for the (export) flows of potatoes and onions, for example.

It is, above all, inland shipping that is expected to be affected by the above developments. The decline in dry bulk volume (coal) will be partially compensated by the increase in containerized flows.

The use of raw fossil-based materials by the chemical industry is also likely to be phased out. Plastics will be replaced by renewable materials, recycled and melted down. This implies that part of the liquid bulk market will shift to the dry bulk market. The industrial clusters where the fossil-based industry is currently located are expected to continue to play a role in the future.

4.2.2 Perishables

The Netherlands has a very specific and dominant position in the European logistics chains of perishables, for two reasons: 1) the large scale of production and export of flowers and bulbs, vegetables, dairy and meat, and 2) the presence of Rotterdam and Schiphol mainports. This combination has led to the country having a dominant position in both domestic and hinterland transport flows when it comes to perishables and temperature-controlled goods. The Netherlands has become the main gateway and supplier for the fresh-food shelfs in supermarkets on a large part of the West and Central European mainland. The Dutch are also a dominant player in the worldwide export of seeds, seed potatoes, onions, flowers and bulbs. These flows are combined with import flows of fruit and vegetables from Central and South America, South Africa and China, benefiting from relatively cheap maritime transport costs.

Of all the HCF segments distinguished, the perishable segment has the highest share of road transport, with demand for speed and flexibility constituting the main rationale. At present, there is hardly any transport of reefer trailers and containers by rail, owing mainly to the lack of connections with Rotterdam (from Spain among other places) and the fact that trains cannot provide sufficient electric power for the reefers. Technological advances as sensoring and temperature control in both rail and inland waterway transport, together with increased congestion, will lead to a better position of these modes in hinterland transport.

Intercontinental import and export of flowers and vegetables is characterized by a high share of air transport. A shift towards maritime transport is likely with new technological developments in the field of temperature control, sensors and tracking and tracing systems. In the long term this will lead to an increase of reefer flows to and from seaports and inland hubs like Venlo. The perishables segment is anticipated to continue to grow faster than overall GDP growth. However, increased prosperity in Eastern Europe and Russia might also alter import flows of fruit via Rotterdam, as growing reefer container flows with citrus and tropical fruit, apples and kiwifruit can be transported directly to Sint Petersburg and Yalta, for instance, bypassing the ports of Rotterdam and Antwerp.

4.2.3 Non-perishable consumer goods

For cost reasons, imports of non-perishable consumer goods will come mainly from outside Europe, although retailers may be sensitive about their environmental profile and take action to reduce the climate impact of their logistics. Automation and digitization of transport and logistics operations will influence how goods are transported from manufacturers via retailers (both online and offline) to consumers. When it comes to consumer goods, e-commerce will play an increasingly important role in transport and logistics developments. It will give a strong push towards more transparent and automated logistics chains, but also lead to fragmented shipments. Under the influence of e-commerce there will be an increase in the numbers of large automated warehouses as well as smaller local (shared) warehouses.

Increasingly automated logistics operations will incorporate smart labelling and 'Internet of Things' applications to make logistics more transparent, efficient and reliable. With information improved, operations can be better planned and organized or even fully automated. In addition, closer cooperation between retailers and manufacturers, the increasing dominance of a few large players and further consolidation of transport companies will lead to higher utilization of trucks, vessels, trains and warehouses. Although a combination of these developments can heavily influence transport flows and the utilization of infrastructure and transport capacity, the human factor will continue to play a key role in the transition towards automation and digitalization. Privacy, trust and cybersecurity issues may hinder data-sharing, though.

4.2.4 Semi-finished products

The supply chains of semi-finished products are business-to-business flows driven mainly by costs. Compared with the bulk segments, the number of supply chains is substantially larger, with chains tending to be more complex as they are longer, with many more links, origins and destinations.

Shortening supply chains can result in better control in terms of product quality, risk reduction, higher reliability and cost reductions. Nearshoring and near-sourcing have therefore been widely discussed and put into practice by an increasing number of companies. In many supply chains, though, production locations are fixed for an extended period, with any shift to a new production location essentially a trade-off between transport and labour costs. As transport costs continue to be relatively low, production locations outside Europe will remain advantageous. Although labour costs in major production countries like China are also rising, there are still many other regions in Asia where labour costs are similar or lower. In the short term, then, transport flows of semi-finished products are not expected to change significantly, especially because sustainability is less of an issue for semi-finished than for finished products, where there is much more pressure from consumers to operate more sustainably.

4.3 Conclusion

Although rising populations, growing incomes and continued globalization point to a further increase in international logistics movements both worldwide and in the Netherlands, efforts to tackle climate change will lead to a redesign of international trade patterns and decarbonization of international transport.

Recent scenarios developed by the Port of Rotterdam indicate that containerized trade is likely to increase by 80% between 2017 and 2050, which is far less than originally projected before serious climate policy became a precondition. Including the 50% growth between 1990 and 2017, the overall growth in emissions is around a factor 2.5.

As a result of climate policies, changing consumer preferences and behaviour, the consumption and import of bulk goods like coal, oil and animal proteins are expected to decline. Fossil fuels will be replaced by renewable fuels, with a limited role for biofuels. Zero-emission energy carriers produced from renewable electricity will be used for propulsion in Paris-proof logistics, but the emergence of new technologies and greater information-sharing will create major scope for logistics improvements.

5 Outlook per segment

In this chapter an Outlook on decarbonization of the HCF sector is presented for each segment, built from trends, segment-specific characteristics and technical potential. The maximum potential of the various decarbonization measures is presented in detail in Appendix E. To what extent this (technical) potential can be realized differs per segment. The logistics chains of each segment obviously have their own specific characteristics in terms of commodities, transport modes, shipper requirements, etcetera. In other words, the decarbonization potential and challenges vary. A qualitative assessment of the specific potential of the decarbonization options per segment is based on expert judgement and has been validated with interviews and work sessions with stakeholders from the relevant sectors . Based on the specific potential and challenges, the transition path towards Factor 6 is then explored.

As the reference trend in terms of absolute CO_2 emissions differs from segment to segment and over time, all graphs in this report related to the Factor 6 challenge are indexed on a scale from 100 to 600 to make them easier to interpret and compare. In addition, the measures to achieve the Factor 6 challenge add up linearly[12] in the graphs: moving from level 100 to 200 requires the same amount of CO_2 reduction (or CO_2 productivity increase) as moving from level 500 to 600.

This chapter starts with an elaboration of the development and line of reasoning of the Outlook. Then, for each of the five segments distinguished, the decarbonization potential and development paths are described.

5.1 Outlook definition and development

The main contribution of this first Outlook for HCF is to develop a set of reference views that sketch a feasible path towards decarbonizing a specific HCF segment. As mentioned in the preface, a reference view is not a prediction of the future, nor a prescription of actions and tasks. Its goal, rather, is to provide a baseline that can be shared and debated and improved upon, to structure discussions among stakeholders. It shows that there is action potential to meet the targets, but it does not exclude other solutions and transition routes. As such, this first version is an invitation to contribute, an invitation to add improvements and an invitation to share it widely.

12 Not to be confused with an exponential interpretation: achieving Factor 2 or level 200 in the graphs does not refer to 200% more efficient logistics or to a 50% reduction in the total CO_2 emissions cuts to be achieved.

The next version will focus more in detail on the coming decade until 2030, providing a more quantitative analysis of transition paths.

In Chapters 3 and 4, the size and current ecosystem of each HCF logistics segment were characterized. The question now becomes:

- What measures and steps are needed to meet the Factor 6 requirements?
- What actions need to be taken, in what sequence, when and by whom?
- How are the uncertainties regarding developments over the coming decades to be taken into account?

The number of factors and actors and the interdependencies among them make it very hard to use standard analytical frameworks to develop a view of one or more feasible paths. The level of complexity is simply too high.

The method adopted in this chapter to define feasible paths is therefore based on the following main principles:

- **Backcasting from Factor 6**
  - Working back from a target to identify what is needed to secure that goal serves as the leading principle. Everything that is needed to achieve the target can be deemed a necessary step, even if that step is not yet widely accepted or not yet laid down in policies, laws or regulations.
- **Following identified internal and external drivers**
  - HCF networks are a service to shippers that service their customers, and as such are subject to external trends.
- **Respecting internal consistency**
  - A system change that creates a new stable situation integrating multiple trends and demands is seen as a more likely solution.
  - All stakeholder perspectives and external trends must be considered, while the path should be acceptable or fair for all. Businesses must be able to remain profitable, reasonable demands must be made of citizens and (de-)central governments must be able to balance conflicting societal demands.
- **Taking inertia into account**
  - Change takes time. The more stakeholders are involved, the longer it takes to innovate. Investment cycles in capital goods and infrastructure require several decades.
  - Gearing up production capacity for new means of transport by OEMs requires investment decisions, time to build and time to recoup the investments.
  - Replacing a large fleet of trucks in their normal replacement cycle takes 15 to 20 years, unless specific incentives are introduced. For barges the cycle is even longer.

It is therefore essential to start 'setting the stage' as soon as possible.

These principles have been used to identify, develop and select the most plausible scenarios for each segment by analysing relevant data and existing reports and using expert judgement, interviews and focus groups to test and refine each view. The required measures and steps are based on a broad identification and review of decarbonization concepts, as presented in Appendix E. These form the basis for the Outlook and for plausible paths for the five segments distinguished, as described in the following sections.

In this Outlook the most plausible path for each logistics segment is quantified as accurately as possible to create 'cascade' graphs showing the sequence of step changes, timing and relative contribution to achieving the Factor 6 goal. This combination we refer to as a 'reference view'.

5.2 Dry bulk

Overall, the hinterland and continental flows of dry bulk are not set to change significantly, with the exception of coal. Inland shipping is the major mode of transport for dry bulk, followed by road and rail transport. In terms of CO_2 emissions, road transport is equally important to inland shipping, while rail transport has a marginal share.

Table 2 presents the decarbonization options for the dry bulk segment, with an indication of the maximum potential of savings per category of measures. This potential has been estimated on the basis of the specific modal split for dry bulk, combined with the logistics characteristics of this segment. These figures may therefore be lower than the estimated decarbonization potential per measure described in Appendix E.

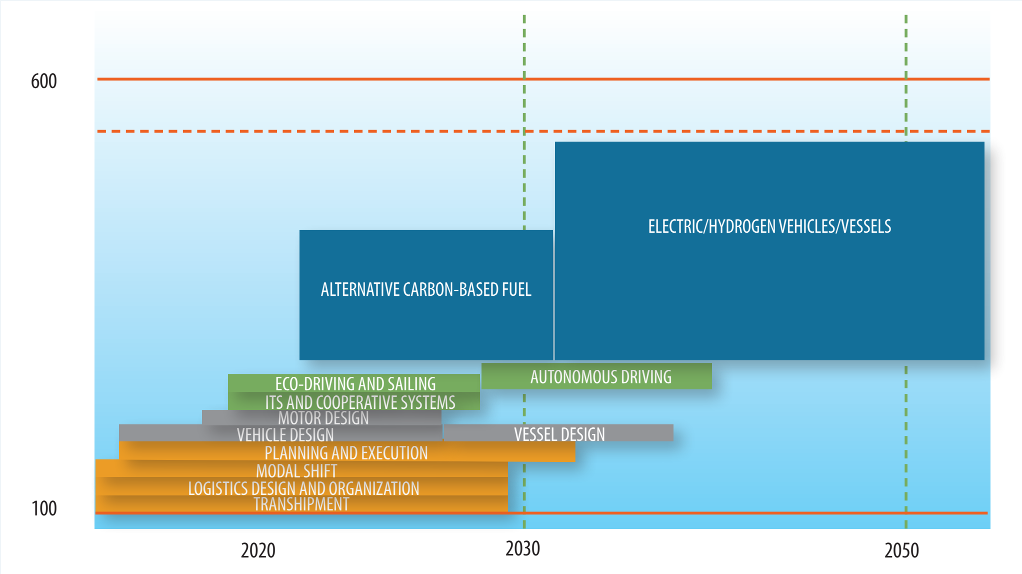
Table 2

Decarbonization potential for dry bulk.

CATEGORY	MEASURES INCLUDED				POTENTIAL
Logistics design and organization	Shipper collaboration, vertical integration in global logistics, circular economy	✓	✓	✓	5%
Modal shift	'Classic'modal shift synchromodality	✓	✓	✓	10%
Planning	Next generation FMS and TMS, synchronized transportation through Real-time visibility and predictive analytics (IoT blockchain)	✓			10%
ITS and cooperative systems	Green wave & traffic control installation, smart sailing routes/locks, increased draft of ships through improved measurement via sensoring	✓	✓		5%
Ecodriving and sailing	Training drivers, skippers and conductors, fuel/energy feedback coach, adaptive cruise control, tyre pressure check ,slow stearning, predictive cruise control, intelligent speed adaptation	✓	✓	✓	10%
Autonomous driving and sailing	Autonomous driving, autonomous sailing	✓	✓	✓	10%
Vehicle and vessel design	Sustainable trailer, chassis, cabin, optimised, streamlined ship/hull design	✓	✓		15%
Motor design and driveline	Engine efficiency, downsizing, transmission technologies, WHR	✓	✓		10%
Alternative fuels	LNG, CNG, and LPG mono and dual fuel BLPG, CBG and LBG	✓	✓		30%
Electric and hydrogen vehicles	Battery electric, pantograph, hybrid fuel cell and diesel-electric	✓	✓		60%
Sustainable transhipment	Efficient cranes green electricity				3%

The estimated potential of decarbonization options in combination with the expected period of introduction provides insight into the transition path towards the required Factor 6 reduction. This is illustrated in Figure 13, showing the transition path towards carbon-neutral transport for this segment. The main categories of decarbonization options are presented in different colours. The length of the block indicates the time it will take for the measure to deploy its full decarbonization potential, with its height indicating the amount of decarbonization it can realize.

Figure 13
Transition path towards Factor 6 for dry bulk



The dry bulk segment can only realize the Paris objectives if all the options for alternative fuels and propulsion techniques are fully deployed. For inland navigation, in particular, decarbonization will be a major challenge.

The decrease in coal flows will create overcapacity of the fleet (including push barges), leading to a decline in transport rates and a market shake-out. As a result of reduced freight rates, small companies will be unable to survive or to invest in new technology, which will put negative pressure on the pace of greening of the fleet. The specific characteristics of the inland shipping sector require a number of structural breakthroughs in both a technical and organizational respect, implying maximum effort from the sector itself, shippers and government. It is expected that shippers will become more proactive in the dry bulk sector and will take the lead in innovation and decarbonization in order to keep the mode available. Government action will prevent a shift back to the road and incentives will be implemented to promote zero-emission operations and a phase-out of diesel engines, replacing them with hybrid-diesel drivelines as a first step.

As logistics chains are less complex in this segment and improvement options are limited, there is only modest potential for logistics solutions compared with other segments. As dry bulk has a relatively low value, there is a natural tendency to limit the use of road transport, decreasing the scope for modal shift in this segment.

In the medium and long term the majority of decarbonization measures will come from alternative propulsion techniques. The first move towards zero-emission inland shipping will be installation of hybrid-electric drivetrains in new-build ships, allowing diesel engines to be replaced by batteries or fuel cells once costs have come down and the fuel/charging infrastructure is available.

5.3 Liquid bulk

Transport of liquid bulk has three main characteristics:

1 The main mode of transport is inland shipping.

2 The transport flows of liquid bulk are generally associated with production plants whose location hardly changes, resulting in relatively fixed routes. These transport operations are therefore already largely optimized.

3 Due to safety reasons, the sector is highly regulated.

The liquid bulk segment will be seriously affected by the energy transition, and it is as yet unclear to what extent current flows will be replaced by other liquid or gaseous flows. The decline in demand for transport of fossil oil products will lead to serious overcapacity in the inland waterway sector, while there is no alternative market where these tanker ships can be used. This overcapacity will result in a market shake-out, as the market is dominated by small companies that cannot easily invest in expensive new ships.
Table 3 gives an overview of the different measures per mode of transport and their expected impact.

Table 3
Decarbonization potential for liquid bulk

CATEGORY	MEASURES INCLUDED				POTENTIAL
Product volume reduction	Concentration and miniaturizing	✓	✓	✓	2-3%
Logistics design and organization	Supply chain data alignment, lead time relaxation and incentive systems, shipper collaboration	✓	✓	✓	2-3%
Modal shift	'Classic' modal shift, synchromodality, trimodal logistics megaparks	✓	✓	✓	5%
Planning	Next generation FMS and TMS, peak shaving, online brokerage & matching platforms, platooning-based planning, synchronized transportation through real-time visibility and predictive analytics (IoT, blockchain)	✓			5%
ITS and cooperative systems	Intelligent vehicle routing/dynamic route information, green corridor information and management, green wave & traffic control installation, smart sailing routes/locks	✓	✓		5%
Ecodriving and sailing	Training drivers, skippers and conductors,fuel/energy feedback coach, adaptive cruise control, tyre pressure check, slow steaming, predictive cruise control, vehicle platooning, intelligent speed adaptation	✓	✓	✓	5%
Autonomous driving	Autonomous driving, autonomous sailing	✓	✓	✓	10%
Vehicle and vessel design	Sustainable trailer, chassis, cabin, cooling/freezing technologies, optimised, streamlined ship/hull design	✓	✓		12.5%
Motor design and driveline	Engine efficiency, downsizing,transmission technologies, WHR	✓	✓		5%
Alternative fuels	LNG, CNG and LPG mono and dual fuel, BLPG, CBG and LBG	✓	✓		30%
Electric and hydrogen vehicles	Battery electric, pantograph, hybrid, fuel cell and diesel-electric	✓	✓		60%

Figure 14 shows the transition path towards Factor 6 for liquid bulk. As with dry bulk, the overall ambition can be somewhat lower than Factor 6 for this segment, since there will be a substantial fall in demand as well.

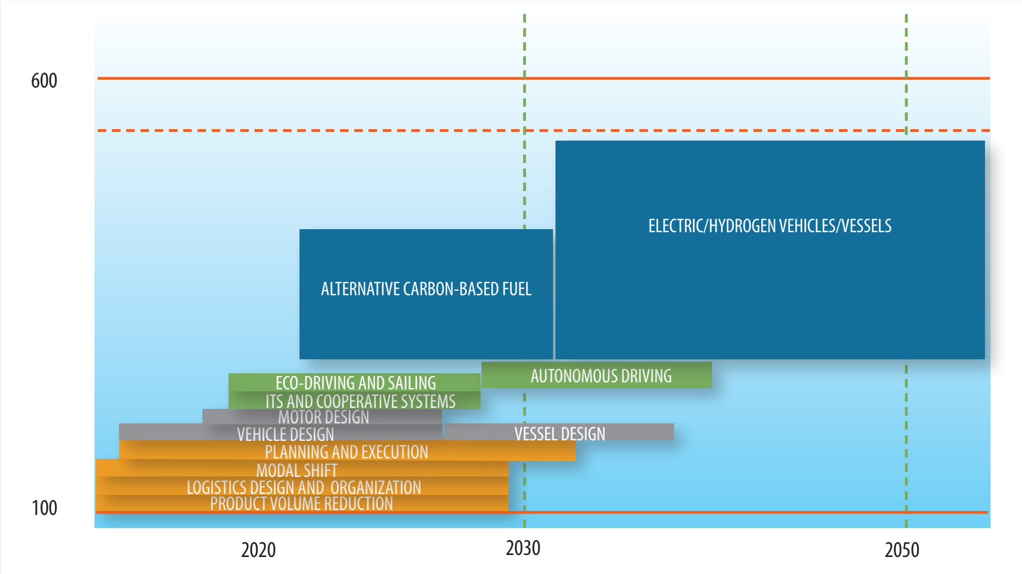


Figure 14
Transition path towards Factor 6 for liquid bulk

As the sector will be unable to make the required investments for greening the fleet, shippers will most likely take the lead in greening and continuation of business, since the competitive advantage of inland navigation is large compared with road transport. Furthermore, inland navigation has safety advantages over road transport. This is of particular relevance for the chemical industry, where safe operations have the highest priority.

Although the first green ships are already on the market, massive greening of the fleet is not expected until after 2030, following technological advance in other sectors.
Driven by both safety and congestion objectives, the government will implement policies focusing on the survival of the liquid bulk market and greening of the fleet. In the relatively short term, incentives will be introduced to phase out diesel engine and replacing them with hybrid-diesel drivelines. In the future the diesel engine can thus be relatively easily replaced by a battery pack or fuel cell.

Compared with the other segments, there is relatively little scope for reducing CO_2 emissions through logistics design and organization and modal shift. For liquid bulk, the bulk of CO_2 reduction must therefore come from decarbonization of energy carriers.

In the short term, limited improvements can be realized through efficient sailing and smart sailing routes in which vessel arrival is better aligned with the opening of locks and bridges, and through various logistics design measures, reduced empty sailing and reduction of ship fuel consumption through green corridor management, better planning and smart sailing. In the medium term, improved motor and vessel design can improve the fuel efficiency of inland vessels. In the long term, vessels using electricity or hydrogen for propulsion will achieve most when it comes to CO_2 reduction.

Similar developments are foreseen for the transport of liquid bulk by road, but given the fact that a smaller volume is transported by road, the impact will be smaller.

5.4 Perishables

The logistics chains in the perishable segment are relatively complex, with a great variety of origins and destinations and relatively long legs. The high share of road transport in combination with the expected high growth of the perishable segment implies that here, too, the decarbonization challenge is relatively high. Because of the wider variety of potential measures available however, the scope for reducing the CO_2 emissions in the perishable segment is also larger than in other segments. Table 4 summarizes the potential of the various decarbonization concepts.

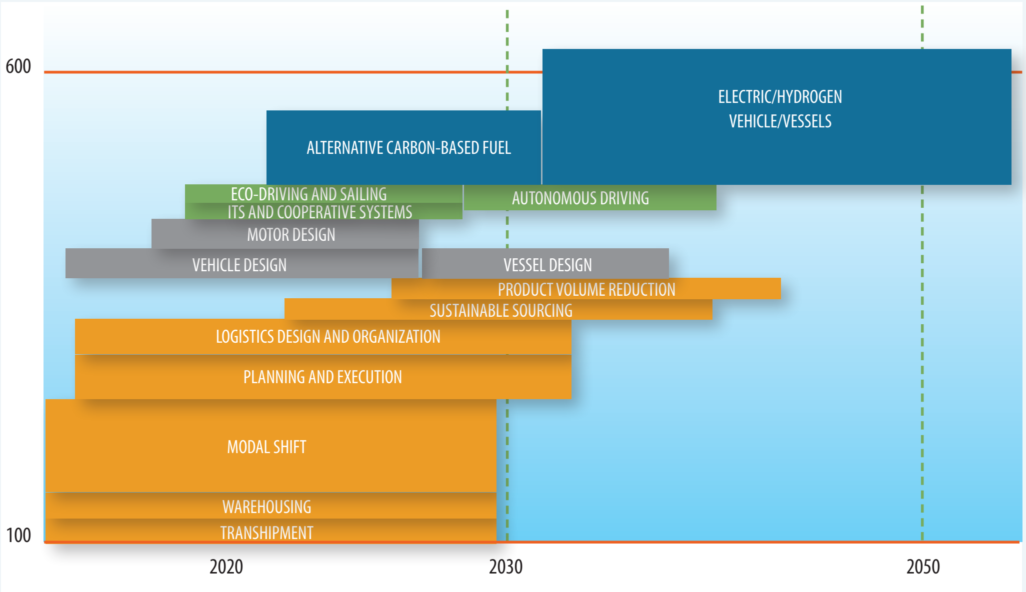
Table 4

Decarbonization potential for perishables

CATEGORY	MEASURES INCLUDED				POTENTIAL
Product volume reduction	Sustainable packaging	✓	✓	✓	5%
Near sourcing and shoring	Sustainable sourcing and near shoring	✓	✓	✓	5%
Logistics design and organization	Destination-based stuffing, sustainable container stuffing, sustainable ordering & procurement, LCL/LTL reconsolidation; supply chain data alignment, shipper collaboration, repositioning empty containers/ emballage, vertical integration in global logistics, flexible hybrid consolidation hubs, asset pooling/white label (idle time), circular economy, refurbishing & LCA, physical internet & self organising logistics	✓	✓	✓	10%
Modal shift	'Classic' modal shift, inland terminals combining transhipment and warehousing, synchromodality, IWT shuttle services along small inland ports and waterway, contextual/green corridor visibility	✓	✓	✓	20%
Planning	Next generation FMS and TMS, peak shaving, online brokerage & matching platforms, platooning-based planning, synchronized transportation through real-time visibility and predictive analytics (IoT, blockchain)	✓	✓	✓	15%
ITS and cooperative systems	Intelligent vehicle routing/dynamic route information, green corridor information and management, green wave & traffic control installation, smart sailing routes/locks	✓	✓		10%
Ecodriving and sailing	Training drivers, skippers and conductors, fuel/energy feedback coach, adaptive cruise control, tyre pressure check, slow steaming, predictive cruise control, vehicle platooning, intelligent speed adaptation	✓	✓	✓	5%
Autonomous driving	Autonomous driving, autonomous sailing	✓	✓	✓	10%
Vehicle and vessel design	Sustainable trailer, chassis, cabin, cooling/freezing technologies, optimized, streamlined ship/hull design	✓	✓		10%
Motor design and driveline	Engine efficiency, downsizing,transmission technologies, WHR	✓	✓		20%
Alternative fuels	LNG, CNG and LPG mono and dual fuel, BLPG, CBG and LBG	✓	✓		30%
Electric & hydrogen vehicles	Battery electric, pantograph, hybrid, fuel cell and diesel-electric	✓	✓		75%
Sustainable warehousing	Efficient buildings, electric forklifts, robotisation, high-bay warehouses				8%
Sustainable transhipment	AGVs, efficient cranes, green electricity				2%

Figure 15 shows the decarbonization path for perishables.

Figure 15
Transition path towards Factor 6 for perishables



For the fresh-food industry, the combination of producing and importing fruits, vegetables and other perishable goods in combination with the mainports of Rotterdam and Schiphol is a unique selling point for providing high-quality services and a wide variety of products to clients in the European hinterland. The industry therefore has a strong interest in maintaining efficient HCF logistics and will make an effort both to keep up the high quality of the hinterland network and to start working on greening the logistics chain, through pressure by retailers who are themselves under pressure from clients. Hinterland logistics hubs will be developed as part of this high-quality network, enabled by technological developments.

Innovation in reefer and ICT technologies will lead to an increased share of slower and less CO_2 emitting transport modes. Rail transport will improve its performance and provide new services for fresh produce and refrigerated cargo. New long-distance rail corridors (including the Silk Road) can provide an alternative for air-freight. The shift towards rail will be enabled by technological developments towards electric power supply in wagons for providing reliable temperature-controlled transport, as well as sufficient new transport services towards the main hinterland regions for perishables. Reefer and cooling innovations, using sensor and data technologies, will enable a shift from air to maritime transport. Maturing fresh produce and flowers and plants during transport provides another opportunity for other slower transport modes, such as inland navigation and short sea.

Government as well as port authorities will work together with industry to maintain high-level hinterland connections, provide incentives for development of green corridors, maintain the level playing field of zero-emission technology adopters and keep congestion levels limited. The figure illustrates the relative importance of logistics measures. Much of the decarbonization can be realized without deployment of alternative fuels and propulsion technologies, but will require intensive cooperation among all stakeholders to create the right conditions.
The storage of fresh produce, meat and dairy is energy-intensive. In this segment, therefore, the contribution of sustainable warehousing is relatively large. As road transport will remain the main mode, the impact of alternative fuels and electric propulsion is also relatively large compared with the other segments (particularly bulk).

5.5 Non-perishable consumer goods

Volumes of non-perishables consumer goods are assumed to increase further in line with economic growth. Owing to the varying characteristics of non-perishable goods (i.e. low or high value, small or large volume, heavy or light weight, customer demands) there are an enormous number of different supply chains. A major proportion of these goods are transported by road, thus providing major potential for CO_2 emissions reduction if transport can be shifted from road to rail and inland waterways. To this end, the goods will need to be transported in standardized transport units (e.g. containers) or need full truck loads (e.g. through cooperation and information sharing).

The next table gives a detailed overview of the measures for each mode of transport and the expected impact.

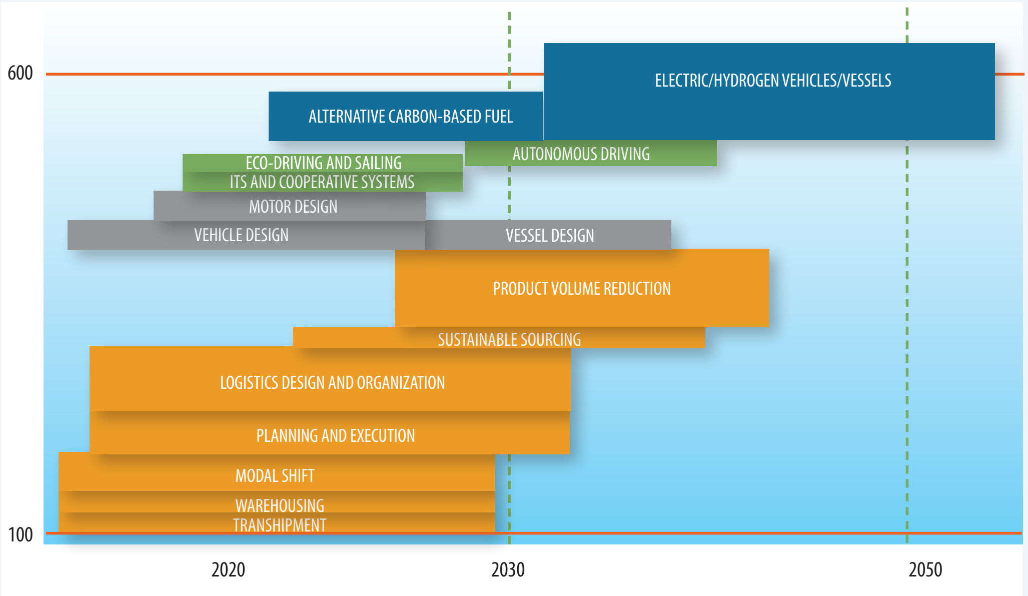
Table 5

Decarbonization potential for non-perishable consumer goods

CATEGORY	MEASURES INCLUDED				POTENTIAL
Product volume reduction	Sustainable packaging, concentration and miniaturizing, digitization, 3D printing	✓	✓	✓	20%
Near sourcing and shoring	Sustainable sourcing and near shoring	✓	✓	✓	5%
Logistics design and organization	Destination-based stuffing, sustainable container stuffing, sustainable ordering & procurement, LCL/LTL reconsolidation; supply chain data alignment, lead time relaxation and incentive systems, shipper collaboration, repositioning empty containers/emballage, reduce pipeline inventory locations, vertical integration in globall logistics, flexible hybrid consolidation hubs, asset pooling/white label (idle time), circular economy, refurbishing & LCA, physical internet & self organising logistics	✓	✓	✓	15%
Modal shift	'Classic' modal shift,air-to-rail (silk road logistics), relaxing JIT enabling alternative modes, inland terminals combining transhipment and warehousing, synchromodality, trimodal logistics megaparks. IWT shuttle services along small inland ports and waterway, distribution parks/ unloading quays, ITS on TEN-T corridors: contextual corridor visibility	✓	✓	✓	10%
Planning	Next-generation FMS and TMS, peak shaving, online brokerage & matching platforms, platooning-based planning, synchronized transportation through real-time visibility and predictive analytics (IoT, blockchain)	✓			10%
ITS and cooperative systems	Intelligent vehicle routing/dynamic route information, green corridor information and management, green wave & traffic control installation, smart sailing routes/locks	✓	✓		10%
Ecodriving and sailing	Training drivers, skippers and conductors, fuel/energy feedback coach, adaptive cruise control, tyre pressure check, slow steaming, predictive cruise control, vehicle platooning, intelligent speed adaptation	✓	✓	✓	5%
Autonomous driving	Autonomous driving, autonomous sailing	✓	✓	✓	10%
Vehicle and vessel design	Sustainable trailer, chassis, cabin, colling/freezing technologies, optimized, streamlined ship/hull design	✓	✓		15%
Motor design and driveline	Engine efficiency, downsizing,transmission technologies, WHR	✓	✓		20%
Alternative fuels	LNG, CNG and LPG mono and dual fuel, BLPG, CBG and LBG	✓	✓		30%
Electric and hydrogen vehicles	Battery electric, pantograph, hybrid, fuel cell and diesel-electric	✓	✓		75%
Sustainable warehousing	Efficient buildings, electric forklifts, robotization, high-bay warehouses				2%
Sustainable transhipment	AGVs, efficient cranes, green electricity				3%

Figure 16 shows the transition path for the segment of non-perishable consumer goods.

Figure 16
Transition path towards Factor 6 for non-perishable consumer goods



Large retailers will press for greening of the logistics chains, driven by community and consumer pressure, allowed by better design of supply chains and improved cooperation, driven by the availability of high-quality data from the supply chain partners.

Ports and terminal owners will join retailers to improve hinterland connections and hinterland hubs in order to limit congestion in and around the port and maintain the competitive position of the Dutch mainports. As part of this cooperation, new hinterland rail connections will be developed.

The relatively large potential of improved logistics operations through planning, new information and communication technologies can be realized in the relatively short term. The necessity of alternative fuels in the longer term is a little less compared with other segments, but still relevant to meet the Paris objectives. The greatest CO_2 reductions in this transition path are already expected in the short and medium term. Product volume reduction, although anticipated to have a large impact, will only occur in the medium to long term.

Economic growth and the growth of e-commerce will further spur the amount of non-perishable consumer goods sold. Product volume reduction will impact the total volume that needs to be transported. To realize further CO_2 reductions much can be gained through improved planning and execution and logistics design and organization, which are both heavily dependent on the willingness to share information data among supply chain members. Government action will push the development of green logistics through the implementation of incentives that allow industry to develop fruitful business cases.

5.6 Semi-finished products

For the transport of semi-finished products, all three modes of transport are used, with a dominant role for road transport. As a result, there is a larger potential for CO_2 reductions through modal shift compared with dry and (specifically) liquid bulk. In particular, an increase of full truck loads and hub development creates increased potential for modal shift from road to rail and inland waterway.

Table 6 gives an overview of the different measures per transport mode and the expected impact.

Table 6

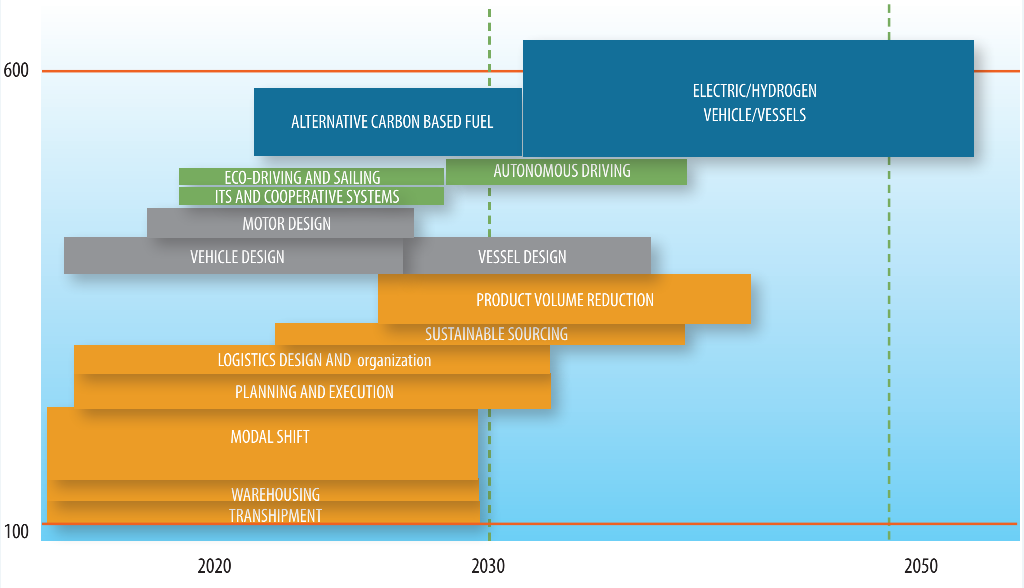
Decarbonization potential for semi-finished products

CATEGORY	MEASURES INCLUDED				POTENTIAL
Product volume reduction	Sustainable packaging, digitization, 3D printing	✓	✓	✓	15%
Near sourcing & shoring	Sustainable sourcing and near shoring	✓	✓	✓	5%
Logistics design and organization	Destination-based stuffing, sustainable container stuffing, sustainable ordering & procurement, LCL/LTL reconsolidation; supply chain data alignment, lead time relaxation and incentive systems, shipper collaboration, repositioning empty containers/emballage, reduce pipeline inventory locations, vertical Integration in global logistics, flexible hybrid consolidation hubs, asset pooling/white label (idle time), circular economy, refurbishing & LCA, physical internet & self organising logistics	✓	✓	✓	10%
Modal shift	'Classic' modal shift, air-to-rail (silk road logistics), relaxing JIT enabling alternative modes, inland terminals combining transhipment and warehousing, synchromodality, trimodal logistics megaparks. IWT shuttle services along small inland ports and waterways, distribution parks/ unloading quays, ITS on TEN-T corridors: contextual corridor visibility	✓	✓	✓	15%
Planning	Next generation FMS and TMS, peak shaving, online brokerage & matching platforms, platooning-based planning, synchronized transportation through real-time visibility and predictive analytics (IoT, blockchain)	✓	✓	✓	10%
ITS and cooperative systems	Intelligent vehicle routing/dynamic route information, green corridor information and management, green wave & traffic control installation, smart sailing routes/locks	✓	✓		10%
Ecodriving and sailing	Training drivers, skippers and conductors, fuel/energy feedback coach, adaptive cruise control, tyre pressure check, slow steaming, predictive cruise control, vehicle platooning, intelligent speed adaptation	✓	✓	✓	5%
Autonomous driving	Autonomous driving, autonomous sailing	✓	✓	✓	10%
Vehicle and vessel design	Sustainable trailer, chassis, cabin, cooling/freezing technologies, optimized, streamlined ship/hull design	✓	✓		15%
Motor design & driveline	Engine efficiency, downsizing, transmission technologies, WHR	✓	✓		20%
Alternative fuels	LNG, CNG and LPG mono and dual fuel, BLPG, CBG and LBG	✓	✓		30%
Electric vehicles	Battery electric, pantograph, hybrid, fuel cell and diesel-electric	✓	✓		75%
Sustainable warehousing	Efficient buildings electric forklifts, robotisation, high-bay warehouses				2%
Sustainable transhipment	AGVs, efficient cranes, green electricity				3%

The transition path is illustrated in the next figure:

Figure 17

Transition path towards Factor 6 for semi-finished products.



Shipment of semi-finished produts is mainly between industrial players. Implementation of zero-emission drivetrains in this market segment will therefore follow the developments in perishables and non-perishables segments. Business arguments will be the main motivator for improving the efficiency of logistics to the hinterland, pressurized by increased congestion and the affected competitive position of the mainports. The drive for greening will be supported by the pressure of large brands to decarbonize logistics chains, and by incentives implemented by governments.

The figure shows that the impact of logistics measures is relatively large, as these can be realized in the short and medium term. This results in a potential transition path in which alternative fuels play a less important role than in other segments, although these will remain relevant for realizing the Paris objectives.

Combining transport networks and using neutral warehouses will provide scope for improved utilization of the available transport and storage capacity. In addition, new technologies like smart labelling can optimize routing in logistics networks. This will require companies to exchange information over the boundaries of their own supply chain, which is considered risky and requires trust. Furthermore, more efficient packaging will result in more products being transporred in containers, for example.

Compared with the other decarbonization concepts, sustainable storage and transhipment will have a relatively low impact.

In contrast to liquid and dry bulk, CO_2 reductions for semi-finished products will also come from organizational and product improvements. Logistics design and planning can only be improved if there is improved insight into transport flows and if information on transport operations is shared. Technologies supporting this are already available. The uptake rate of these tools and the level of information sharing will determine the size of the impact.

5.7 Conclusions

Although the differences between market segment are significant, HCF transport is expected to grow by 80% until 2050, while society will put pressure on meeting the Factor 6 objectives at the same time. If the full range of decarbonization concepts are fully deployed, each of the HCF segments will be able to achieve the Factor 6 objective in 2050.

While advanced technology on the one hand will lead to lower transport costs, it will on the other hand make logistics more efficient, amongst other things due to the connection of currently isolated networks. Furthermore, the development of technologies and the transparency within logistics chains will drive towards further optimization and a reduced carbon footprint. Some of the trends do, however, not apply to all segments to the same extent. Customer pressure and leading shippers play a more important role in the market segments with a close link with citizens. Together with governments, these companies act as frontrunners and leading the majority of the market. The zero emissions solutions implemented will be both innovative and competitive in the international market. This requires new and optimized business models using vertical integration, better utilization of equipment and advanced technologies. Applied in a certain scale, such new technologies can be implemented in a competitive way and will guide the rest of the market, as costs will come down. The new market organization may, however, lead to significant changes of individual positions in the market, as small companies do not have the same possibilities to react to changing market forces. Market consolidation is therefore an important objective driver to prepare the market for upcoming changes. In the B2B trade, greening is expected in a later stage and with greater need for government intervention.

Bulk transport, and, more particularly, inland navigation, will be impacted most by the decrease in fossil fuel flows leading to overcapacity in coal and tanker ships in the near future. Congestion in the Port of Rotterdam and the strategic importance of shippers being able to choose among transport modes will lead to new networks and new revived organizational models in this sector. The gateway position of Rotterdam is likely to come under pressure, and the need for rail and IWT connections will become increasingly important. Under pressure of shippers and government, inland navigation will become green in order to remain attractive and competitive in the market.

The bulk segments will rely more on zero-emission technology solutions, whereas the perishable and non-perishable consumer goods segments will be able to introduce signficantly more energy-efficient logistics concepts. The expected contribution of vehicle and vessel technologies, autonomous driving and ITS is more or less similar for all segments, while the impact of logistics measures, including modal shift, is far more important for the non-bulk segments. The supply chains of these segments are generally more complex, with larger numbers of links, logistics activities and actors. The contribution of sustainable, energy-efficient transhipment and storage is low in all segments except for perishables.

In order to keep the mainports accessible, initiatives will be started focussing on the development of new services and hinterland nodes for rail and inland navigation. Both industry and governments will jointly work on maintaining the position of the mainports - also in the interest of, for example, the perishable food sector and the non-road modes. The non-road modes are to be kept alive in order to maintain the multilateral hinterland network that has provided the Dutch mainports its competitive position in the past.

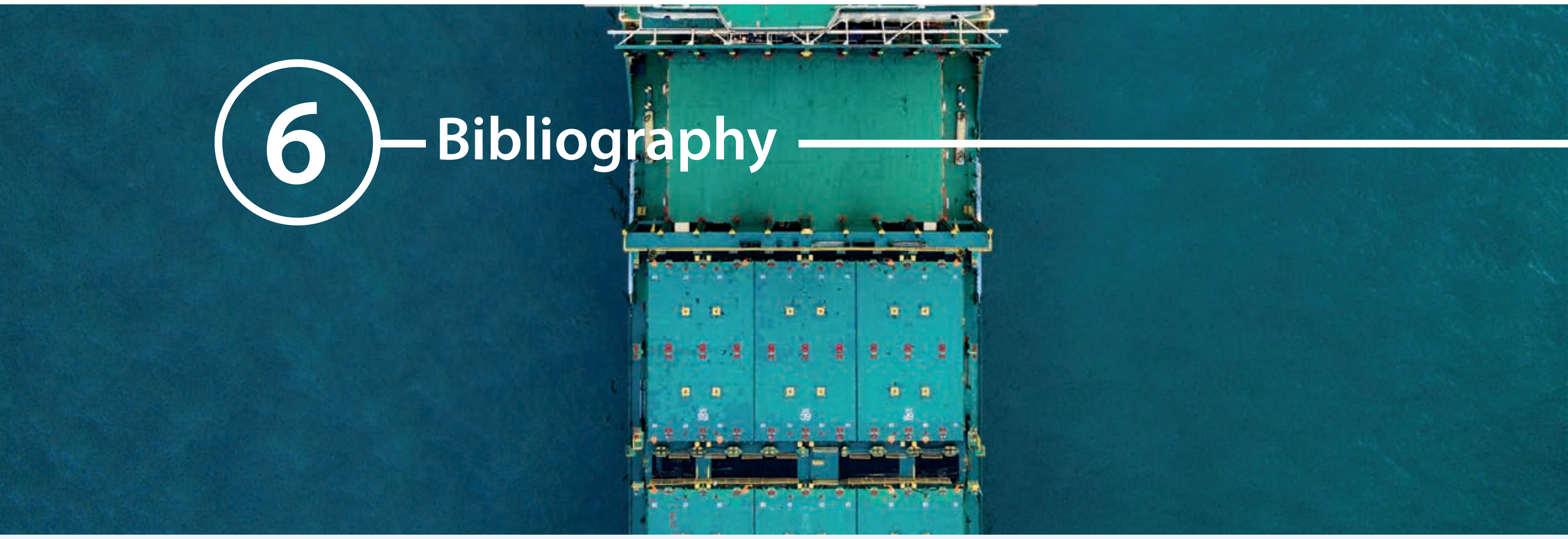
Followed by community pressure, governmental policy development will be aimed at taking care that:

- infrastructure is available and the risk for industry will be acceptable to invest,
- new technologies reach maturity, and
- new technologies can be used by logistics operators on a level playing field that ensures acceptable business cases.

Regulation of emissions is another relevant policy instrument that is already being deployed, particularly by the European Commission who have recently introduced CO_2 standards for heavy-duty vehicles. Spatial policies also influence the design and operation of supply chains, for instance the provision of infrastructure for modal shift, such as terminals, rail and inland waterways. Stimulating technical innovations by creating awareness and changing (driving, sailing) behaviour are policy options that can be effective in the short term, harvesting low-hanging fruit.

The use of biofuels will be limited in the transport modes used for HCF flows. Air and deep-sea will most likely utilize the largest share of the future available biofuels. The emergence of solar fuels, produced in regions with abundant sunshine, may lead to major changes in bulk flows and create potential for CO_2 reduction, but at this moment there are too many uncertainties about this technology to take it's impacts into account.

What is certain, though, for all the decarbonization paths in all the segments studied, is that it is of vital importance to start implementation immediately, as every element needs to be brought into play as soon as possible if the Factor 6 objectives agreed in Paris are to be achieved within the time frame required.



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A Data on transport volume and CO_2 emissions

International freight transport is not the only transport taking place. National transport flows like city logistics, national distribution and intra-company transport are also significant. To put international freight transport into perspective, Tables 7 to Table 11 show the share of international transport in overall freight transport performance in the Netherlands, comprising both national and international flows.
Totals in the tables may slightfy differ from the sum of individual numbers, due to rounding if figures. Road figures only comprise truck transport. Vans are not included. Emissions cover the well-to-wheel/propellor energy cycle

Table 7
National and international transport volume (Mt)

	NATIONAL	INTERNATIONAL					TOTAL INT.
		EXPORT	IMPORT	TRANSIT	HINTERLAND NL	HINTERLAND ABROAD	
IWT	34	22	24	46	79	156	327
Rail	0	3	2	2	3	32	42
Road	389	75	75	21	125	35	331
Total	423	100	101	69	207	223	700

Table 8
National and international transport volume on Dutch territory (Mt-km in 2015)

	NATIONAL	INTERNATIONAL (IN NL)					TOTAL INT.
		EXPORT	IMPORT	TRANSIT	HINTERLAND NL	HINTERLAND ABROAD	
IWT	3,295	3,155	3,338	7,964	9,739	21,047	45,243
Rail	64	294	232	324	402	5,229	6,481
Road	24,477	6,113	6,120	2.838	8,302	3,847	27,220
Total	27,836	9,562	9,690	11,126	18,443	30,123	78,944

Table 9
National and international transport volume on Dutch territory and abroad (Mt-km in 2015)

	NATIONAL	INTERNATIONAL (IN NL AND ABROAD)					TOTAL INT.
		EXPORT	IMPORT	TRANSIT	HINTERLAND NL	HINTERLAND ABROAD	
IWT	3,295	3,821	5,743	20,426	9,739	43,321	83,050
Rail	64	1,600	1,260	1,072	402	19,952	24,241
Road	24,477	33,400	29,312	15,105	8,302	16,503	102,622
Total	27,836	38,821	36,315	36,558	18,443	79,776	209,913

Table 10
CO_2 emissions of national and international transport volume on Dutch territory (Mt in 2015)

	NATIONAL	INTERNATIONAL (IN NL)					TOTAL INT.
		EXPORT	IMPORT	TRANSIT	HINTERLAND NL	HINTERLAND ABROAD	
IWT	0.2	0.2	0.2	0.4	0.5	1.1	2.4
Rail	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Road	3.4	0.9	0.9	0.4	1.1	0.5	3.8
Total	3.6	1.1	1.1	0.8	1.6	1.7	6.3

Table 11
CO_2 emissions of national and international transport volume on Dutch territory and abroad (Mt in 2015)

	NATIONAL	INTERNATIONAL (IN NL AND ABROAD)					TOTAL INT.
		EXPORT	IMPORT	TRANSIT	HINTERLAND NL	HINTERLAND ABROAD	
IWT	0.2	0.2	0.3	1.1	0.5	2.3	4.5
Rail	0.0	0.0	0.0	0.0	0.0	0.2	0.2
Road	3.4	4.8	4.2	2.0	1.1	2.3	14.6
Total	3.6	5.0	4.6	3.1	1.7	4.9	19.3

B Examples on scoping of this annual outlook

This annex presents a number of examples to illustrate the scope of this outlook. The following colour codes are used:

Red = national and not part of AOI

Yellow = international, outside NL and not part of AOI

Green = international, inside NL and part of AOI

Example of hinterland transport from an origin in the Netherlands: the export of flowers

Flowers grown in the Westland area are transported from the grower to the flower auction in Aalsmeer. This is **national** transport, as can be seen in Figure 18. The flowers are then transhipped in Aalsmeer **(international section)** and transported to the airport **(international transport)**. Then, there is again transhipment to the plane **(international section)**, after which the flowers are transported by air to, for example, the United States **(international transport, not included)**.

Figure 18

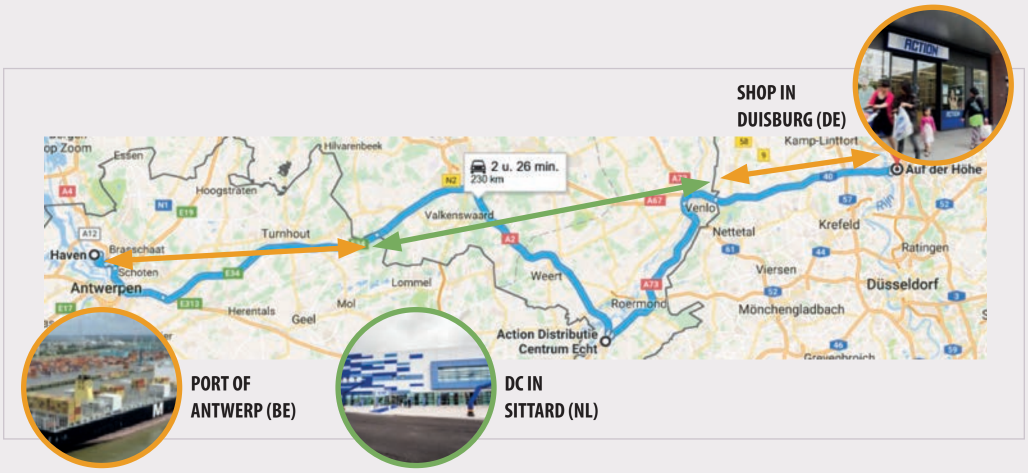
The export of flowers from the Netherlands. This example shows which part of the transport and which transhipments are included in this study.

Example of import (hinterland transport from an origin outside the Netherlands) and export

Transport flows associated with goods imported from abroad and exported abroad are regarded as fully international, with only the share of transport on Dutch territory being included. Figure 19 shows an example for the company Action, which has a distribution centre in Sittard, the Netherlands. Goods are supplied by deep-sea container vessels from China **(international, not included)** through the ports of Antwerp (BE) and Rotterdam.

They are subsequently transported to Action's distribution centre in Sittard by road **(international, with the transport on Dutch territory included)** or by barge via the terminal at Echt **(international, with the transport on Dutch territory included)**. Handling takes place at the Sittard distribution centre **(international)**, with the goods subsequently being distributed to shops in Belgium **(international, included until border)** and Germany **(international, included until border)**. Distribution to shops in the Netherlands is **national**.

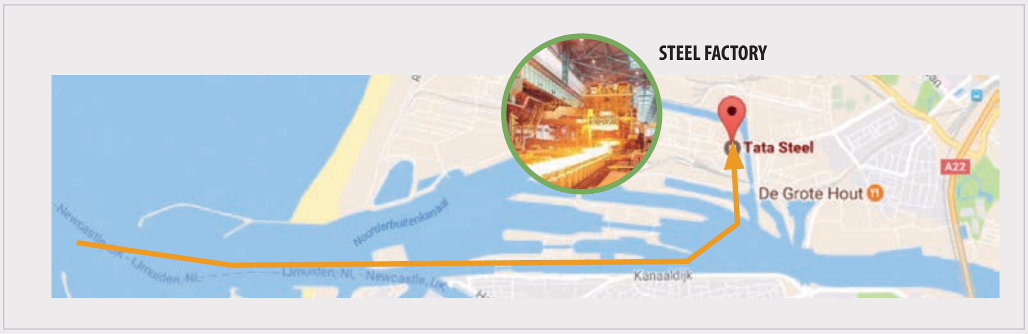
Figure 19
The import of overseas products into the Netherlands, Germany and Belgium via the Action distribution centre in Sittard, the Netherlands. The element of the associated transport flows taking place on Dutch territory is included in this Outlook.



Example of hinterland transport to a destination in the Netherlands, export and hinterland transport to a destination in the Netherlands

Transport of products that are imported and directly used is considered to be fully international, but only the transhipment and storage on Dutch soil is included in the study. Steel (ore and coal), for example, are transported from abroad by deep-sea vessel to the Netherlands **(international, not included)** and then transhipped and stored at the steel plant in Velsen **(international)** (Figure 20).

Figure 20
The import of steel into the Netherlands. Only the transhipment and storage at Tata Steel in Velsen are considered to be part of this Outlook.



Transport of freight that is further shipped to destinations in the Netherlands or abroad is considered to be fully international; the transport on Dutch territory is included. Coal, for example, is transported by deep sea to Amsterdam **(international, not included)**. It is then transhipped and transported by rail and inland shipping to Germany **(international, included until border)** and by barge to Geertruidenberg and Eemshaven, where it is transhipped and stored **(international)**.

Figure 21
The import of coal into the Netherlands. Transport and transhipment on Dutch territory is included in this Outlook.

C Breakdown of segments

The data for the market segments is based on NST-R 3-digit statistical division.

Table 12
Breakdown of segments in this outlook.

MAIN CATEGORY	SUB CATEGORY	MARKT SEGMENTS
Raw materials	Liquid bulk	Oil and oil products
		Chemicals
		Edible oils, juices
	Dry bulk	Ores and minerals
		Coals and Cokes
		Sand, gravel, cement
		Dry chemicals, plastics
		Scrap and waste materials, paper pulp
		Agricultural products
Consumer and (semi-) finished products	Semi-finished products, machines, transport and industrial equipment	Time critical: spare parts, semi-finished products
		Other, non-time-critical products
	Perishable goods	Flowers and plants
		Fruit and vegetables
		Meat and fish
		Diary
	Non-perishable consumer goods	High value: electronics, textile etc.
		Low-value: non-food discounting products
		Non-perishable food products

D The logistics function

The two main elements of the logistics function are storage and transhipment. Within the storage function, four categories are distinguished:

1 **Ambient:** general warehousing, including distribution centres (DCs) and cross-dock centres.
2 **Cool-freeze:** warehouses and DCs with conditioned temperatures.
3 **Dry bulk:** outdoor storage of bulk, and partially indoor storage of grain, salt, fertilizers, etc.
4 **Liquid bulk:** storage of oil, chemicals and food in silos.

The transhipment function also comprises four categories:

1 **Deep sea container:** transhipment of maritime containers in seaports.
2 **Inland container:** transhipment of maritime and inland containers in inland ports.
3 **Dry bulk:** transhipment of dry bulk cargo in ports and inland ports.
4 **Liquid bulk:** transhipment of liquid bulk cargo in ports and inland ports.

D.1 Approach

The CO_2 emissions of the cited logistics functions were estimated using a two-way approach: top-down and bottom-up.

The top-down approach consists of an analysis of the results from global studies on the carbon footprints of logistics functions, long-term energy agreements on energy savings in specific sectors (MJA and MEE programmes) and other literature on energy and emission factors in transport (incl. STREAM).

Data on company-level energy consumption and emissions form the basis for the bottom-up approach. The plans submitted by participants in the Lean and Green Logistics programme were analyzed and relevant data on CO_2 emissions and/or energy consumption were collected and analyzed.

The results of the bottom-up calculations were compared with the top-down data. Matching these results and checking the assumptions during interviews with logistics experts led to reliable overall insight into the size and scale of the footprint of each logistics function. Below, the assumptions and results are described per function.

D.2 Storage

D.2.1 Ambient storage

This includes the storage and handling of (palletized) products in warehouses, distribution centres and cross-dock facilities. It is of relevance for the segments 'Semi-finished products' and 'Non-perishable consumer goods'.

The total CO_2 emission associated with ambient storage in the Netherlands amounts to an estimated **300,000** tonnes/year, with international storage accounting for an estimated 40% (in tonnes), leading to a CO_2 emission of **120,000** t/y for international ambient storage.

This calculation is based on the following lines of reasoning and assumptions:

- The overall surface of ambient warehouses (larger than 2,500 m^2) is 25 million m^2 (source: BCI 2015).
- The average CO_2 emission per m^2 is derived from the Lean and Green plans of companies that have included warehousing in their scope: this emission ranges between 2 and 4 kg CO_2/pallet location.
- With 4 pallet locations per m^2 (expert judgement), the average CO_2 emission per m^2 is 12 kg.
- Internal transport and handling by forklift trucks, reachstackers etc. are not included in this calculation; a rough estimate based on 1 truck/500 m^2 warehouse and an emission of 6 kg CO_2/hr sums to a 2,400 t CO_2 emission annually, which is marginal compared with the overall emissions of ambient storage.

D.2.2 Cold storage

The temperature-controlled storage of perishables in cold stores (cool and freeze) is mainly relevant for the perishables segment (temperature-controlled goods).

The total CO_2 emission associated with cold storage is estimated to be 400,000 t/year, based on the calculations and assumptions below. The share of international storage is 40% (in tonnes), leading to a CO_2 emission of **160,000** t/year.

This calculation is based on the following lines of reasoning and assumptions:

- The overall capacity of cold warehouses in the Netherlands is approximately 16 million m^3 (source: MJA), with an average height of 4 metres (expert judgement); the overall surface is estimated to be 4 million m^2.
- The average CO_2 emission per m^2 derived from the Lean and Green plans of companies that have included cold storage warehousing in their scope is approx. 95 kg CO_2/m^2, summing to a total of 380,000 t CO_2 emissions.
- The total energy consumption of the MJA participants is 3 PJ (source: RVO 2015), translating to approx. 420,000 t CO_2.
- Internal transport and handling by forklift trucks, reachstackers etc. are not included in this calculation; a rough estimate based on 1 truck/500 m^2 warehouse and an emission of 6 kg CO_2/hr sums to approx. 400 t CO_2 emission annually, which is marginal compared with the overall emissions of cold storage.

D.2.3 Dry bulk storage

The open-air storage of sand, ores, coal etc., as well as the storage in silos and covered sheds of grains, rice, fertilizers etc. are all relevant for the segment 'Dry bulk'.

The emission associated with dry bulk storage is estimated at 30,000 t CO_2/year. If the share of international storage is assumed to be 50% (to be validated), the annual CO_2 emission for dry bulk storage is **15,000** t/year.

This calculation is based on the following lines of reasoning and assumptions:

- The energy consumption and CO_2 emission of open-air storage of dry bulk is considered to be close to zero. The storage of food in bulk (grains, rice) in silos and covered sheds will use some energy. It is expected to be marginal and assumed to be less than 10% of the energy consumption for ambient storage (warehousing).
- The energy consumption of handling (transhipment) of dry bulk is substantial; this is calculated in the next section.

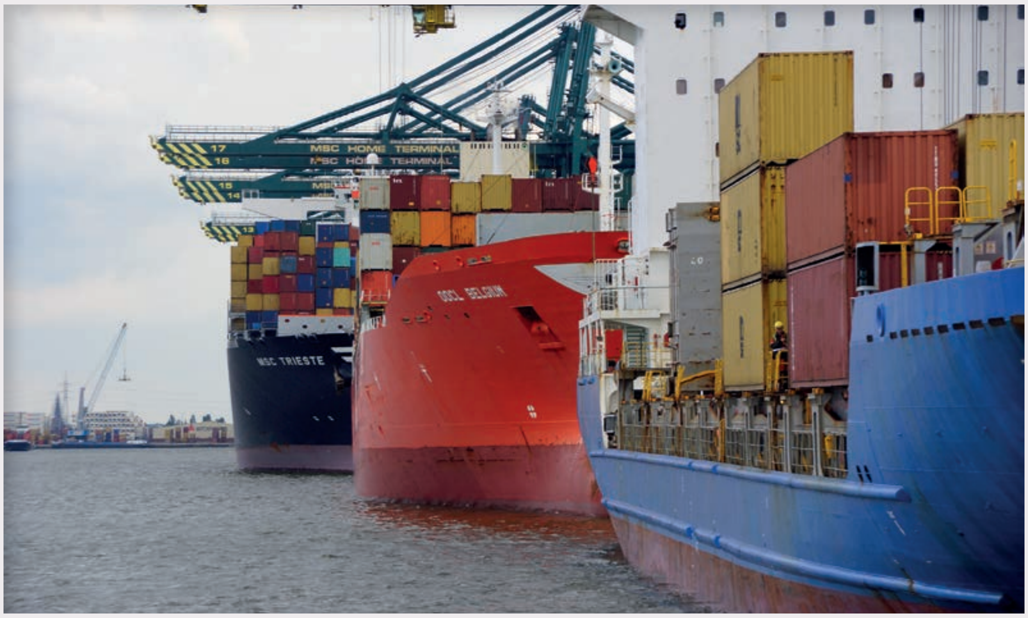
D.2.4 Liquid bulk storage

Storage of liquid bulk (petrochemical products, liquid food) in tanks relates above all to the segment 'Liquid bulk'.

Based on a rough estimate, a distinction is made between the CO_2 emissions of transhipment, storage and pipeline transport of liquid bulk. The total CO_2 emission for liquid bulk storage is estimated to be 300,000 t/year (transhipment excluded). If the share of international storage is assumed to be 50%, the annual CO_2 emission for liquid bulk storage is **150,000** t/year.

The calculation is based on the following lines of reasoning and assumptions:

- The MJA participants (all liquid bulk storage companies) have an overall energy consumption of 2.5 PJ, which corresponds to 694 million kWh.
- With 0.5 kg CO_2 per kWh, the total annual CO_2 emission is 350,000 t.
- This includes transhipment to, from and within the tank storage sites. This figure is calculated to be 50,000 t/year (see section D.3.4).



D.3 Transhipment

D.3.1 Deep-sea containers

Transhipment of deep-sea containers in port terminals (mainly Rotterdam) is relevant for the segments 'Semi-finished products', 'Non-perishable consumer goods' and 'Temperature-controlled goods (perishables)'. A minor part of the segments 'Dry bulk' and 'Liquid bulk' is also containerized, so there may be some marginal overlap.

The total emission of the transhipment of deep-sea containers is estimated to be **150,000** t CO_2/year. This is 100% international.

The calculation is based on the following lines of reasoning and assumptions:

- The total number of containers transhipped in Rotterdam in 2015 is 12.3 million TEU or 7.3 million containers. This is over 95% of all deep-sea containers processed in the Netherlands.
- Annual emission Maersk worldwide (source: Maersk 2016) per container: 15 kg CO_2 (9 kg/TEU).
- Bottom-up approach ECT (Lean and Green): 16.4 kg CO_2 per TEU.
- 12.5 kg CO_2/TEU seems to be an adequate average per TEU.
- 12.3 million TEU x 12.5 kg = 150,000 tonnes CO_2.
- The calculation does not include the energy consumption of reefers plugged at the terminals. This needs to be calculated, but is expected to be marginal.

D.3.2 Inland containers

The transhipment of containers at inland terminals is relevant for the segments 'Semi-finished products', 'Non-perishable consumer goods' and 'Temperature-controlled goods (perishables)'. A minor part of the segments 'Dry bulk' and 'Liquid bulk' is also containerized, so there may be some marginal overlap.

The total emission associated with the transhipment of inland containers is estimated to be **30,000** t CO_2/year. This is 100% international.

The calculation is based on the following lines of reasoning and assumptions:

- Total number of TEU in national IWT transport: 2,000,000 (source: CBS, 2017a).
- Total TEU transhipped at inland rail terminals in NL: 200,000 (source: RCI 2016).
- From Lean and Green terminal plans: average CO_2 emission per TEU: between 4 and 7 kg, average of 6 kg/TEU-move.
- Number of moves/TEU: 2; number of inland TEU-moves x 2 = 4.4 million.
- Transhipment at rail port terminals (RSC): 300,000 TEU/year, x2 = 600,000 TEU-moves.
- Number of TEU-moves total: 5,000,000.
- 5 million TEU-moves x 6 kg = 30,000 t CO_2.

D.3.3 Dry bulk transhipment

This involves the transhipment of ores, sand, coal, grains, fertilizers etc. at sea terminals, inland terminals and production and storage sites with cranes, conveyor belts and mobile equipment (shovels). This relates entirely to the segment 'Dry bulk'.

The total emission for dry bulk transhipment is estimated to be 190,000 t CO_2 per year. With a share of 50% international flows (similar assumption as for dry and liquid bulk storage), the annual CO_2 emission for dry bulk transhipment is **95,000** t/year.

The calculation is based on the following lines of reasoning and assumptions:

- Total amount of dry bulk transhipped in seaports in 2015 (source: BCI 2015, CBS 2017a): 145 million t.
- Average energy consumption for transhipment per tonne dry bulk (source: Stream 2016): 1.3 kWh. With 0.5 kg CO_2 per kWh and on average 2 transhipments per tonne (from ship to stock and then to ship/barge/truck/rail v.v.), the total CO_2 emission amounts to 145 million x 2 x 1.3 x 0.5 / 1,000 = 190,000 t CO_2/year.

D.3.4 Liquid bulk transhipment

This involves the transhipment of liquid petrochemicals and food products at sea terminals, inland terminals and production and storage sites, using pumps. This relates entirely to the segment 'Liquid bulk'.

The total emission for liquid bulk transhipment is calculated to be 110,000 t CO_2 per year. With a share of 50% international flows (similar assumption as for dry and liquid bulk storage), the annual CO_2 emission for liquid bulk transhipment amounts to **55,000** t/year.

The calculation is based on the following lines of reasoning and assumptions:

- Total amount of liquid bulk transhipped at seaports in 2015 (source BCI/CBS): 270 million tonne.
- Average energy consumption for transhipment per tonne liquid bulk (source: Stream): 0.4 kWh.
- With 0.5 kg CO_2 per kWh and on average 2 transhipments per tonne the total CO_2 emission amounts to 270 million x 2 x 0.4 x 0.5 / 1,000 = 110,000 t CO_2 /year.

E Decarbonization concepts

In the previous appendix, international transport and the associated logistics processes were defined and quantified and global trends affecting international transport and logistics identified. As the international transport sector as a whole is expected to grow as a result of these trends, its CO_2 emissions are likely to increase accordingly. This calls for action. This appendix takes the first step, by identifying the options available for reducing the sector's carbon footprint - the so-called decarbonization concepts - and by assessing their CO_2 emission abatement potential.

E.1 Introduction

We consider nine components of logistics decarbonization. Seven of these relate to the carbon footprint of freight transport, the other two to the wider logistics function: warehousing and transhipment. The components considered are:

1 Transport volume reduction (volume needed).
2 Transport distance reduction (volume kilometres, supply chain design, etc.).
3 Transport mode choice (modal shift and vehicle/vessel type, load unit).
4 Utilization of transport means (load factor/consolidation, empty running).
5 Vehicle use and driver behaviour.
6 Vehicle design (motor, drivelines, resistance reduction).
7 Alternative carbon-based fuels.
8 Sustainable warehousing.
9 Sustainable transhipment.

The order in which these are listed follows a line of reasoning whereby we start by considering whether we can reduce the volume of freight transported over the world. Then, we consider reducing the distance of a shipment journey. Next, we consider which modes are to be applied to meet the transport needs, followed by consideration of the utilization rates of the chosen modes. Then, we consider the use and execution of the transportation means, their design characteristics and the corresponding fuel mix. Each of the above-mentioned components consists of one or more groups of decarbonization concepts ('improvement measures'), which are described in sections E.2 to E.14.

For each decarbonization concept, a qualitative assessment is made of the CO_2 reduction potential, based on a combination of sources and inhouse expertise of TNO and CE Delft. For the potential of the technical measures, the MEO (Multilevel Energy Optimization) system has provided input. For organizational, logistics and behavioral measures input has come from a variety of sources and studies (see the references section), as well as from lessons learned from initiatives and programmes, such as Lean and Green and multi-annual energy saving covenants (MJA/EEP). The potential is presented as a range, of which the upper level can be seen as the maximum potential. To what extent this potential can be utilized depends on a great number of factors and interdependencies. These figures have been used as a basis for the estimation of the decarbonization potential per segment. During interviews with sectoral representatives and sessions with stakeholders and experts these figures have been validated.

E.2 Transport volume reduction

Description

Supply chain design choices largely determine how the fulfilment of customer orders take place: what routing, via which warehouses, where to consolidate or deconsolidate. Freight integrators offering door-to-door logistics services and shippers both apply supply chain designs for their supply chain optimization, including multiple echelons of stock-keeping positions, like European DCs, satellite DCs and local DCs, with generation of replenishment orders between DCs. These design choices optimize logistics costs whilst meeting customer requirements such as requested delivery time, location and quantities of goods. Within these supply chain structures it is decided where, when and how to consolidate shipments, having a large impact on the efficiency of the transportation.

Packaging and product design options, such as transporting fruit juice concentrates, milk powder or LNG, also have a direct impact on the number of vehicle-kilometres needed to move the corresponding goods from origin to destination. Targeted programmes in breweries and in healthcare logistics reveal that major improvements can be realized. In addition, current incentive systems stimulate use of inefficient packaging and container stuffing. Detailed analysis of an import trade lane of consumer goods from China revealed common practices to stuff products in huge boxes to comply with the volumetric threshold for stuffing goods in containers to be treated as Full Container Load (FCL shipment). Under the contracts of carriage and split of responsibility and costs in corresponding Incoterms, FCL treatment means substantially lower transportation and handling costs for the exporter and shorter delivery times, even if the importer ultimately pays the bill for highly inefficient transport.

Economic and technical constraints

Packaging has many functions, primarily serving the protective, storage, loading and transport functions. The sales, promotional, service and guarantee functions are also important, though. When considering implementation of concepts for more sustainable packaging there may therefore have to be a trade-off with some of the packaging's other functions. 3D-printing leads to a shift from transporting (semi)-finished products to transporting raw printing materials, probably reducing total transport volumes as well as transport movements for all kinds of assembly parts.

The same applies to supply chain redesigns. Existing design choices are often a result of optimizing transportation costs, warehousing and handling costs and inventory carrying costs. For freight integrators, the optimization formula also includes asset utilization (fleet capacity, warehouse capacity, available slots on ocean, air and rail transport). Sustainable consolidation and fulfilment concepts may consequently result in a trade-off with increasing other logistics cost elements.
Current incentive systems and limited supply chain visibility result in non-sustainable packaging and stuffing practices. In e-commerce fulfilment, we see adoption of the right incentives resulting in efficient packaging and stuffing; other segments could adopt similar incentive systems and practices.

Potential

The sustainability potential of supply chain redesign is rather limited. Small incremental improvements are possible by new trade-offs, horizontal collaboration and near-sourcing. The potential of 3D-printing is large in niche markets and may disrupt existing business models and corresponding supply chains. However, on a global scale, its impact on freight transport volumes and trade lanes is expected to be rather limited. Concentration and miniaturization is already taking place for dairy, fruit juices and concentrates. Most potential is expected to come from sustainable packaging and incentive systems that incentivize sustainable and efficient packaging and stuffing. The total potential of these design-related concepts is in the range of 10% to 25%.

Policy options

Sustainability best practices and voluntary agreements in packaging strategies can be stimulated. CO_2 pricing policies will automatically result in new and more sustainable optimal configurations as a result of the economic trade-off between transportation, warehousing and inventory carrying. Production could also be influenced by suitable policies, for instance by subsidies.

MEASURE	MODE(S)	INTRODUCTION	POTENTIAL
Sustainable packaging	RO/IW/RA	Short term	20-30%
Concentration and miniaturizing	RO/IW/RA	Short term	
Digitization	RO/IW/RA	Short term	
Additive manufacturing and 3D printing	RO/IW/RA	Medium term	10%

E.3 Sustainable sourcing and near-shoring

Description

Globalization has led to a shift in production to countries with low labour costs or highly-efficient specialized production. As a consequence, production is being outsourced to destinations further away from the customer base. Despite the increased transport distances, the total landed costs to produce the products and move them to customers is lower. Though in many sectors this globalization trend still continues, there are segments and niche markets where we now observe an opposite trend. Pushed by increasing labour costs in countries like China, congestion in Chinese ports, and, more importantly, sharper lead time requirements, companies are deciding to shift back to near-shoring. In the latter case, it is sometimes the only option to apply make-to-order production in combination with tight lead time requirements.

Economic and technical constraints

It would require substantial adjustments in our global production systems to facilitate substantial near-shoring, which needs time and strong support policies to adjust the framework conditions (e.g. local production stimuli and internalizing the external costs of global transportation).

Potential

The potential of sustainable sourcing and near-shoring is large and is expected to lie between 35 and 50%.

Policy options

The influence of policy-makers on near-shoring can be substantial (and disputable) in the case of import restrictions and other restrictive economic policy measures. Pricing policies will also influence the distance goods are transported.

MEASURE	MODE(S)	INTRODUCTION	POTENTIAL
Sustainable sourcing/near-shoring	RO/IW/RA	Long term	35-50%

E.4 Green logistics design and organization

Description

Logistics efficiency can be improved by applying new logistics concepts, horizontal cooperation and new IT concepts. A key element of all the options is the sharing of information. Bundling of cargo to reduce empty-space containers or trailers can be done by utilizing flexible or hybrid consolidation hubs that can be enlarged or used when there is a demand for bundling. In this way the optimum location can be used, based on the area from which all the cargo originates and the common area where it all needs to be distributed. Another option is to consolidate less-than-container-loads or less-than-truck-loads at hubs like seaports, so that full containers or truck loads can be distributed throughout the European continent via road, rail, inland or short sea shipping.

Transport of empty containers or trailers can also be reduced through asset pooling or use of white label equipment. By sharing equipment there is less need to reposition it, as there is more potential for reusing the equipment where it was unloaded. If there is still a need to reposition the empty containers or emballage, bundling the flows can result in utilizing more sustainable modes of transport like inland shipping and rail.

Sharing of information is required in order to bundle cargo and containers, to reuse empty equipment and to identify cargo flows that can be matched. Already, online brokerage and matching platforms are available. By making transparent what the available capacity and/or equipment is and what the origins or destinations of (ideally all) cargo flows are, a large potential arises for realizing more efficient transport. As a result, the overall amount of transport required will be significantly reduced. This can, for example, be done when shippers start to cooperate by sharing information with the aim of bundling cargo and realizing full truck or container loads. In the Netherlands, these initiatives are slowly evolving. Although at the European level this is still hardly taking place at all, it can obviously contribute to improving asset utilization.

Finally, with the development of the physical internet and, as a part thereof, self-organizing logistics, in the longer term the most efficient logistics solution based on asset availability, a different demand for transport and customer requirements will be selected and used. These new concepts will result in better ways to combine information about cargo flows and reduce the need for human interventions that can result in inefficient transport.

Economic and technical constraints

Although the potential for improving logistics efficiency through new logistics concepts, cooperation and new IT concepts is substantial, current supply chain and industry ecosystems stand in the way of grasping the full possibilities. A lack of trust vis-à-vis sharing information, unwillingness to share benefits and an enormous amount of owned assets by many different transport companies constitute major barriers to change. Legacy systems in which companies have made large investments are also hampering the transition towards IT systems, platforms and infrastructure through which information can be shared more easily.

Potential

Since there are a substantial number of empty containers being transported and containers and trailers that are not fully stuffed, there is major potential for substantially reducing the current number of vehicle-kilometres. This potential reduction is less than the percentage of empty transport, though, because there will always be circumstances in which empty equipment need to be repositioned. Cooperation among shippers and/or logistics service providers on bundling cargo or matching import and export flows can contribute to further efficiency improvements. In a future world where everything is connected via the internet, and cargo transport organizes itself, even more efficiency can be gained.

Policy options

CO_2 pricing policies will automatically result in new and more sustainable optimal configurations as a result of the economic trade-off between transportation, warehousing and inventory carrying.

Price agreements between shipping lines have resulted in large fines and adjusted rules and regulations. Although price agreements cannot be accepted, adjustments in rules and regulations also make shippers and logistics service providers hesitant about entering into tighter cooperation. Reducing any doubts that might exist with regard to horizontal cooperation can be beneficial.

Investments in new IT systems that can contribute to sharing information in order to reduce transport should be made more attractive, by providing subsidies and cheap loans and/or by accept beneficial accounting principles for such investments.

The potential of different green logistics design and organization concepts are shown in the table below.

MEASURE	MODE(S)	INTRODUCTION	POTENTIAL
Destination-based stuffing	RO/RA/IW	Short term	10-15%
Sustainable container stuffing (shift to 40 ft HQ/45 ft)	RO/RA/IW	Short term	
Sustainable ordering & procurement	RO/RA/IW	Short term	
LCL/LTL reconsolidation deepsea/continental shipments	RO/RA/IW	Short term	
Supply chain data alignment	RO/RA/IW	Short term	
Lead time relaxation and incentive systems (slow steaming/consolidation/modal shift)	RO/RA/IW	Medium term	15-25%
International Shipper Collaboration	RO/RA/IW	Medium term	
Repositioning empty containers and other emballage	RO/RA/IW	Medium term	
Reduce pipeline inventory locations	RO/RA/IW	Medium term	
Vertical Integration in Global Logistics	RO	Medium term	
Flexible hybrid consolidation hubs	RO/RA/IW	Medium term	
Asset pooling/white label (idle time)	RO	Medium term	
Circular economy, refurbishing & LCA			
Physical Internet & Self Organising Logistics	RO/RA/IW	Long term	25-60%
Sustainable sourcing and near shoring	RO/RA/IW	Long term	

E.5 Sustainable modal shift

Description

Mode selection is primarily based on price, reliability and transit time. Sustainability is to a lesser extent a driver for the selection of a particular transport mode. Currently, transport via rail and inland waterway / sea are generally performing better with regard to CO_2 emissions compared with road and air transport. However, these modes of transport, in multimodal concepts, are not always the preferred solution owing to past experiences or expectations about longer transit times, insufficient frequencies and unreliable performance. Still, in many instances, inland shipping and/or rail transport can be a good alternative to road transport within Europe. Such a modal shift from road to rail or barge remains an option, even when the increasing scarcity of truck drivers and pricing of road transport is taken into account.

An 'improved' way of organizing intermodal transport involves the logistics service provider taking responsibility for mode selection, basing this on the shipper's requirements and the available capacity of the infrastructure and transport vehicles. Synchronizing this transport demand with the available capacity of the different modes is termed synchromodality. Synchromodal transport requires extensive contextual information about the situation on the infrastructure (i.e. congestion and expected transit times), available capacity on the transport assets and the frequency and departure and arrival times of the connections. Synchromodal transport may be an option for intercontinental transport, too.

By using reefer containers, for example, cargoes like flowers and pharmaceuticals can be transported by sea, while the development of rail infrastructure between Asia and Europe means rail transport can be used. Supply chain trends like 'relaxing' Just-In-Time enables alternative transport modes, as these may have a longer transit time owing to lower frequencies and/or slower average speed. In synchromodal transport, the bulk of the transport will be executed using more sustainable modes (i.e. rail and water), as these tend to be cheaper and, as a positive side-effect, have lower CO_2 emissions.

Over relatively short distances, intermodal transport via inland waterways, and especially rail, becomes difficult. If pre- and end-haulage of the container is limited, however, barge transport becomes feasible over the short distance. For example, barge transport is increasingly being used to exchange containers between terminals at Rotterdam.

Stimulating the use of these more sustainable modes can be achieved through new logistical concepts like 'trimodal megaparks', whereby high volumes of cargo are transported to or from the port using high-frequency connections. Also, metro-like concepts in inland waterways, where an inland vessel stops at multiple inland terminals en-route to or from the port, can result in a better service and better asset utilization. For rail transport this concept is a little more difficult, but can also be applied. Another option to reduce costs and make barge and rail transport more attractive is to reduce pre- and end-haulage by road by providing warehousing on or directly connected to the inland terminal.

Economic and technical constraints

Multimodal, and ultimately synchromodal transport, depends on there being sufficient volumes to realize high utilization rates and on sufficient connectivity between ports and inland locations to become attractive for shippers. There is currently an imbalance at multiple locations that is hampering use of multimodal transport. While cargo bundling across multiple locations for transportation on trunk lines offers a solution, this often requires substantial efforts. Cargo bundling is receiving growing attention in the Netherlands, but is limited across borders. In addition, in some instances there is insufficient infrastructure in place to facilitate efficient utilization of, and a shift to, rail and/or inland waterway transport.

Besides the available volume and infrastructure, the more sustainable modes also need to be attractive to interested decision-makers. For example, rail operators tend to act rather inflexibly. This is due partly to the procedures in place on the infrastructure, but also to their own in-house processes. For rail infrastructure, moreover, usage needs to be paid for (which is not the case for truck and barge transport) and the assets are also expensive, which sometimes makes it difficult to offer rail transport at competitive prices.

Synchromodal transport requires a substantial amount of data about the (real-time) capacity of the infrastructure and transport assets in order for the best mode to be selected. Retrieving all the necessary data for this purpose is still a challenge. Some data is not even available, while other data is difficult to retrieve, as connections with databases are problematical or third parties are unwilling to share their data.

Potential

Hinterland transport of maritime containers by road is generally restricted to short distances. For example, only around 5% of the containers entering or leaving the Port of Rotterdam by road crosses a border. Another one-third of the volume transported by road remains within the vicinity of the port. This means that around 60% of the containers transported by road could also go via one of the many inland terminals in the Netherlands. A shift of 10-20% of the containers from road to barge or rail, with or without the usage of synchromodality, is feasible. This would result in a substantial reduction of CO_2 emissions. If trucks start driving on hydrogen, however, a modal shift from road to rail or barge is no longer relevant and desirable from a sustainability perspective.

Policy options

To stimulate a shift towards more sustainable modes of transport, current policies that create awareness, facilitate cooperation and data-sharing can be expanded. More rigorous policies that can be developed include creating a level playing field through an obligation for operators to internalize external costs.

Policy can also focus on providing positive or negative incentives for using more sustainable modes of transport. For example, rail transport could be subsidized as being the least emitting mode in order to stimulate its usage. On the other hand, negative incentives could also be introduced, such as the Port of Rotterdam Authority issuing fines to terminal operating companies when modal split targets are not met.

The potential of the various modal shift measures are shown in the table below.

MEASURE	MODE(S)	INTRODUCTION	POTENTIAL
'Classic'modal shift	RO/RA/IW	Short term	10-20%
Air-to-Ocean (e.g. flowers Kenia, pharma, ..)	OF	Short term	
Air-to-rail (Silk Road logistics)	RA	Short term	
Relaxing JIT enabling alternative modes	RA/IW	Short term	
Inland terminals combining transhipment and warehousing	RA/IW	Short term	
Synchromodality	RO/RA/IW	Medium term	15-25%
Trimodal logistics megaparks	RO/RA/IW	Medium term	
IWT shuttle services along small inland ports and waterway distribution parks/unloading quays	IW	Medium term	
ITS on TEN-T corridors: contextual corridor visibility	RA/IW	Long term	25-30%

E.6 Green transport planning and execution

Description

In the planning and execution of transport and logistics there is often a focus on just the single order, with limited visibility of the previous and/or following parts of the supply chain and with no further situational awareness. This implies substantial opportunities for CO_2 reductions. Real-time end-to-end visibility of the supply chain, through use of Internet of Things and Blockchain and with the support of big data analytics can help to better plan and execute transport. For example, if there is better knowledge of when a quay wall, rail track or docking station is precisely available, the vehicle can adjust its speed (and operate more efficiently) to arrive at the location exactly on time. Additionally, better use can be made of the (expected) situation on the infrastructure, primarily roads. A knowledge of expected congestion levels can help flatten peaks during rush hours, as companies can make well-informed decisions on the best time to set out. Furthermore, visibility of trips made available by different trucking companies provides an opportunity for platooning. Dynamic trip and transport planning within transport management systems can facilitate these opportunities[13].

Besides such improvements to transport execution, orders can be better planned. With visibility of many more orders within different supply chains, load factors can be increased and transport and handling can be reduced through destination-based stuffing (which is already being done to a limited extent in so-called container freight stations operated by freight forwarders). Additionally, better understanding of optimally sustainable order quantities helps better informed decisions to be made and creates scope for more efficient transport.

Economic and technical constraints

Although these concepts can be implemented using current forms of data analysis and bilateral information-sharing, large-scale benefits will only materialize when the required new technologies become available. However, these technologies are still only in the initial stage of development. Furthermore, actual adoption of these new technologies is governed by the costs and savings they can bring to the companies involved, and these are still unclear. Besides technical and economical limitations, there also needs to be a willingness to cooperate (i.e. trust) for these concepts to work.

Potential

Transport and logistics are already planned and executed fairly efficiently. However, there are also hidden inefficiencies in both planning and execution due to a lack of urgency, a lack of visibility to highlight them and a lack of effective incentive systems to avoid such inefficiencies. Accumulated inventories throughout the chain and buffers in the lead times of transport services are familiar examples of how we cope with uncertainties in supply chains. Further improvements hinge on the transport orders becoming visible as well as the similarities between them.

13 Initiatives like Lean analytiX that give detailed views of transport performance levels generate options to improve the supply chain

Policy options

Information needs to be shared in order to be able to become more efficient. This can be done through giving positive or negative incentives for more efficient behaviour. Another option is to further stimulate the development of new innovative applications that can facilitate transport and logistics companies to operate more efficiently.

MEASURE	MODE(S)	INTRODUCTION	POTENTIAL
Next generation FMS and TMS (dynamic, real-time and green)	RO	Short term	5-10%
Peak shaving	RO	Short term	
Online brokerage & matching platforms	RO/RA/IW	Short term	
Platooning-based planning	RO	Medium term	10-20%
Synchronized transportation through real-time visibility and predictive analytics (IoT, Blockchain)	RO/RA/IW	Medium term	

E.7 Sustainable ITS and cooperative systems

Description

The infrastructure side of ITS (Intelligent Transport Systems) offers various opportunities for increasing the efficiency of transport and decreasing its negative impacts. This part of the transport system is generally managed by public bodies (road, rail and IWT infrastructure managers). ITS measures include intelligent vehicle routing and dynamic route information using dynamic route information panels (DRIPs). Traffic control installations are becoming more intelligent, enabling green waves for specific flows, such as heavy freight trucks. The energy-savings potential of trucks not having to slow down for a red light is substantial. 'Green' corridors can be introduced, using dynamic and real-time transport data from roadside and on-board navigation and communication devices. Green corridor development, smart routing and combination of navigation and infrastructure data can also be applied in the other transport modes, such as IWT and rail transport. Planning of locks and bridge openings, for instance, can be combined with sailing routes and times of vessels.

Economic and technical constraints

Among the societal benefits of more efficient infrastructure use are reduced congestion and pollutant emissions, while companies profit from reduced transport times and fuel consumption / costs. The required investments in infrastructure are very high, however, impeding rapid introduction. If combined with pricing infrastructure and systems, introduction can be accelerated and the costs and benefits be better distributed among stakeholders. Combination with environmental zones is also a development that can enhance the development of ITS systems in infrastructure.

Potential

The potential for green waves and corridors is limited, as there will always be conflicting traffic flows that will not benefit from the green wave. Dynamic routing is leading to improved system performance on congested networks. The overall potential is estimated to be between 5 and 15%, though it must to be taken into account that combining dynamic routing with on-board systems and network optimization of transport operators will increase the overall potential.

Policy options

To fully deploy the potential of ITS in infrastructure, it is important that public bodies (infrastructure managers) and private stakeholders (transport operators, vehicle manufacturers, shippers) work together on an international level. The variety in road pricing systems in Europe illustrates the difficulties of such a move. The perceived growing importance of reducing carbon footprints along with other environmental and societal needs (air quality, safety) might boost the development and employment of ITS.

MEASURE	MODE(S)	INTRODUCTION	POTENTIAL
Intelligent vehicle routing/dynamic route information	RO	Short term	5-10%
Green corridor information and management (contextual visibility)	RO/RA/IW	Medium term	10-15%
Green wave & traffic control installation	RO	Medium term	
Smart sailing routes/locks	IW	Medium term	

E.8 Ecodriving, sailing and steaming

Description

As long as trucks, trains and ships are not fully automatically operated, the human factor has a substantial influence on energy consumption and CO_2 emissions. An anticipatory, energy-efficient driving style can be taught and has become everyday practice at many road haulage companies. Train drivers and inland skippers can also reduce energy consumption by altering their driving and sailing behaviour. Reducing engine idling and anticipating driving and sailing behaviour also has fuel-saving potential in these modes of transport. The required behaviour can be further supported by technical monitoring systems, such as systems providing feedback on fuel consumption. Driving behaviour data can be collected and analyzed automatically using on-board computer and communication systems. Start-stop systems, cruise control (adaptive and predictive), automatic speed limiters and regenerative braking systems can further support and facilitate drivers. These systems also allow trucks to drive like trains: so-called vehicle platooning. The final step is fully autonomous driving and sailing, which eliminates the human factor in the energy consumption. There is a growing relation with the physical and ICT infrastructure. Green waves, routing and planning will become more and more integrated with on-board driving systems, enabling system optimization and pricing schemes.

Economic and technical constraints

Efficient driving courses, checking tyre pressure and speed limiters can all be considered low-hanging fruit with a short pay-back period. Advanced feedback and monitoring systems can further contribute to the potential. The return on investment of advanced feedback and monitoring systems will improve as motor management and on-board computer and GPS systems are increasingly integrated and costs decrease. With autonomous driving/sailing and platooning there are still a number of technical and legal barriers to be overcome. The same applies to high infrastructure investments on sensors, cameras, etcetera. As international coordination, standardization and involvement of a range of public and private stakeholders is required (similar to the development of ITS described in the previous section), it is unlikely that all the legal and technical barriers will be overcome within the next 5 to 10 years.

Potential

There needs to be continuous attention to driving behaviour, as the impact of one-off training without repetition is limited to a short time only. The average reduction of energy use and CO_2 emissions achieved through training is between 4 and 8%, depending on the level of feedback and intensity of the training programme. Vehicle platooning and autonomous driving largely eliminate the human factor, but an additional reduction compared with systems relying on human behaviour can be expected. The fuel reduction potential of platooning is calculated to be approximately 12% under optimal conditions. The energy reduction potential of driverless trains and autonomous barges will be limited (less than 5%), though.

Policy options

Legal obligations for (repetitive) training of drivers can be introduced, as well as a standard maximum level for speed limiters. Truck manufacturers can be required to install fuel monitoring and registration systems, as well as tyre pressure monitoring systems. The development of autonomous driving and sailing systems can be accelerated by stimulation of R&D and test programmes.

MEASURE	MODE(S)	INTRODUCTION	POTENTIAL
Training drivers, skippers and conductors	RO/IW/RA	Short term	5-10%
Speed limiter	RO	Short term	
Fuel/Energy Feedback Coach	RO/IW/RA	Short term	
Adaptive Cruise Control	RO	Short term	
Tyre pressure check	RO	Short term	
Slow steaming	IW	Short term	
Predictive Cruise Control	RO/IW/RA	Medium term	10-15%
Vehicle platooning	RO/RA	Medium term	
Intelligent speed adaptation	RO	Medium term	
Autonomous driving	RO/RA	Long term	10-15 %
Autonomous sailing	IW	Long term	

E.9 Sustainable vehicle and vessel design

Description

The design of trucks, trains and vessels can be improved with respect to fuel efficiency. Reducing weight and air, flow and rolling resistance are the main routes to this end. Weight reduction can be achieved by using light-weight materials such as aluminium and downsizing vehicles. Reduction of air resistance is realized by improving the streamline. For trucks there is still substantial savings potential, e.g. by covering wheels and trailer sides, applying boat tails and through design and use of tear-drop shaped trailers. Reduction of the flow resistance of barges is possible by means of hydrodynamic hull design and air flow systems (bubble hull), anti-fouling coating and new loading designs. The air resistance of container trains can be improved through optimized loading schemes as well. Tyres are an important element in the potential for reducing the rolling resistance of trucks. Energy-efficient tyres have been widely introduced, while automatic tyre control and inflation systems (ATIS) are being developed and will soon become available for market introduction. A separate category of measures applies to cooling trailers and containers, where e.g. CO_2 is used for cryogenic cooling.

Economic and technical constraints

The rate at which the above-mentioned techniques are introduced depends largely on their economic viability, expressed in pay-back period. Costs will decrease as techniques become more widely used. Because of the large number of road vehicles and their relatively short economic lifespan, introduction of technical concepts can be relatively fast here compared with other modes. Replacement of the entire IWT fleet will take decades, for example.

Potential

The impact of weight and resistance reduction measures is between 2 and 10% per measure. As these measures interact, the maximum potential will be approximately 20%. The potential of the medium-term measures in inland navigation are higher: between 15 and 25%.

Policy options

The full reduction potential of the short-term measures can be realized if CO_2 emission standards are introduced. The European Commission is working on carbon emission standards, which could push truck manufacturers to speed up the introduction of fuel-saving vehicle design options.

MEASURE	MODE(S)	INTRODUCTION	POTENTIAL
Roof spoiler	RO	Short term	10-20%
Covers for rear-truck wheels	RO	Short term	
Closeable front grille	RO	Short term	
Moveable 5th wheel	RO	Short term	
Redesign vehicle front	RO	Short term	
Covers for trailer wheels	RO	Short term	
Rounded edges of trailer	RO	Short term	
Tractor / Aerodynamic Mirrors	RO	Short term	
Trailer / Side Wings	RO	Short term	
Trailer / Aerodynamic Mud Guards	RO	Short term	
Trailer / Boat Tail	RO	Short term	
Trailer / Tear Drop	RO	Short term	
Low rolling resistance tyres (Tyre Label A)	RO	Short term	
Single Wide Tyres	RO	Short term	
Tyre pressure monitoring system (TPMS)	RO	Short term	
ATIS truck + trailer	RO	Short term	
Lifting axles	RO	Short term	
Wheel alignment monitoring	RO	Short term	
Aluminium wheels	RO	Short term	
Aluminium chassis	RO	Short term	
Cabin downsizing	RO	Short term	
Alternative cooling/freezing	RO/IW/RA	Short term	
Streamlined container train loading	RA	Short term	
Hydrodynamic ship design	IW	Medium term	15-25%
Bubble hull	IW	Medium term	
Optimised ship loading design	IW	Medium term	
Antifouling coating	IW	Medium term	

E.10 Motor design and driveline

Description

Improved vehicle and engine design can also be a means to reduce CO_2 emissions. This includes driveline efficiency improvements (increasing engine efficiency or reducing transmission losses). Various proven technologies aimed at increasing driveline efficiency are available for all types of conventional combustion engines, e.g. engine downsizing, improved turbocharging, dual-clutch transmission and various stages of hybridization. These technologies can be applied in road vehicles as well as in diesel trains and shipping vessels.

Economic and technical constraints

Technologies that increase drivetrain efficiency have little if any impact on performance or operational capabilities. They do not therefore require additional infrastructure for supplying the required energy carrier, planning or (much) training on the part of drivers / shippers. The increased amount of (complex) components may affect maintenance, however, which means maintenance personnel may need a certain amount of additional training.

Deployment of these technologies results in increased vehicle prices and therefore higher investment costs for end-users. On the other hand, their use also leads to lower fuel consumption and therefore lower fuel costs. The fuel cost reduction that can be achieved by deploying the more cost-effective technologies available today can significantly outweigh the investment cost. Their implementation will therefore lead to net lower costs for end-user and society and will additionally reduce CO_2 emissions.

Potential

A fair number of driveline-related technologies that have been proven and are already being deployed on a large scale on light-duty diesel vehicles have not yet found their way to heavy-duty road vehicles, diesel trains or shipping vessels. This is due partly to European CO_2 regulations being in place for light-duty vehicles only. The CO_2 reduction potential for heavy-duty road vehicles is consequently substantial: an anticipated 20%, with a similar figure holding for trains and ships.

Policy options

For light-duty vehicles (passenger cars and LCVs), EU CO_2 regulations have been in place since 2009 and have been a major driver for increasing drivetrain efficiency and thus reducing CO_2 emissions. The potential for implementing CO_2 regulations for heavy-duty vehicles is currently under investigation. Depending on the final design, such policy may promote not only deployment of efficiency-increasing technologies for conventional combustion engines, but also development of zero-emission alternatives, as this could become a cost-effective way for manufacturers to meet certain CO_2 standards. For other modes, too, this kind of policy could be developed.

Other possible policy measures to stimulate or enforce higher energy efficiency include:

- environmental zones, permitting use of low-emission vehicles only
- (fiscal) incentives for low-emission vehicles
- including CO_2 emission levels as an award criterion in tenders aimed at acquiring
  - road vehicles, vessels or trains, or
  - services that include the use of road vehicles, vessels or trains
- On-shore power supply.

MEASURE	MODE(S)	INTRODUCTION	POTENTIAL
Improved turbocharging and EGR	RO/IW/RA	Short term	10-20 %
Improved SCR and optimised SCR heating methods	RO/IW/RA	Short term	
Engine efficiency (friction reduction through mech. fitting and lubricants, increased peak firing pressure, ...)	RO/IW/RA	Short term	
Engine downsizing	RO/IW/RA	Short term	
Waste Heat Recovery (WHR)	RO/IW/RA	Short term	
Engine supervisory controls (IEM)	RO/IW/RA	Short term	
Transmission efficiency (friction reduction, driveline shaft, differentials, axles)	RO/IW/RA	Short term	
AMT	RO/IW/RA	Short term	
Dual clutch transmission (adv. downspeeding)	RO	Short term	
Mild - start/stop + regenerative braking + efficiency	RO	Short term	
Cooling fan, steering pump, air compressor, A/C compressor, generator, lights	RO/IW/RA	Short term	
Onshore power supply (cold ironing)	IW	Short term	

E.11 Alternative carbon-based fuels

Description

Besides petrol and diesel, 'alternative' carbon-based fuels are already available and some of them can be a means to reduce transport CO_2 emissions. They can be produced from either fossil or bio-based resources. Examples of fossil-based 'alternatives' are LPG (produced from oil) and CNG/LNG (produced from natural gas). Compared with conventional petrol and diesel, these fuels have a higher energy output per amount of CO_2 emitted and therefore lower TTW emissions. Their WTT emissions are comparable with those of other fossil fuels. Bio-based equivalents can be produced for all these fossil fuels, such as biodiesel, bio-CNG (CBG), bio-LNG (LBG) and bio-LPG (BLPG). These fuels have TTW CO_2 emissions comparable with their fossil equivalents, but result in significantly lower WTW emissions, as the CO_2 emissions are absorbed by biomass.

Solar fuel or, more generally, power-to-X (PTX) fuel is a black swan, leaving fuel logistics relatively unchanged. It can theoretically be produced by using (cheap) renewable energy in areas with abundant space and wind or sunshine, taking water to produce H_2. Hydrogen can be bound to heavier atoms like nitrogen to generate a gas or liquid, or even to generate hydrocarbons in a reaction with CO_2. If, due to innovation, costs drop to a competitive level, it might be possible that energy producing countries start to evolve using this process, generating new liquid fuel flows to Rotterdam.

Economic and technical constraints

As mentioned above, some of these alternatives are fossil fuels. The CO_2 emission reduction due to using such alternatives is approximately 15% relative to petrol and therefore not nearly enough to contribute significantly to the 95% COP21 CO_2 reduction goal. Use of these fuels should therefore be restricted to situations where no (cost-effective) renewable options are available. The non-fossil alternatives are all bio-based and produced from dedicated biomass or waste. In the former case, agriculture and therefore land-use is required. Land mass is scarce, however, and growing crops to produce biofuels can limit the availability of farmland for other purposes like food production. Also, bio-based waste resources are limited. These biofuels should therefore also be deployed wisely. Given these restrictions, the use of alternative carbon-based fuels seems especially favourable in the following cases:

- if no (competitive) zero-emission alternative is available;
- in areas where no infrastructure is available for carbon-neutral energy carriers;
- for modes with long lifespans using carbon-based fuels that will not be fully depreciated, such as diesel trains and ships.

Compared with diesel and LNG, the energy density of gaseous LPG and CNG is limited and therefore the vehicle range is as well. As a consequence their use is mostly restricted to buses and urban distribution by truck. CNG/LNG can also be used in dual-fuel engines. These are compression ignition engines that can run on either diesel or a blend of diesel and CNG. In the latter case the diesel fuel is used as an ignition fuel. Blends of up to 20% CNG can be used in conventional diesel engines; blends of up to 75% require limited engine adaptation.

The use of high-biofuel blends can accelerate engine wear and the road vehicle industry therefore limits the amount of biofuels in blends, especially for use in modern, more complex engines. For FAME, the maximum share is 7%, for other kinds of biodiesel, such as HVO and BTL, the upper limit is 30%. Higher shares of biofuel require costly engine adaptations.

Fuel prices vary significantly per country, depending on the excise duty applied. In the Netherlands the excise duty on LPG, CNG and LNG is relatively low, making it a relatively low-cost fuel. The same excise duty applies to biofuels as for conventional fuels. As their production cost is generally significantly higher, so too is their price. The higher the blend of biofuel, the more expensive the fuel will be.

Potential

Fossil LPG, CNG and LNG reduce CO_2 emissions by approximately 5% compared with conventional diesel. The CO_2 reduction resulting from the use of (a share of) biofuels depends very much on the resources, production and origin. The range of CO_2 reduction is large, depending on the resources used and the production route. In the case of waste being used as a feedstock, the CO_2 emission reduction can be as high as 90%. In the case of high ILUC emissions, the use of biofuels can result in net higher CO_2 emissions than with fossil diesel fuel. The CO_2 reduction potential of these alternatives is therefore restricted mainly by the availability of traceable biofuels.

Policy options

Excise duty levels strongly affect fuel prices. By lowering the duty on low-carbon alternative fuels their use could be increased. Another way of influencing the biofuel use is by increasing the minimum share of biofuels to be blended in. Production could also be influenced by policy, for instance by subsidies.

MEASURE	MODE(S)	INTRODUCTION	POTENTIAL
LPG Mono-Fuel (Si)	RO	short term	0-5%
CNG Mono-Fuel (Si)	RO	short term	
LNG Mono-Fuel (Si)	RO/IW/RA	short term	
LPG Dual-Fuel	RO/IW	short term	
CNG Dual-Fuel	RO	short term	
LNG Dual-Fuel	RO/IW/RA	short term	
BLPG Mono-Fuel (Si)	RO	medium term	65-90%
CBG Mono-Fuel (Si)	RO	medium term	
LBG Mono-Fuel (Si)	RO/IW/RA	medium term	
BLPG Dual-Fuel	RO	medium term	
CBG Dual-Fuel	RO	medium term	
LBG Dual-Fuel	RO/IW/RA	medium term	
LPG Dual-Fuel (RCCi)	RO/IW/RA	medium term	
LNG Dual-Fuel (RCCi)	RO/IW/RA	medium term	
CNG Dual-Fuel (RCCi)	RO	medium term	
BLPG Dual-Fuel (RCCi)	RO	medium term	
CBG Dual-Fuel (RCCi)	RO	medium term	
LBG Dual-Fuel (RCCi)	RO/IW/RA	medium term	

E.12 Electric and hydrogen vehicles

Description

Use of zero-carbon energy carriers like elecricity or hydrogen results in zero tailpipe (TTW) CO_2 emissions. Vehicles with a drivetrain powered by such energy carriers are known as zero-emission vehicles. It is possible to deploy both a zero-emission drivetrain and a conventional drivetrain in a single vehicle, making it hybrid. In that case the resulting tailpipe CO_2 emission depends on the share of kilometres powered by the conventional combustion engine, the energy efficiency of both drivetrains and the GHG emisisons from the production of the energy carriers used (the 'carbon intensity' of the energy used). If the zero-carbon energy carrier can be supplied externally, as is the case for plug-in hybrid vehicles, for example, the vehicle is deemed a ULEV (Ultra-Low-Emission vehicle). If it cannot be supplied externally, the hybridization is regarded as a CO_2 reducing technology on a conventional vehicle.

If fossil recources are used, CO_2 is emitted during the production of the zero-carbon energy carrier. Depending on the resource, these WTT emissions can be quite significant. The use of clean or renewable sources results in (close to) zero WTW CO_2 emissions.

Economic and technical constraints

Battery prices have fallen significantly over the last decade. However, the battery of an electric vehicle still represents a large share of the production cost. As a result, a trade-off exists between the vehicle price and the electric range. The energy density of battery packages is currently such that a package required for a substantial electric range significantly increases the vehicle mass. Large-scale production of electric heavy-duty vehicles with a large range is therefore not expected in the short term. In such cases, a fuel cell may be a feasible zero-emission alternative. A third possibility to reduce CO_2 emissions is to combine a zero-emission drivetrain with a conventional one. Although this will not reduce CO_2 emissions completely, significant reductions can be achieved for many applications.

The production costs of all three drivetrain configurations described above are significantly higher than for conventional drivetrains. As the cost of certain zero-carbon fuels is lower than for diesel, these higher investment costs will be partly compensated by lower fuel costs. The break-even point strongly depends on the distance driven.

It is expected that further research and economies of scale will reduce the costs of these alternative drivetrains in the future.

Potential

The use of zero-emission drivetrains can reduce CO_2 emissions substantially, in theory even completely. The deployment of such vehicles and therefore the CO_2 reduction potential depends on the availability of such vehicles in various vehicle segments and on market demand. Especially for larger long-haul vehicles, no (cost-competitive) alternatives are available today.

Policy options

For light-duty vehicles, CO_2 emission standards have been an important driver for the increase of plug-in hybrid and zero-emission vehicles. Such policy could also be developed for heavy-duty vehicles, trains and vessels. Another policy option is implementation of low-emission zones, allowing only (close to) zero-emission vehicles in areas such as cities.

Besides these 'repressive' policy options, the use of zero-emission vehicles can also be stimulated by means of a beneficial tax system for such vehicles or by subsidies.

MEASURE	MODE(S)	INTRODUCTION	POTENTIAL
Battery Electric Vehicle	RO	Medium term	40-60%
Hybrid trucks (plugin)	RO	Medium term	
Hybrid locomotives (plugin)	RA	Medium term	
Hybrid barges (plugin)	IW	Medium term	
Diesel-electric barges	IW	Medium term	
Fuel Cell Electric Vehicle	RO	Long term	90-100%
Pantograph Electric Vehicle	RO	Long term	
Battery Electric Vessel	IW	Long term	
Fuel-cell/hydrogen trains	RA	Long term	

E.13 Sustainable warehousing

Description

Reducing the CO_2 emissions associated with storage and warehousing can be realized via two routes: the buildings with their installations (lighting, cooling) and the internal transport equipment (forklifts, cranes, reachstackers, conveyor belts etc.). For the second category, more or less similar measures can be distinguished as with other transport equipment: use of alternative fuels, electric traction, motor and driveline design. The design of energy-efficient warehouses can be realized by means of insulation, LED lighting, solar panels and high-rise storage. Certification with e.g. BREEAM is also applied for logistics real estate, such as warehouses and distribution centres.

Economic and technical constraints

The return on investment is a crucial element in investments in buildings and assets by private partners. High energy prices will accelerate improved energy efficiency of buildings and equipment. Breakthrough technology such as LED lighting and solar panels can lead to quick and large reductions of carbon emissions.

Potential

Savings of up to 30% can be realized, albeit that the absolute savings are relatively low compared to the transport and logistics activities.

Policy options

Energy pricing and subsidies for sustainable energy (solar panels, wind turbines) can boost CO_2 emission reduction. Regulation of CO_2 emissions (standards) will be of great influence.

MEASURE	MODE(S)	INTRODUCTION	POTENTIAL
Energy efficient buildings (lighting, insulation, climate control)	N/A	Short term	10-30%
Electric forklift trucks, reach-stackers, alternative fuels	N/A	Short term	
Motor and driveline design	N/A	Short term	
Robotisation and autonomous order picking	N/A	Medium term	20-30%
High bay warehouse design	N/A	Medium term	

E.14 Sustainable transhipment

Description

Transhipment is carried out by a variety of equipment: gantry cranes, reachstackers, straddle carriers, forklift trucks, conveyor belts and pipes. More or less similar measures can be distinguished as with other transport equipment: use of alternative fuels, electricity, motor and driveline design. Additionally, autonomous driving using AGV technology has energy-saving potential. For electric cranes, recuperation of electricity is a promising technique, whereas the purchase of green electricity also adds to the CO_2 emission reduction potential.

Economic and technical constraints

As for logistics real estate, the speed and scale of introduction of energy-efficient technologies will be largely determined by the return on investment in equipment.

Potential

Up to approximately 25% can be realized in the short to medium term.

Policy options

The introduction of emission standards and subsidies can enhance the increase of energy efficiency and reduction of CO_2 emissions

MEASURE	MODE(S)	INTRODUCTION	POTENTIAL
Automated Guided Vehicles (AGV)	N/A	Short term	15-25%
Energy efficient gantry cranes, straddle carriers, stackers etc.	N/A	Short term	
Green electricity	N/A	Short term	

F Barges in the Netherlands: age and class statistics

Figure 22
New built NL barges per age group, per CEMT-class

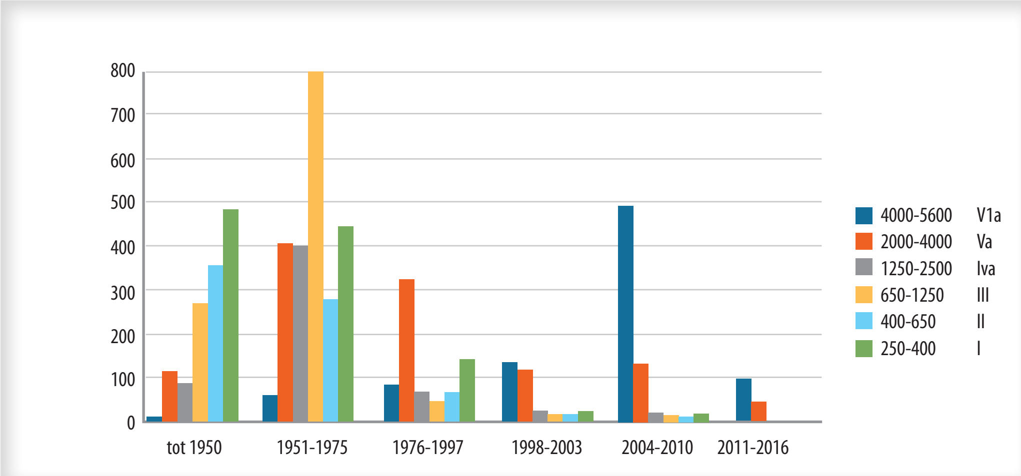


Figure 23
Cumulative number NL per CEMT-class

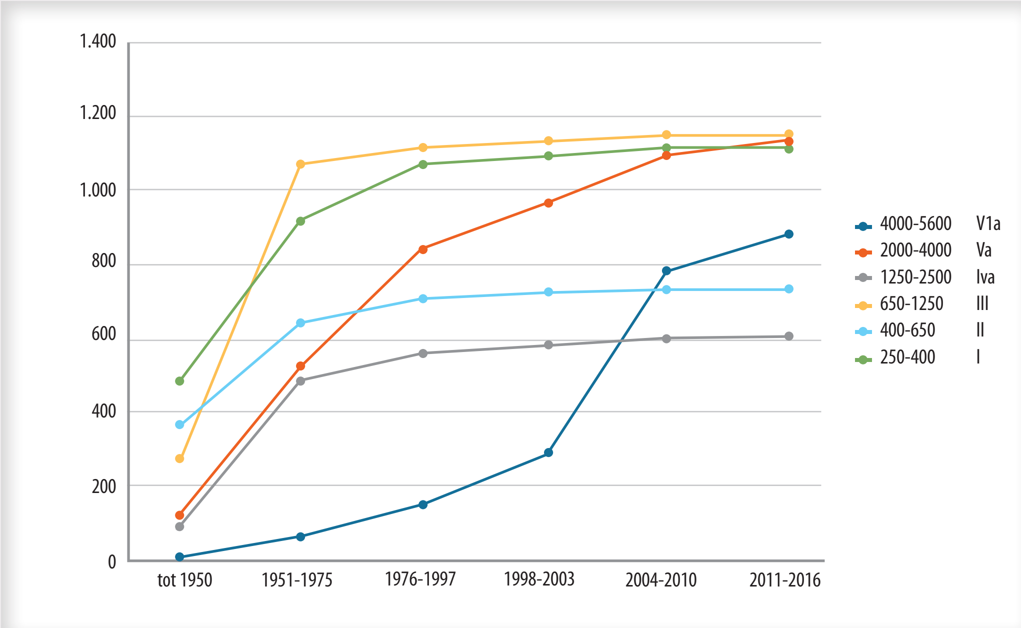


Figure 24
New built NL liquid bulk per age group, per CEMT-class

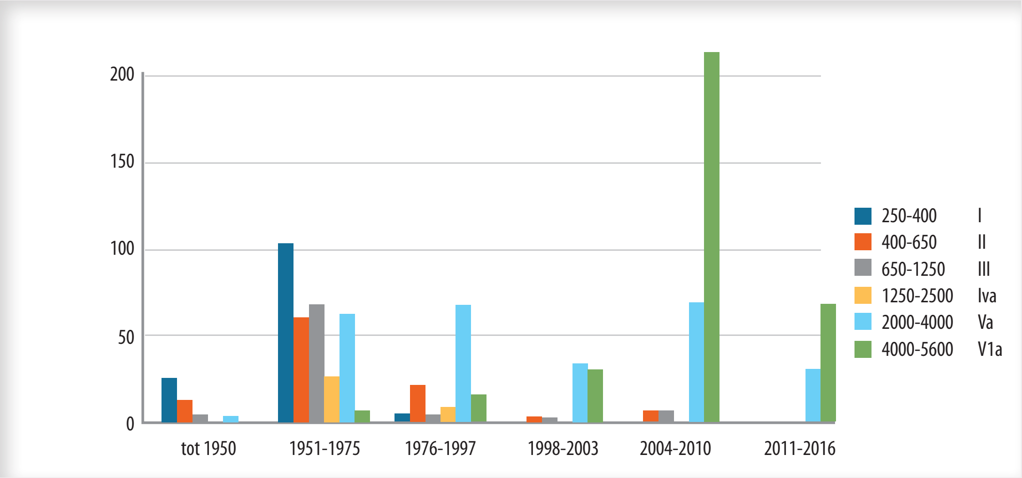
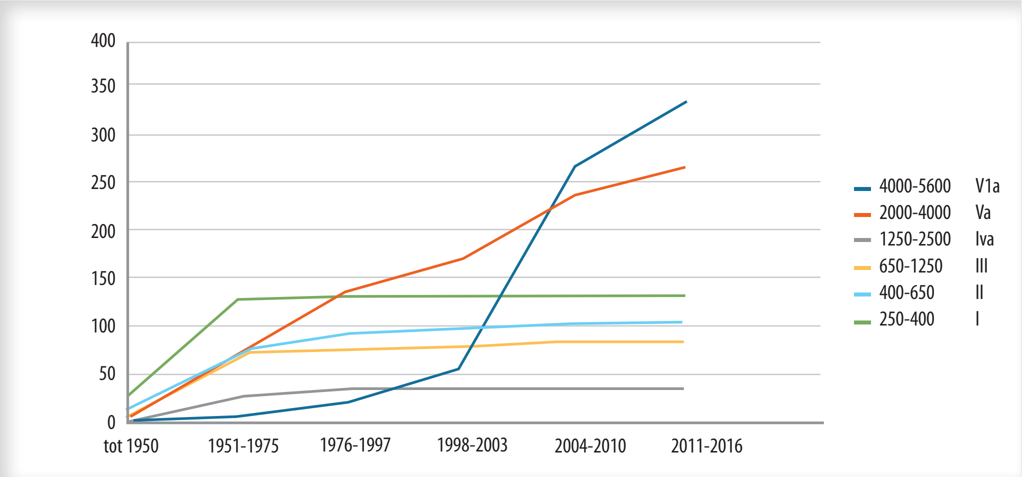


Figure 25
Cumulative number NL liquid bulk carrier barges per CEMT-class



Source: The Blue Road

These statistics do not include pusher boats that push barges which carry containers. This class of boats are predominantly used to transport coal and other bulk goods.

Disclaimer

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