



Ministerie van Infrastructuur
en Waterstaat

Moving towards a new energy system

Background report on the energy transition in transport in the Netherlands

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Moving towards a new energy system

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Summary

The energy transition involves a shift from a fossil fuel-based system to one based on renewable energy sources. This is a major challenge, also for the transport sector, be it in the Netherlands or in other countries. Rapidly changing geopolitics mean that in addition to climate change mitigation also other objectives such as energy security, autonomy, competitiveness and affordability are gaining in significance, creating a complex puzzle. Due to technological uncertainties and trade-offs between certain objectives, adaptive policy will be necessary: adjusting course must be possible. Electrification is often the most efficient and cost-effective solution where possible, but the bulk of the energy demand for Dutch transport will still consist of fuels by 2050. For all modes of transport, the transition will not happen automatically: additional supporting policy is needed for a successful transition.

Various objectives highlight the importance of the energy transition

Combating climate change is a key driver behind phasing out the use of fossil fuels in the transport sector. A rapidly changing world order, in which wars affect the oil market and energy is used as an economic or political weapon, adds further objectives. Energy supply security, strategic autonomy, industrial competitiveness and affordability are now at least as important as climate. This has only increased the urgency of the energy transition.

Future energy mix varies by mode of transport

The transport sector accounts for around 40% of total final energy demand in the Netherlands, and 94% of the energy supply for transport is based on petroleum. Of the various renewable energy sources, electrification is by far the most energy-efficient and cost-effective option. Road transport – passenger cars, buses, vans and lorries – could largely be electric by 2050. A small proportion of renewable fuel will still be required, and there may also be a limited role for hydrogen for trucks. The energy-saving effect of large-scale electrification will reduce total energy demand.

For aviation and shipping – which account for 58% of current energy demand in the Dutch transport sector – electrification and hydrogen are only possible to a (very) limited extent until 2050. Biofuels and e-fuels will therefore also play a major role in the energy mix. The balance between these fuels remains unknown and will depend on developments in costs, technology and infrastructure, as well as on the development of the industry and the petrochemical cluster during the energy transition.

Large quantity of biofuels required but scaling up feedstock and production challenging

The costs of biofuels are uncertain, but are often estimated to be lower than those for e-fuels. Due to this cost advantage, carbon-neutral scenarios for 2050 in the Netherlands project that demand for biofuels will be 3 to 8 times higher than it is today. The current feedstocks for this, such as used cooking oil, are insufficient to meet this future demand. However, there are opportunities for sustainable biomass from residue streams or (intermediate) crops from European agriculture. The availability of cellulosic biofeedstocks could be substantial, given the potentially available land in the EU, particularly due to the possibility of growing intermediate crops on existing agricultural land and taking into account additional crops on fallow

and degraded land. Additional policy, in collaboration with the agricultural sector, can help to mobilise this potential.

The current strong role of bunker fuels in the Dutch energy mix is closely linked to the future of the bunker position of the Port of Rotterdam and the petrochemical cluster. However, this position is under pressure from international competition and the global transition to renewable energy. A shift towards the refining of sustainable biofuels offers economic and strategic opportunities. However, this transition requires significant capital investment and time. For biorefineries, and in particular production facilities for sustainable aviation fuel (SAF), there is a risk that no investments will be made to scale up due to a short-term oversupply compared to the policy mandates up to 2035. Policy support, coordinated with other EU countries, and recent initiatives such as the Hydrogen Bank, the Innovation Fund and the Sustainable Transport Investment Plan, can help reduce investment risks.

Synergies and trade-offs between policy objectives: adaptive policy needed

The energy transition offers opportunities to contribute to various policy objectives, but there may also be tension between them.

The transition creates new dependencies, particularly in battery supply chains, including critical raw materials. China's recent restrictions on high-quality graphite (needed for batteries) and rare earth metals (needed for electric motors and semiconductors) can be seen as a warning. Affordability is also not necessarily improving for all groups in society, meaning that a just energy transition is not a given.

The goal of a carbon-neutral energy system by 2050 stands, but the path to achieving it is not yet clear. For example, because the affordability of energy may come under pressure or barriers to electrification may be greater than expected, it may be justified to adjust existing policies or take additional measures to mitigate adverse effects.

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1 Introduction

According to Jan Rotmans, professor of transition science, the energy transition is the Netherlands' largest reconstruction project ([BNR Nieuwsradio, 2024](#)). In the field of electricity generation, there is substantial progress in the Netherlands, with more than 50% renewable energy, compared to 10% ten years ago ([Compendium for the Environment \[CLO\], 2025](#)). However, when it comes to modernising the electricity grid and the transition to clean energy in other sectors, such as industry, buildings and transport, we are still only at the beginning. This is despite the fact that the pace of the changes required to be carbon neutral by the middle of this century, as laid down in the European Climate Law, is unprecedented. We are now closer to 2050 than we are to the year 2000.

The Dutch Coalition Agreement 2026-2030 also endorses the importance of the energy transition. It focuses on European cooperation with the aim of achieving a 90% CO₂ emission reduction by 2040, with possible additional national measures if this target is not within reach. Security of supply, strategic autonomy and affordability are key considerations when taking measures.

In the road transport sector, we are seeing an increasing share of electric vehicles and biofuel blends: 14% of diesel consumption in Dutch road transport is now renewable ([Netherlands Emissions Authority \[NEa\], 2025](#)). In international aviation and shipping, however, this share is still much lower. To meet the ambitious climate targets set for 2030, 2040 and 2050, solutions must be scaled up rapidly. This includes electrification, but also large quantities of alternative fuels, whether derived from biomass or renewable hydrogen. The energy transition in the transport sector presents a range of challenges: technical, economic, social, industrial and environmental.

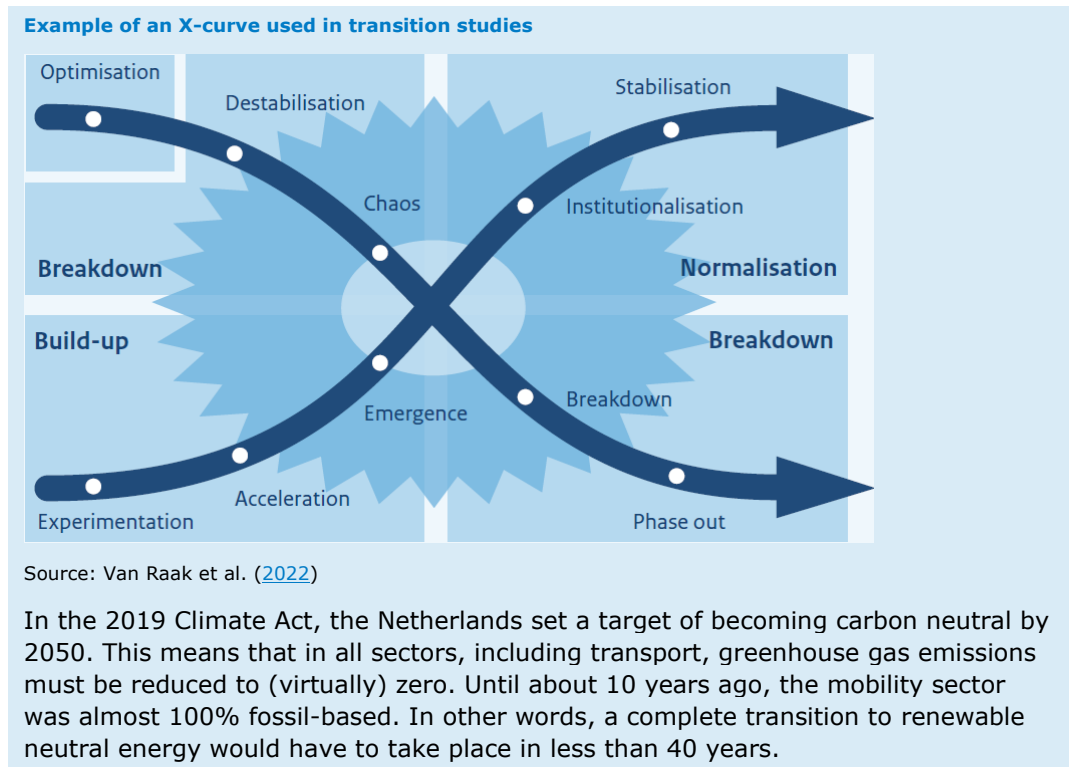
Box 1.1 What is an energy transition?

A transition is a fundamental and irreversible structural change in which an existing system – be it the energy supply, healthcare or a personal life stage – transforms into a new state of equilibrium.

It is not a simple adjustment or incremental improvement (optimisation), but a process of profound renewal in which old ways of thinking, working and organising give way to a radically different approach. This process is illustrated by the X-curve below.

A transition is often accompanied by a period of chaos, resistance and uncertainty, as the established order is challenged by innovative forces, until the new reality eventually becomes the norm.

For the energy system, the (intended) transition involves the phasing out and conversion of a system based on fossil fuels to one based on renewable energy. This contributes to combating climate change, but also touches on other (policy) objectives, which we will explain in more detail in the following chapter.



At the same time, rapid changes are taking place in the world and in the Netherlands that provide a different context for this transition. This makes it relevant to provide an up-to-date and coherent overview of the energy transition for transport, with considerations for policymakers in the transport sector. Our analysis is based on existing literature, mainly from Europe and the Netherlands, including both academic and grey literature.

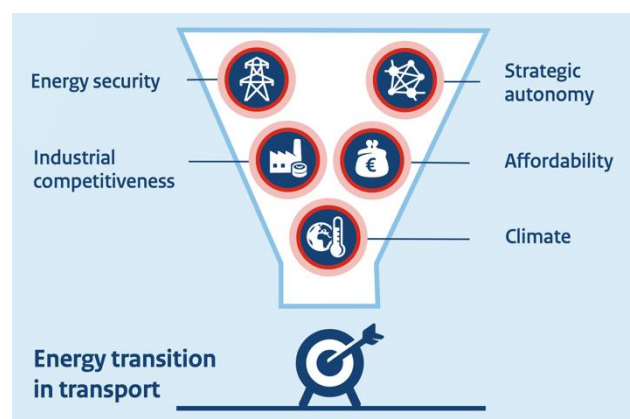
This report focuses primarily on technology: in terms of the 'avoid-shift-improve' approach (Creutzig et al., 2022), the focus is on 'improve', i.e. carbon-neutral fuels and improving the energy efficiency of vehicles, while demand for transport and mode choice are largely taken as given. This is not to say that 'avoid' and 'shift' are not important strategies. Another recent study (Bakker & Moorman, 2025a) examines such policy approaches to achieving energy savings in greater depth. It is also possible to consider the broader relationship between transport and economic development (Zijlstra & Wagenvoort, 2025), which may indirectly be relevant to the energy transition as well. Finally, the present study builds on the publication Energy chains for carbon neutral transport (Bakker et al., 2022), which provides a techno-economic analysis of renewable energy in transport.

We begin with a consideration of the changing drivers behind the energy transition (Chapter 2). Chapter 3 presents facts from recent, mainly Dutch, literature on transport and energy. Chapter 4 examines energy scenarios for different modes of transport. The following chapters discuss the most important renewable energy carriers: renewable electricity, biofuels and renewable hydrogen/e-fuels. These chapters address specific policy considerations for the energy carriers and transport modes. Chapter 8 discusses some key aspects of and strategies for energy efficiency. Finally, Chapter 9 briefly summarises the preceding chapters and provides an overarching policy considerations.

2 Why the energy transition?

This chapter analyses the objectives behind the energy transition through five interrelated perspectives: climate, security of supply, affordability, strategic autonomy and industrial competitiveness. We demonstrate that these objectives can support one another, but may also conflict.

Figure 2.1 Multiple policy objectives play a role in the energy transition in transport



In policy and implementation of the energy transition, combating climate change goes together with new and existing objectives: security of supply, strategic autonomy, industrial competitiveness and affordability.

Source: KiM.

The energy transition is central to the strategy set out in the European Green Deal ([European Commission \[EC\], 2019](#)). This includes, among other things, the legally binding target of climate neutrality by 2050, which is enshrined in the European Climate Law ([European Union \[EU\], 2021b](#)), Fit for 55 ([EC, 2021](#)) and the REPowerEU plan ([EC, 2022](#)). The importance of the energy transition extends far beyond environmental objectives: it is, in fact, an integral part of the EU's economic model, industrial competitiveness and capacity for strategic autonomy ([EU, 2024c](#)).

As Draghi ([2024](#)) noted in his analysis to define priority actions, the energy transition also lies at the heart of the current global challenge in the field of competitiveness. It is therefore important that Europe takes measures to ensure that its implementation is a socio-economic success.

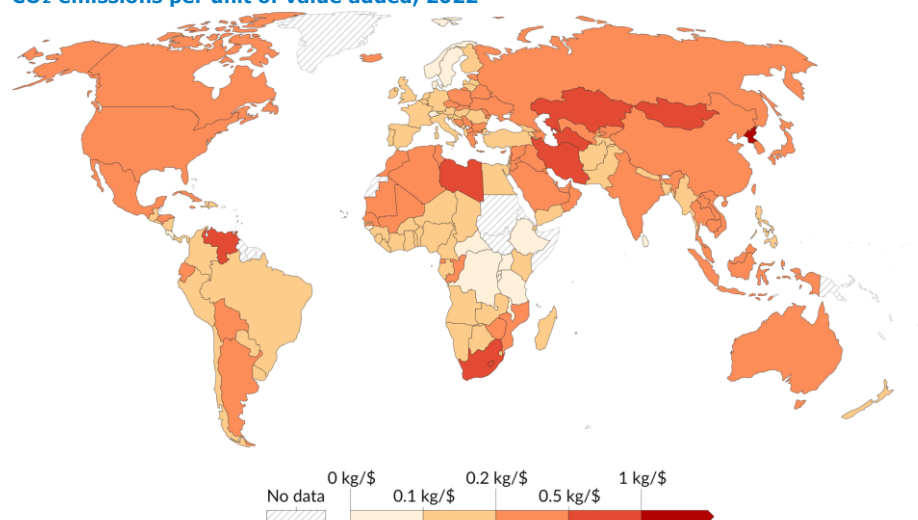
2.1 Tackling climate change

Addressing climate change is a major challenge for the coming decades, with ever-increasing consequences for people, nature and the global economy. Extreme weather events such as droughts, heatwaves, floods and wildfires are becoming more frequent and severe, threatening ecosystems, infrastructure and long-term prosperity. Human-induced greenhouse gas emissions are the main cause of global warming, which has reached unprecedented levels, with 2023 being the warmest year on record. Europe is warming faster than the global average ([Copernicus Climate Change Service \[C3S\], 2024](#)), and vulnerable regions and population groups are at greatest risk. Without urgent climate action, tipping points could be crossed, with irreversible and high-risk consequences. The economic damage could amount to 10–12% of global GDP by the end of the century ([International Monetary Fund \[IMF\], 2025](#)), which is much higher than the costs of mitigation. The human and societal toll of climate change is already significant and is expected to increase further.

The EU has long positioned itself as a leader in international climate policy by taking a key role in shaping the Paris Agreement, incorporating a climate neutrality target into its legislation (EU, 2021b) and developing a wide range of policy measures to achieve this. In doing so, it also recognised the findings of climate science and the need to take action against the associated increasing risks, while striving to ensure that climate measures could present an opportunity for all sectors of the Union’s economy (EU, 2021b).

EU Member States are characterised by relatively low emission intensity (i.e. low levels of greenhouse gas emissions per unit of value added generated) compared to other countries and regions (Figure 2.2). These low emissions per unit of value added stem from the long-standing need to diversify energy sources and maximise energy efficiency, given the limited supply of fossil fuels in Europe. The European economy is also characterised by a long-standing focus on transforming primary raw materials into high-value goods. This has been made possible by robust access to financial resources, institutions capable of supporting strategic infrastructure investments, and a high level of human capital and education compared to developing countries. Together, these factors have fostered technological innovation and enabled Europe to achieve a relatively high level of total productivity, leading to the development of knowledge-intensive production capacity.

Figure 2.2 CO₂ emissions per unit of value added, 2022



Source: Ritchie et al. (2025) based on data from Bolt & Van Zanden (2024).

The need for action is reinforced by geopolitical pressures, including the wars in Ukraine and Iran and the rise in energy prices. In addition, reducing air pollution, including SO₂, NO_x, ozone, and particulate matter, may drive a shift to cleaner energy, particularly electric mobility. Cost challenges are also linked to the heavy burden of welfare costs for an ageing population, as this limits the availability of resources for investment in innovations that can deliver productivity gains. The challenge, therefore, is not only to maintain climate ambitions but also to embed them in a coherent and competitive economic model.

2.2 Energy security of supply

Traditionally, the security of supply is understood as the uninterrupted availability of energy sources at an affordable price. In the 20th century this concept focused primarily on ensuring a stable supply of fossil fuels, such as oil and natural gas. National energy security was often equated with the ability to secure energy imports and maintain strategic reserves to cope with supply disruptions. This view of

security of supply has evolved into a broader and more dynamic framework. In particular, a recent summit of the International Energy Agency emphasised the need to integrate energy security into a comprehensive security framework that addresses the multifaceted challenges of the energy transition ([International Energy Agency \[IEA\], 2025](#)). In addition to the aspects mentioned above, this includes:

- Decarbonisation and climate resilience: recognising that climate change brings new vulnerabilities, modern energy security emphasises the need for energy systems that are both low-carbon and resilient to climate-induced disruptions.
- Electrification and grid reliability: due to increased reliance on electricity, it has become crucial to ensure the resilience of electricity systems against disruptions and cyber threats. This entails improving grid infrastructure and implementing technologies that guarantee an uninterrupted electricity supply.
- Supply chain security: the transition to clean energy technologies requires securing critical minerals and components that are essential for renewable energy systems. This aspect of energy security relates to the geopolitical and logistical challenges associated with the extraction and processing of these materials (see also 2.3).
- Energy efficiency: improving energy efficiency is seen as a key strategy for enhancing security of supply. By reducing energy consumption, countries can decrease their dependence on external energy sources and thereby strengthen their security of supply.

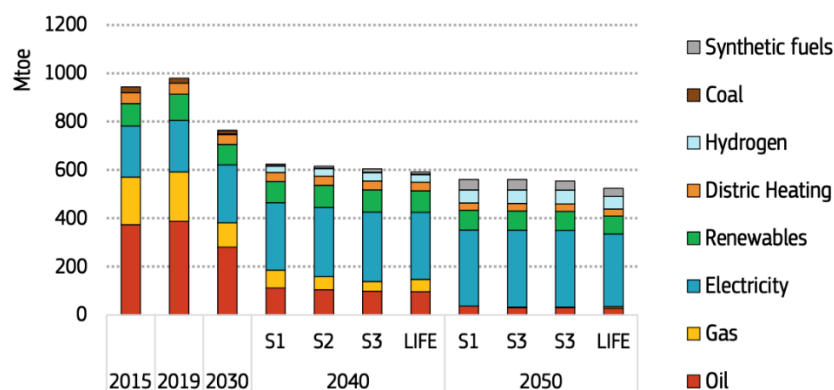
Europe remains one of the world's largest importers of fossil fuels, with over 90% of its oil supply¹ and nearly 90% of its gas supply consisting of imports in 2024 ([Eurostat, 2025](#)), and oil and gas accounting for 55% of its total primary energy supply ([IEA, 2025f](#)). This dependence on imports has repeatedly exposed the continent to external shocks. Examples include the historic oil crises of 1973–1979 and the wars in Ukraine and Iran, which led to unprecedented price rises for oil, natural gas and, indirectly, for electricity (particularly in areas where gas is, or was, a major source of energy for electricity generation).

These geopolitical changes are taking place against a backdrop of rapid technological developments. Key factors here are the electrification of end-use energy and renewable energy sources. In particular, the electrification of end-use energy enables significant improvements in energy efficiency, thereby creating opportunities to reduce demand for fossil fuels. Wind, solar and hydro power are particularly well-suited to linking the shift towards the electrification of energy demand with a low-cost, low-carbon electricity supply, which is widely available across the EU. Technological shifts play a key role in distinguishing current energy-related challenges from those of the past, pointing to a growing tension between economic systems based on fossil fuels and low-carbon technologies ([Viñuales, 2023](#)).

Various analyses show that the net energy and cost savings resulting from electrification (Figure 2.3, combined with an accelerated deployment of renewable energy, offer opportunities for a significant reduction in total energy demand and fossil fuel imports (Figure 2.4). Key examples of this include the impact assessment of the European Climate Law ([EC, 2020](#)), studies by the International Energy Agency ([IEA, 2021b, 2023b](#)) and analyses supporting the European climate target for 2040 ([EC, 2024](#)).

¹ For data on the Netherlands, see Chapter 3

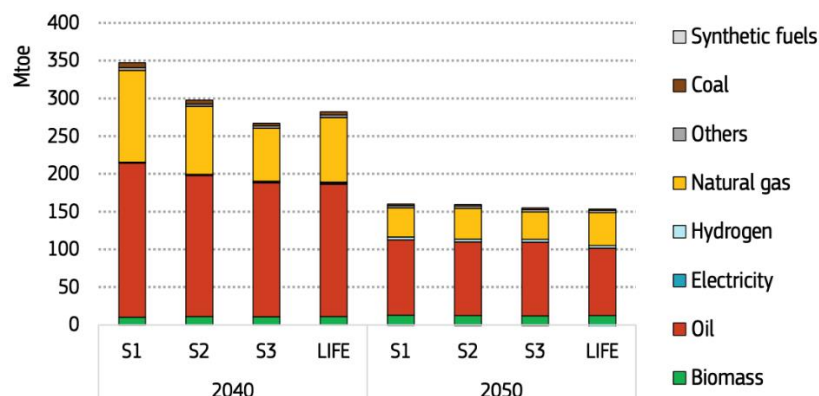
Figure 2.3 Final energy consumption in scenarios developed for the analysis of the EU’s 2040 climate targets, 2015–2030



Source: EC (2024).

Note: Scenario S1 aims for a net reduction in greenhouse gas emissions of nearly 78.5% in 2040 compared to 1990, in line with a 'linear' trajectory between 2030 and 2050. S2 aims for a net reduction in greenhouse gas emissions of at least 85% by 2040. S3 aims for a net reduction in greenhouse gas emissions of at least 90% by 2040 compared to 1990. The LIFE scenario illustrates the additional impact of various assumptions on the circular economy, transport and the food system.

Figure 2.4 Net imports by energy carrier in scenarios developed for the analysis of the EU’s 2040 climate targets, 2015–2050



Source: EC (2024).

Note: the scenarios are the same as those described for Figure 2.3

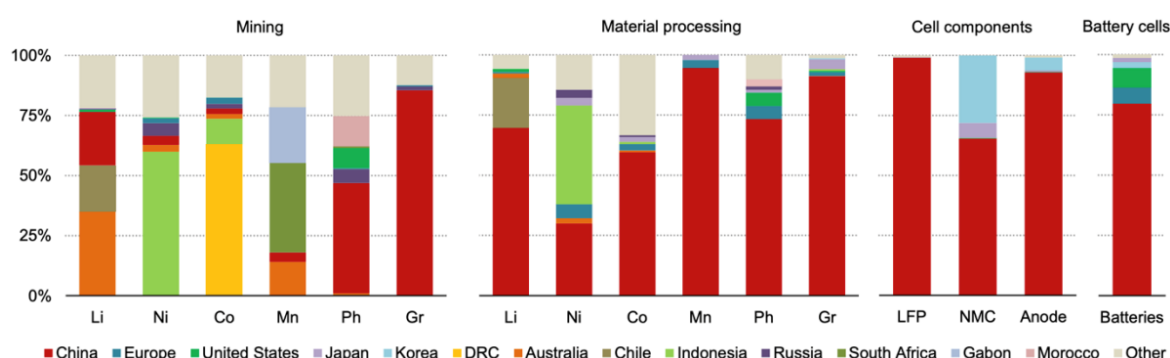
2.3 Strategic autonomy and industrial competitiveness

Although the potential for cost savings, economic competitiveness and improved energy security is clear, the energy transition is not without risks. Unless Europe develops competitive supply chains in the fields of renewable energy generation, batteries, electric vehicles and other low-emission technologies such as biofuels and e-fuels, dependence on fossil fuel exporters may be replaced by dependence on external suppliers of clean technologies and critical minerals (European Commission: Joint Research Centre [JRC], 2020; Draghi, 2024). In particular, lithium, cobalt and some rare earth elements are essential for batteries, wind turbines and digital systems, but their extraction and processing are highly concentrated outside the EU (Figure 2.5). At the same time, the Draghi report emphasises that Europe must identify strategic sectors where it cannot afford to lose industrial capacity and where maintaining technological leadership is essential for autonomy and resilience (Draghi, 2024).

In the field of electric transport and associated batteries, Chinese companies not only control the majority of every stage in the lithium-ion battery supply chain, but are also global leaders in cobalt processing and prominent players in nickel processing (IEA, 2021a, 2022; Cheng et al., 2024; IEA, 2025a; Deberdt & DiCarlo, 2024).

Although these dependencies are real and underpin key policy measures related to the concept of open strategic autonomy², they need not be permanent. Circular economy strategies, battery and metal recycling, and material substitution offer opportunities to mitigate long-term risks.

Figure 2.5 Geographical distribution of supply chains for EV batteries and materials, 2024



Source: IEA (2025a).

All countries that are heavily dependent on fossil fuels – including major powers such as China and India – are motivated to reduce their exposure to this challenge. At the same time, they are actively seeking effective frameworks, expertise and funding for the development of cleaner, less energy-intensive and cheaper production processes. They are doing this by utilising technological developments and by seeking opportunities that can also help them diversify their supply chains (EU, 2024). The main reasons for this therefore lie in the desire to promote economic competitiveness and industrial development, rather than weaken them, during the transition.

In particular, the scale and speed with which China is deploying clean technologies has left Europe vulnerable, especially if it remains dependent on outdated industrial facilities and continues to be exposed to higher energy costs (Draghi, 2024). China's competitive advantage is rooted in economies of scale, automation and lower labour costs, whilst Europe is grappling with diminishing returns from outdated, CO₂-intensive infrastructure.

A further challenge to Europe's industrial competitiveness lies in the outflow of European capital to Asia, which could create a perverse dynamic that undermines the EU's development prospects. In 2024, the EU imported batteries from China worth €22 billion (European Commission: Directorate-General for Trade and Economic Security [DG TRADE], 2025). Attracted by the combination of economies of scale, faster returns on investment and structurally lower energy and labour costs in China, European investors are already investing more in China than Chinese investors are in Europe.³ On the one hand, this facilitates access to new markets (a

² Although definitions vary in scope and emphasis, open strategic autonomy generally refers to the EU's ability to act autonomously (i.e. without being dependent on other countries) in strategically important areas, including economic development, technological progress, security and defense (Damen, 2022).

³ The EU's investment portfolio in China stood at €232 billion in 2023, whilst the EU's foreign direct investment (FDI) reached €10.1 billion in 2024. EU investment in China in 2024 was primarily focused on the automotive, basic materials and information and communication technology sectors. The Chinese investment stock in the EU stood at €65 billion in 2023, and Chinese FDI flows amounted to €9.4 billion in 2024 (compared to €5.2 billion in 2023) (DG TRADE, 2025).

positive development for the EU), but it can also undermine growth opportunities for European industries (if not lead to contraction due to loss of market share).

This dynamic is also relevant for industries focused on carbon neutrality. While it may help European industries gain access to more competitive inputs through trade, it can also have the adverse effect of strengthening China's global leadership in clean technologies, whilst undermining Europe's own competitive position.

Draghi ([2024](#)) warns that Europe risks deindustrialisation if it fails to provide a competitive investment climate. He emphasises that Europe's fragmented capital markets and high energy costs make Chinese companies relatively more attractive.

In the transport sector, the automotive industry is a prime example of this worrying industrial trend. Once a bastion of European industrial leadership, the sector is now being challenged by the rise of China as a net exporter of vehicles, including electric vehicles (EVs) that are increasingly targeting European premium market segments ([Cazzola et al., 2025](#)). Chinese companies have consolidated their lead by controlling a large part of the global supply chain for EV batteries, from raw materials to cell production. In doing so, they benefit from domestic cost advantages, including discounts on Russian fossil fuels after 2022 ([Ishii et al., 2023](#)).

For European car manufacturers, China's lead creates a double squeeze: a declining market share at home and limited access to crucial raw materials. The result is a self-reinforcing cycle in which European capital risks strengthening competitors abroad, thereby further eroding the continent's relative competitiveness. Without corrective industrial policy and coordinated investment in European production capacity, this development threatens to undermine Europe's industrial base in one of its most strategic sectors.

It is important to respond to this challenge in order to sustain economic growth in Europe, particularly given that Europe's growth model is based on the conversion of primary raw materials into higher-value goods to generate added value. On this basis, a green industrial policy – for example in the Industrial Accelerator Act and the Battery Booster Strategy – is now regarded as an essential complement to other aspects of the energy transition, to prevent Europe from losing control of strategic sectors.

In short, if car manufacturers wish to become less dependent on Chinese battery producers, alternative supply chains will need to be developed, with more production of batteries and components taking place in Europe. This may, however, make it more difficult to compete with affordable EV models from outside Europe, which could result in EVs becoming more expensive.

2.4 Affordability, social justice and inclusion

The affordability of energy is crucial not only for industrial productivity but also for social justice. Thanks to the potential for reducing energy costs, the energy transition also plays a central role in supporting this development. However, it is not a given that affordability will improve for everyone during the transition.

Prices of batteries for electric vehicles continue to fall, following impressive declines over the past decade, to below the level that guarantees cost parity with internal combustion engines ([Jayanthan, 2025](#)) and to below 110 USD/kWh at the battery level ([Delgado et al., 2025](#)).

In combination with electrification technologies, such as electric vehicles, variable renewable electricity generation can also lead to additional efficiency gains for the entire system, as electric powertrains are generally three times more energy-efficient than internal combustion engines ([Cazzola et al., 2023b](#)). This can deliver

additional benefits in terms of affordability, as it accelerates the opportunities for end-users to reap the benefits of a low-carbon electricity supply.

Despite these advantages, zero-emission electricity generation and end-use electrification technologies entail high initial investment costs compared to electricity production from fossil fuels. They also require investment in grid capacity to ensure accessibility for all and to avoid the risk of remaining dependent on more expensive fossil fuel-fired power stations.⁴ Electric vehicles are also more expensive to purchase than vehicles with internal combustion engines, particularly in markets – such as Europe – where their deployment has focused on premium models, as these have a higher profit margin (Cazzola et al., 2025). Due to the higher investment costs and higher financing costs for households and businesses with greater constraints on capital availability, there is a risk that the benefits will not be distributed evenly.

Draghi (2024) notes that financing instruments must ensure affordability for households and competitiveness for businesses. In doing so, he emphasises the dual necessity of social justice and economic strength. Without targeted supportive policy measures – including concessional financing and redistributive tax measures aimed at households and small businesses for whom these investments are unaffordable – the transition could exacerbate social inequality.

In particular, access to the most cost-effective EV charging points – typically at home with cheaper electricity tariffs and/or solar panels – is heavily skewed in favour of higher-income households, as they are more likely to have their own parking space. Furthermore, the higher purchase costs of EVs pose a greater financial barrier for lower-income buyers, who may need to take out an interest-bearing loan, effectively increasing the total cost of ownership compared to wealthier households. Similar examples can also be found in logistics. Larger companies with fewer capital constraints are more likely to benefit from technologies such as e-trucks, compared to small and medium-sized enterprises that use conventional vehicles due to capital constraints.

At the same time, the costs of using vehicles with internal combustion engines are rising. Prices for fossil fuels are expected to continue rising, partly due to policy, and renewable fuels may also become more expensive due to increasing demand (see Chapters 6 and 7).

The European Commission's recent initiative to accelerate the development of small, affordable cars built in Europe (EC, 2025a) can be seen as a proposal to enhance social justice. To this end, the Social Climate Fund (EU, 2023) was established to channel revenue from emissions trading into measures supporting vulnerable groups. This aligns with a broader agenda for a just transition enshrined in the European Green Deal, which aims to ensure that no region or community is left behind.

Social justice considerations are also relevant to the labour market. The shift from fossil fuels to renewable energy sources and electrification offers opportunities for new employment, but also carries the risk that workers in CO₂-intensive sectors will lose their jobs. In the EU, the Just Transition Fund (EU, 2021a) is specifically targeted at regions that are dependent on coal and are CO₂-intensive, to limit job losses and economic disruption.

The additional investment needs associated with the deployment of clean energy and related transport technologies and infrastructure (including electric vehicle

⁴ Variable renewable electricity generation can reduce the utilisation rate of gas and coal-fired power stations. This can lead to an increase in the costs of fossil fuel generation, and consequently in electricity prices.

charging) are estimated at €450 billion,⁵ which corresponds to 2.6% of the EU's gross domestic product ([Draghi, 2024](#)). The Draghi report advocates for common borrowing⁶ to unlock these funding streams. It is unlikely that the private sector will be able to finance this investment on its own. The scale of the challenge emphasises once again that financing the transition in a socially inclusive and affordable manner (including in terms of product distribution) will be crucial from the perspective of justice and social stability.

2.5 Some considerations for the Netherlands

The Netherlands is an open, trade-dependent economy with a large energy-intensive industrial and logistics cluster (the port of Rotterdam, the chemical industry and petrochemical refining) that plays a central role in European value chains. The Netherlands' policy choices therefore have implications for the EU's energy security, the competitiveness of industry and the geopolitics of critical technologies.

Although strong industrial and maritime clusters are key assets for the Netherlands, its historical role as a gas producer and petrochemical hub means that the Netherlands must manage its transition policy carefully (see Chapter 6). Hydrogen has been identified as a strategic option that could help in this regard, but several major hydrogen-related projects have faced delays and uncertainty regarding funding ([IEA, 2025c](#)), due to challenges relating to technical complexity and costs.

As the chemical and petrochemical industries are likely to contract in a transition to net-zero emissions ([IEA, 2021b, 2023b](#)) and as renewable energy and electrification gain ground on the basis of economic competitiveness ([Liebreich, 2025](#)), the Netherlands will increasingly face the need to diversify its industrial base. Furthermore, it will also face competition in the production of clean energy technology. As with other industrial clusters in the EU, without strategic support at EU level and better utilisation of the opportunities offered by the EU's internal market, Dutch companies risk losing ground to Chinese competitors who benefit from economies of scale and subsidies ([Draghi, 2024](#)). As long as the tax incentives introduced by the Inflation Reduction Act remain in force, this also applies to North American competitors.

The Netherlands is therefore an example of how individual Member States seek to strike a balance between national traditional industries and EU-wide requirements, while facing international competition in key technologies. The EU's ability to mobilise investment, prioritise strategic industries and leverage its structural efficiency advantage will determine whether the energy transition delivers prosperity and resilience in the coming decades. That is why the Netherlands is also an example where European cooperation on strategic autonomy, combined with domestic innovation policy, will be of crucial importance.

This chapter also showed that the objectives relating to the energy transition can reinforce one another, but can also sometimes get in each other's way. This makes it necessary to prioritise these objectives. Not all objectives can be achieved simultaneously; choices must be made. It must also be possible to adjust policy during the energy transition. Chapter 9 explores this further.

⁵ This does not take into account the sums required to secure sufficient production capacity in critical technologies within the EU and to ensure that the necessary skills are also available. A further €350 to €400 billion is also needed to make the EU a leader in digital technologies, strengthen defense capabilities and support groundbreaking innovations to boost productivity.

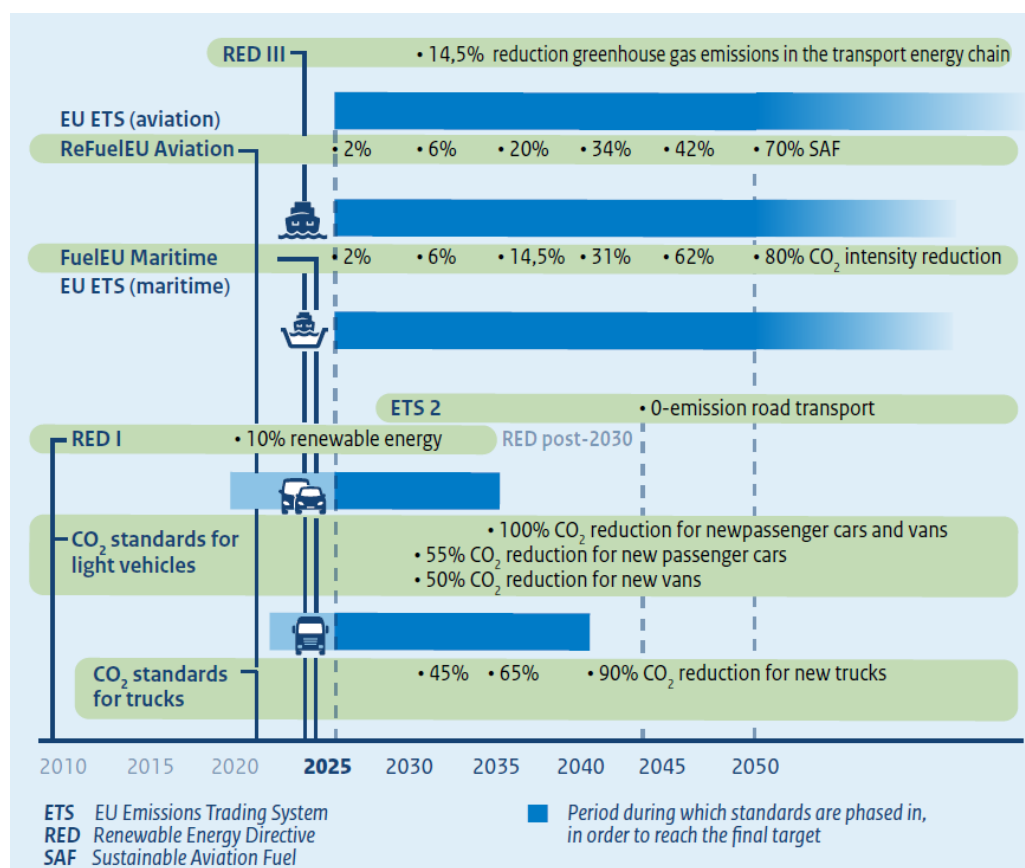
⁶ The EC borrows money on the financial markets by issuing EU bonds.

3 A sketch of the present and the future

The previous chapter outlined the main drivers behind the energy transition in the mobility sector. This chapter provides a snapshot and some key figures on what this transition might look like in the Netherlands. Chapter 4 discusses the transition by mode of transport.

Policy plays a crucial role in this. As a result of policy implemented since the start of this century for road transport and later for other modes, a start has been made on the transition to a new energy system. In this and the following chapters, we will discuss these policy measures. Figure 3.1 provides an overview of the key instruments in force at European level at the start of 2026 (i.e. excluding the recent amendments proposed by the European Commission).

Figure 3.1 Timeline for European policy aimed at the decarbonisation of transport (early 2026)



This figure illustrates the key instruments at European level that have a direct impact on CO₂ emissions and the energy mix of the various modes of transport. The blue bar indicates the time period during which the CO₂ or energy targets set out in the various policy measures are in force. For ETS2, we assume that by 2044 no emission allowances will be available for fuel suppliers to road and inland waterway transport, nor will there be any offsetting options, and therefore all these fuels must be carbon neutral.

Source: KiM

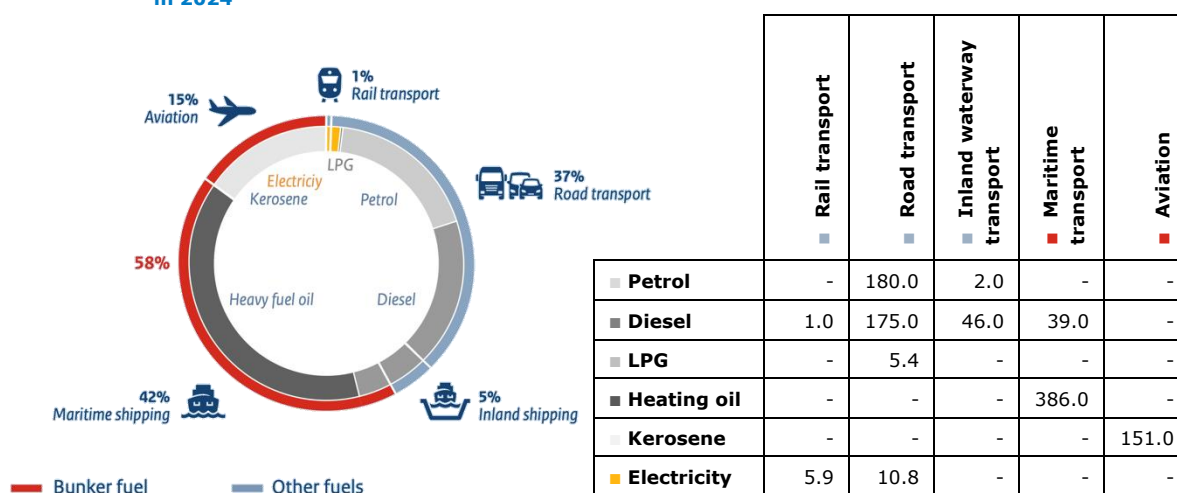
3.1 Bunker fuels for shipping and aviation accounted for 58% of transport energy consumption in the Netherlands in 2024

The Netherlands has a unique profile globally in terms of the distribution of fuels for transport, comparable only to that of Singapore, Panama, Malta, Gibraltar and the United Arab Emirates. The majority of fuel sold in the Netherlands consists of bunker fuels for maritime shipping and aviation, which together accounted for approximately 58% of the country's transport sector's final energy consumption in 2024 (Figure 3.2).⁷ This reflects the fact that Dutch ports (collectively) handle approximately 16% of total maritime freight transport in the EU, with Rotterdam alone accounting for 13% (Eurostat, 2024; Port of Rotterdam Authority, 2025). Around half of the weight of goods handled in Rotterdam consists of liquid bulk (Buitendijk, 2025).

Road transport accounts for approximately one-third of final energy consumption in the transport sector, divided almost equally between petrol for passenger cars and diesel for trucks and vans.⁸

There is considerable uncertainty regarding the future volume of bunker fuels for shipping from the port of Rotterdam. The WLO scenarios (PBL Netherlands Environmental Assessment Agency [PBL], 2025b) indicate, for example, a 50–75% decline by 2060, whilst the 2023 National Energy System Plan (Ministry of Economic Affairs and Climate Policy [EZK], 2023) still assumed stable bunker fuel demand (see also Chapters 4 and 6).

Figure 3.2 Final energy consumption (PJ) by mode of transport and by energy carrier, including bunker fuels, in 2024



Source: CBS; visualisation and calculation by KiM, as described in Bakker and Moorman (2025a).

3.2 Energy for transport is mainly based on imported petroleum

In 2024, only 6% of the Netherlands' energy demand for transport was met by renewable energy (KiM Netherlands Institute for Transport Policy Analysis, 2025). In road passenger transport, up to 10% ethanol (E10) and 7% biodiesel (B7) are blended into the fuel,⁹ while 7% of passenger cars are battery electric vehicles (BEVs) (Netherlands Enterprise Agency [RVO], 2026). In marine and aviation fuels, the share of non-fossil fuels is much lower, but the ReFuelEU Aviation and FuelEU Maritime regulations will bring about significant changes in the future.

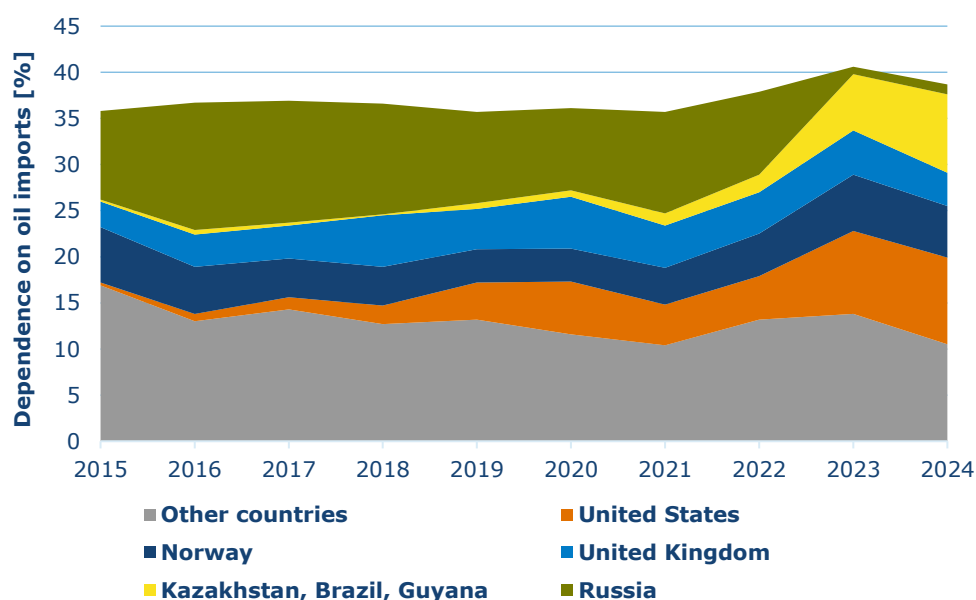
⁷ As a result, the transport sector accounts for a relatively high share of around 40% of total final energy consumption in the Netherlands (Uitbeijerse et al., 2024).

⁸ By 2025, less than 10% of passenger cars in the Netherlands run on diesel, and this share is declining.

⁹ Moreover, more than 300 Dutch fuel stations offer HVO100.

As the Netherlands has limited oil production, fossil fuels are largely imported. In total, the Netherlands' energy import dependency stands at 78%, approximately half of which is attributable to oil imports. Figure 3.3 shows the countries from which oil is imported. Significant shifts in recent years include a sharp decline in imports from Russia as a result of sanctions, offset by an increase in imports from the US, Kazakhstan, Brazil and Guyana. The Netherlands imports three-quarters of its oil from just seven countries. In the graph, 'other countries' mainly comprises Nigeria, Iraq and Saudi Arabia (CBS, 2025b).

Figure 3.3 The Netherlands' energy dependence on oil, by country of origin



Source: CBS, 2025b.

3.3 The energy transition in transport: from petroleum-based to four energy carriers

In the current energy system, crude oil is transported by ship from producing countries to refineries in the Netherlands. Some oil products are also imported directly. Refined oil products are either re-exported or used in the Netherlands as transport fuels and industrial raw materials (for example, for plastics). Transport fuels consist mainly of (various types of) heavy fuel oil for shipping, kerosene for aviation and diesel or petrol for road transport. Fuel is transported to petrol stations via pipelines or lorries, sometimes in combination with inland waterway vessels. All in all, the petroleum-based energy system has a relatively linear chain,¹⁰ from energy production to use in vehicles.

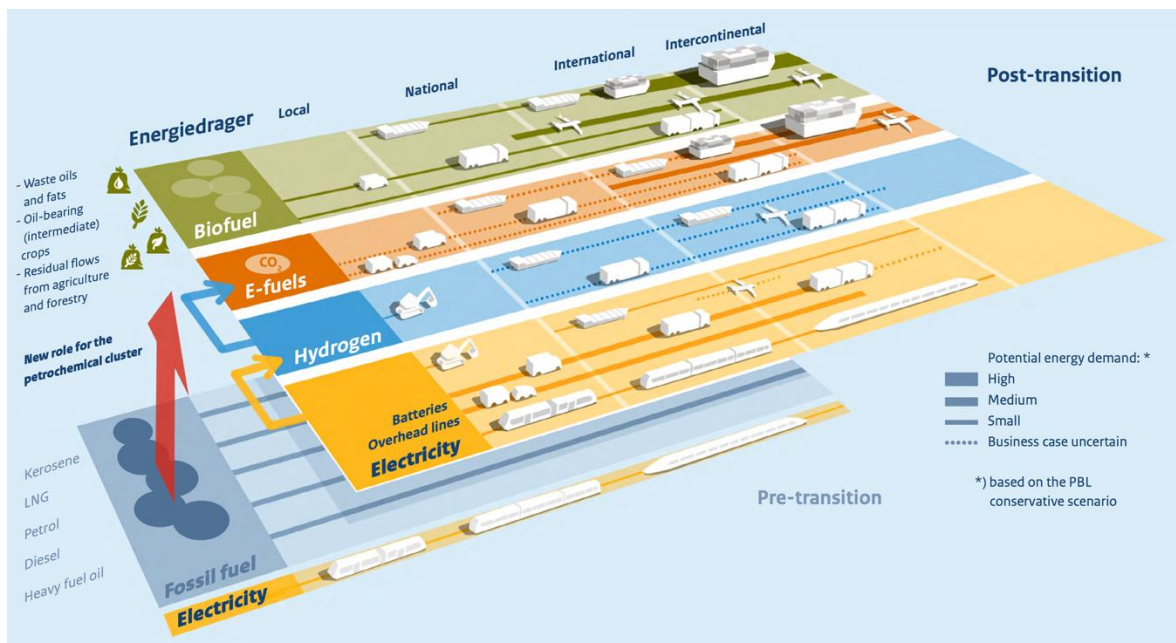
The energy transition entails a shift towards an entirely different system (see Figure 3.4) and is likely to have significant consequences for the nature of trade via Dutch ports, particularly if this transition takes place at the global and EU level (see also Chapter 6).

Electricity, biofuels, e-fuels produced from hydrogen and possibly hydrogen itself are expected to play a significant role in a low-carbon energy system for the mobility sector (see also Figure 3.5). Electricity is generated from various sources within the Netherlands itself, or imported from neighbouring countries via the electricity grid. Demand for and production of electricity are expected to increase.

¹⁰ The fossil fuel chain is, however, strongly integrated with the industrial use of oil and oil products, involving refineries, the chemical industry, the plastics industry, the pharmaceutical industry, etc.

Biomass as a feedstock for biofuels can, in theory, be imported from virtually any country (see Chapter 6), and renewable hydrogen and/or e-fuels can be produced competitively in countries that have sufficient potential for the production of renewable electricity. Demand for these energy carriers is also expected to rise, necessitating the scaling up of and changes to supply chains.

Figure 3.4 Illustration of the energy transition in transport



This figure outlines the composition of the energy system in transport, before and after the energy transition. In the current system, fossil fuels (in various forms, including kerosene, LNG, petrol, diesel and heavy fuel oil) are the primary energy carriers. After the energy transition, various energy carriers will be used: electricity, hydrogen, e-fuels and biofuels. These energy carriers are sometimes interdependent, such as hydrogen being produced from electricity, and hydrogen in turn being needed for the production of e-fuels. The use of these energy carriers will also vary: electricity is most suitable for certain transport modes, while other modes, particularly heavy transport such as shipping and aviation, are more likely to require biofuels or e-fuels. For each energy carrier, the expected energy demand per mode and distance travelled is expressed using varying line thicknesses, based on the conservative carbon neutral scenario in Geilenkirchen et al. (2024a). In the transition from fossil to renewable energy carriers, a new role awaits the petrochemical cluster.

Source: KiM

In other words, the Netherlands is likely to remain heavily dependent on imports. However, rather than being dependent on a small group of oil-exporting countries, this will shift to a larger group of potential suppliers, many of which are potentially in Europe. As argued in Chapter 2, this could improve security of supply.

The total volume of fuels and liquid bulk goods is, however, likely to decline, as the transition to greater reliance on electricity from low-carbon sources will be accompanied by a structural decline in demand for physical imports: studies conducted in the context of the EU's climate targets show that oil consumption will fall by 25–50% by 2030 and by 75% or more by 2050 (compared to current levels) (Tsiropoulos et al., 2020, IEA, 2021b), and demand for refined products is expected to peak globally and then decline (while there will be a net decline in the EU), even in more conservative scenarios (IEA, 2025d).

For biofuels and some e-fuels, existing storage, distribution and refuelling infrastructure can be utilised. For some alternative fuels that are not yet common today, such as dimethyl ether (DME), ammonia or methanol, modifications must be

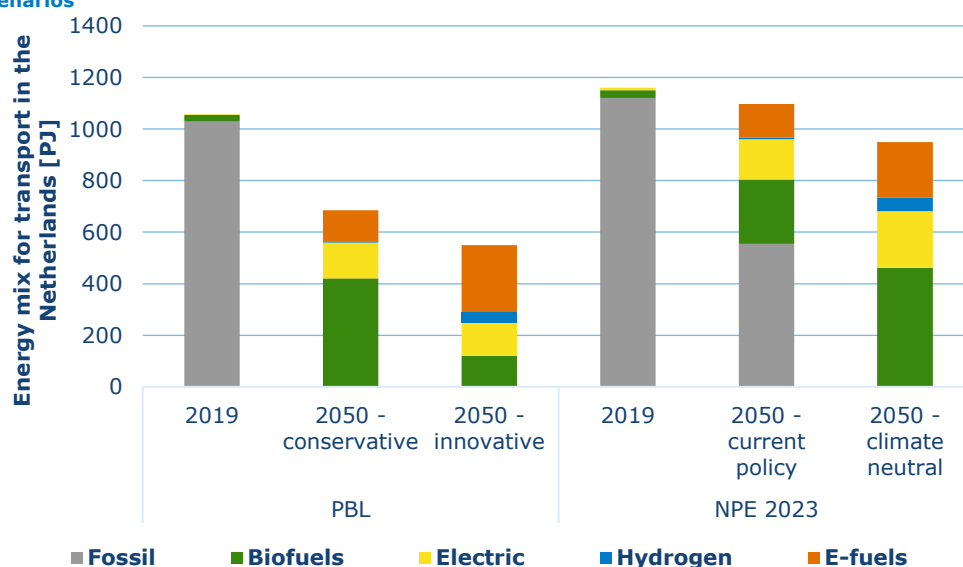
made or new infrastructure built to meet safety requirements. New refuelling or charging infrastructure is required for the direct use of hydrogen and electricity.

The energy chains for electricity, hydrogen and e-fuels are intertwined, as (renewable) electricity is needed for the production and compression of hydrogen, and e-fuels are in turn produced from hydrogen and carbon. In addition, there are links with other sectors: electricity is also used in buildings and industry, meaning that the demand for and production of electricity will need to be coordinated between sectors. Demand for hydrogen is currently almost exclusively limited to the chemical industry, and this sector is expected to remain the main consumer of hydrogen in the future ([Ajanovic et al., 2024](#); [International Transport Forum \[ITF\], 2024c](#); [Cazzola et al., 2023a](#)).

3.4 Biofuels (and e-fuels) account for the largest share of final energy consumption in a carbon neutral scenario

Electrification of transport modes is the most energy-efficient option (see Chapters 5 and 8). Electrification is attractive for road and rail transport, as well as for short-distance maritime and inland waterway transport. Electrification will be much more difficult for other modes of transport and journey profiles. In particular, long-haul flights and international maritime shipping are cases where a switch to electric propulsion is unlikely ([Cazzola et al., 2023a](#)). Hydrogen in internal combustion engines or fuel cells is also expected to play a role (Chapter 7), although this will be relatively limited due to cost differences with competing technologies. Apart from the decline in total energy demand resulting from electrification, the majority of fuel consumption in transport will still consist of (liquid) fuels used in internal combustion engines. This is evident, for example, from the scenarios of the National Energy System Plan (NPE), developed in 2023 ([Ministry of Climate and Green Growth \[KGG\], 2023](#)), and of the PBL ([Geilenkirchen et al., 2024a](#)); see Figure 3.5. To replace current oil consumption, the supply of biofuels and possibly e-fuels will need to increase significantly.

Figure 3.5 Final energy consumption by energy carrier, now and in 2050, in two PBL scenarios and two NPE scenarios



Source: KiM, data from Geilenkirchen et al. (2024a) and EZK (2023).

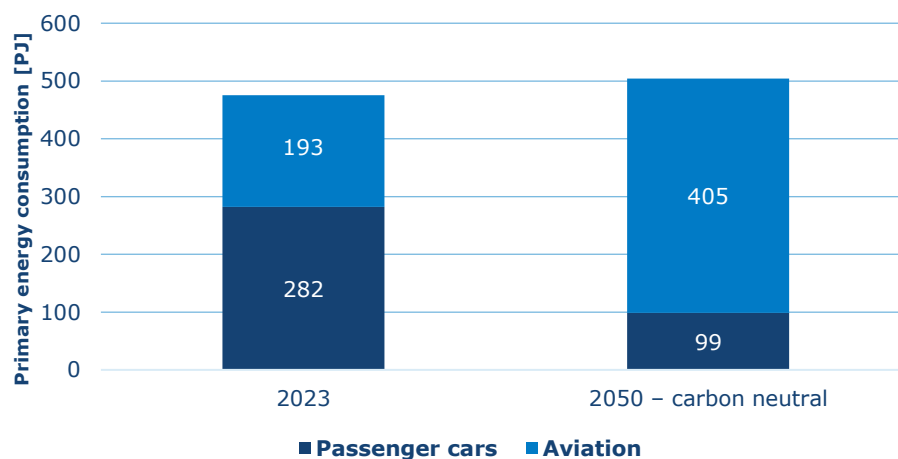
Notes. 1. Scope includes bunker fuels, excludes mobile machinery; 2. The use of electricity is approximately three times as efficient as the combustion of fuels, which 'skews' the overall picture; 3. The NPE scenario is based on policies in force in 2022; since then, EU policy, particularly regarding the decarbonisation of shipping and aviation, has become more ambitious.

3.5 Primary energy consumption in road transport will fall significantly due to electrification, whereas that of aviation will increase

The electrification of road transport will lead to a sharp decline in primary energy consumption for passenger cars (see Chapter 5). On the other hand, aviation will start using biofuels and e-fuels. The EU ReFuelEU Aviation Directive ([European Commission: Directorate-General for Mobility and Transport \[DG MOVE\], 2024](#)) stipulates that by 2050, at least 70% of the fuel supplied to EU airports must be sustainable aviation fuel, of which at least half must be based on synthetic fuel (e-SAF). The production of e-SAF will increase primary energy consumption compared to other fuels due to energy losses in the production chain (Chapter 7). This means that total primary energy consumption in aviation will increase.

Figure 3.6, which shows the primary energy consumption of passenger cars and aviation based on the NPE, illustrates this effect. In 2050, the combined primary energy demand of these two sectors will be roughly the same as in 2023. However, whereas in 2023 passenger cars used 50% more energy than aviation, by 2050 it is projected that aviation will use more than four times as much primary energy as passenger cars.

Figure 3.6 Primary energy consumption of passenger cars versus aviation in the Netherlands, in 2023 and 2050 in the NPE



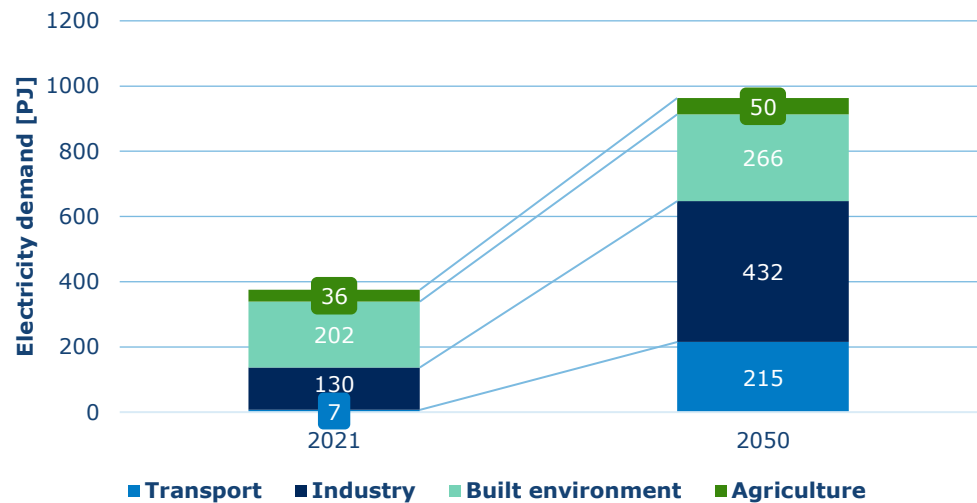
Source: Bakker and Moorman (2025a), in which primary energy consumption is calculated relative to final energy consumption in the carbon-neutral scenario in the NPE 2023 (EZK, 2023).

3.6 Transport sector’s share in Dutch electricity consumption may rise to 22% in 2050

In the carbon-neutral NPE scenario, road transport is almost entirely electrified in 2050. This implies a significant increase in electricity consumption in this sector. Other sectors, particularly industry, are also switching to electricity where possible. As a result, the total share of transport in electricity demand rises to 22% (Figure 3.7).

If we add e-fuels to this, electricity consumption in the transport sector would rise even further, as a substantial amount of electricity is required to produce these fuels. However, a significant but unknown proportion of this additional production does not take place in the Netherlands, as e-fuels (or the required hydrogen) can only be synthesised using (abundant) affordable, renewable electricity.

Figure 3.7 Electricity demand by sector in the carbon-neutral NPE scenario



Source: KiM; data from EZK (2023).

Scaling up production, for example via offshore wind, is currently a challenge, although additional funding has been provided for in the new coalition agreement. Transport competes with other sectors (such as buildings and industry) in this regard, both for direct use in road transport and for potential domestic production of e-fuels. On the other hand, electric vehicles can also help reduce grid congestion by serving as temporary storage for electricity and feeding it back into the grid during shortages. With electricity, the problem ultimately boils down to matching supply and demand at the right time and in the right place. In the long term, calm winter days in particular remain an issue that needs to be resolved.

The scenarios presented in this chapter outline a plausible trajectory for the entire transport sector. However, there are significant uncertainties regarding the feasibility and desirability of the various energy sources for the different modes of transport. Many (policy) decisions still need to be made, some of which we will discuss in the following chapters.

4 An outlook by mode

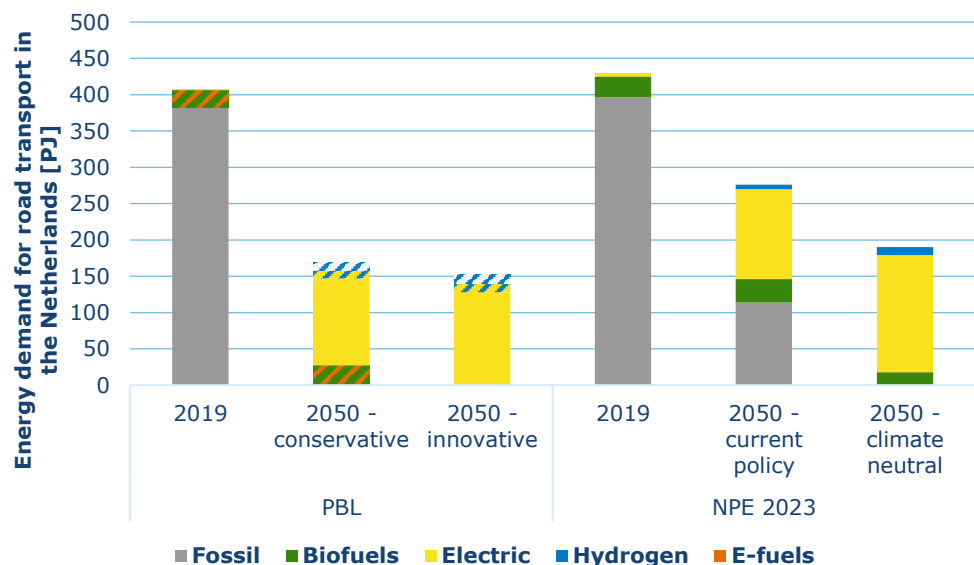
The energy transition will vary by mode of transport. This involves, for example, considerations regarding which future energy mix is most suitable for which application, and what the advantages and disadvantages are in the production, distribution and use of the various energy carriers across the different modes of transport.

In this chapter, we discuss the possible evolution of the energy mix across the various transport modes based on different energy transition scenarios and other studies. In the following chapters, we will examine in more detail the considerations and challenges associated with the various energy carriers: electrification, biofuels, and hydrogen and e-fuels.

4.1 Road transport

Road transport currently relies predominantly on fossil fuels, supplemented by biofuels (mainly blended with fossil fuels) and a small but growing share of electric transport. Bioethanol is blended into petrol at up to 10% (E10) and FAME (biodiesel) is blended into diesel at up to 7% (B7). In addition, HVO (renewable diesel) is available at some filling stations.

Figure 4.1 Total energy demand and energy mix for road transport, now and in 2050, in two PBL scenarios and two NPE scenarios



Source: KiM; data from Van Meerkerk et al. (2024) and EZK (2023).

In the PBL scenarios for road transport, biofuels and e-fuels are treated as a single category. Furthermore, the role of hydrogen remains uncertain and may or may not be significant (in which case the future share of electricity would fall slightly and total energy consumption would rise slightly). For this reason, hydrogen is shown in a striped pattern, which partially overlaps with the share of electricity.

The NPE scenarios show the total energy consumption of passenger cars, light commercial vehicles and heavy commercial vehicles.

Figure 4.1 shows that existing scenarios for energy demand in road transport in the Netherlands clearly point to a growing role for EVs, which results in a net decrease in final energy demand despite increasing activity, as improvements in energy

efficiency outpace the growth in demand. The WLO scenarios published by the PBL ([PBL, 2025a](#)) also primarily feature BEVs for the energy transition of road vehicles. According to PBL, electrification, potentially supported by logistical or technical solutions (e.g. *electric road systems*), is the option with the greatest potential, even for heavy duty vehicles. Biofuels, hydrogen and e-fuels will play a limited role in road transport in the long term.

Other recent literature supports this assessment: various sources show that electrification is increasing significantly for new passenger cars and light commercial vehicles, and that heavy-duty electric trucks for local and regional distribution are becoming increasingly feasible (e.g. [Plötz, 2022](#); [IEA, 2025b](#)). Only for heavy long-distance road transport does an as yet undefined role remain possible for other energy carriers and engine technologies such as hydrogen (see Chapter 7). The extent of this role depends primarily on the development of more efficient, high-capacity batteries, which constitute hydrogen's main competitor in this segment.

Biofuel or e-fuel as a transition fuel for the existing vehicle fleet

The average lifetime of cars in the Netherlands is around 20 years ([Auto Recycling Nederland, 2025](#)). Despite policies aimed at phasing out fossil fuels and the sale of new road vehicles with internal combustion engines by 2050, there will therefore still be demand for road transport fuels, as a significant proportion of the vehicle fleet in 2050 will still have internal combustion engines ([EZK, 2023](#); [Van Meerkerk et al., 2024](#)). This could involve several million passenger cars and tens of thousands of trucks with combustion engines in the Netherlands. Consequently, a number of scenarios assume that sustainable biofuels (liquid or gaseous) or e-fuels will continue to play a role in making road transport more sustainable in 2050. Renewable (bio)fuels or e-fuels that can be used as drop-in fuels, which can be used in existing engines and with existing infrastructure, are a suitable but potentially expensive option for this.

Given that e-fuels are expected to be limited in availability and affordability for road transport (see Chapter 7), particularly if there are no major shifts in the energy mix and the costs of renewable electricity do not fall drastically, sustainable biofuels could play a significant role in meeting the remaining demand for fossil energy. These renewable fuels will not be the primary long-term solution, but will be necessary in the short and medium term to meet climate targets ([Social and Economic Council \[SER\], 2020](#); [Van Meerkerk et al., 2024](#)).

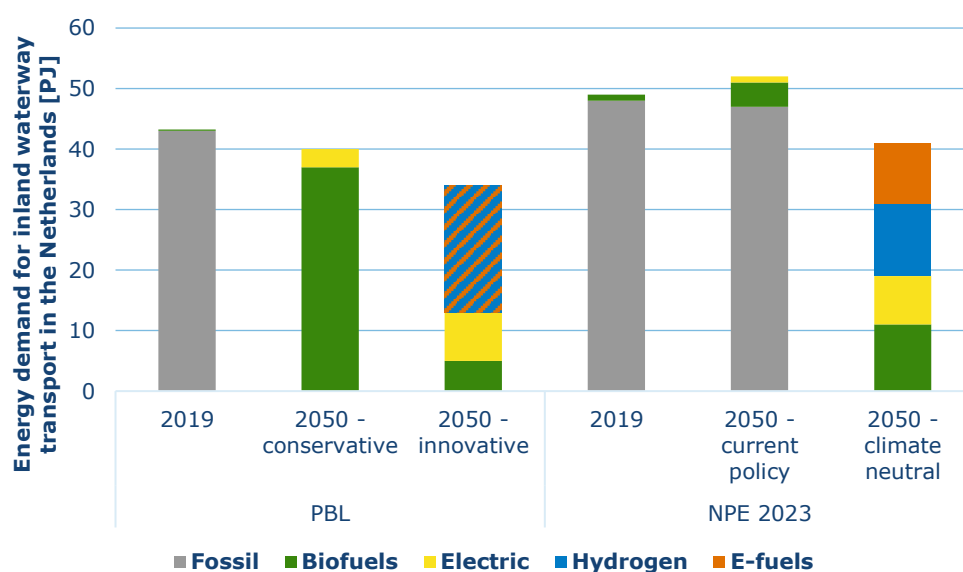
An example of a drop-in biofuel is the diesel substitute HVO, which is already widely used. HVO can be used as a fuel in diesel engines in blends of up to 100% ([NEa, 2025](#)). Furthermore, HVO allows the existing refuelling infrastructure to be used and the same vehicle usage patterns to be maintained. However, HVO is limited to certain feedstocks and production processes, and may become scarcer if production capacity cannot keep up with demand.

Higher blends of other fuels, such as B30, E85, DME or biomethane, may therefore also be suitable as a complement to the electrification of road vehicles, thereby enabling CO₂ emissions to be reduced sooner, meeting the obligations of the Dutch Climate Act, and replacing the demand for fossil energy in the future. However, without a technical breakthrough—such as an additive that enables the use of these fuels as drop-in fuels—these fuels require modifications to the engine ([Uslu et al., 2020](#); [Mulder et al., 2022](#); [Bakker & Moorman, 2025b](#)). In some countries, such as France, this is already being done: E85 (85% ethanol) is available at many petrol stations and conversion kits can be used to adapt the engine to run on this fuel. Research is currently also being conducted into the necessary engine modifications, retrofits and costs to apply this to the remaining Dutch ICE vehicle fleet.

4.2 Inland waterway transport

The trajectory of the energy transition is less certain and less well researched for inland waterway transport than for other sectors. This is despite the relatively large share of inland waterway transport in the Dutch modal split for freight transport and despite the fact that the Dutch government is aiming for climate neutrality in inland waterway transport by 2050. Factors contributing to this uncertainty include the relatively minor global significance of inland waterway transport, which makes this sector dependent on other sectors (such as heavy road transport) for engine technology and the availability of energy sources, and the long life span of inland waterway vessels. Currently, inland waterway vessels are powered by diesel (Figure 3.2), mainly in engines adapted from those used in heavy goods vehicles.

Figure 4.2 Energy mix of the Dutch inland waterway transport sector, now and in 2050, in two PBL scenarios and two NPE scenarios



Source: KiM; data from Traa et al. (2024) and EZK (2023).

In the 'PBL, 2050 – innovative' scenario, the majority of the energy mix can be met by hydrogen or e-fuels. This is indicated in this figure by a striped pattern. The 'NPE, 2050 – residual demand met' scenario is also an innovative scenario, with a large share of hydrogen and e-fuels. In a more conservative scenario for this residual demand, biofuels account for the largest share of energy demand in 2050, comparable to the PBL's conservative scenario.

The scenarios for the energy mix for inland waterway transport differ significantly from those for road transport (Figure 4.2). PBL (Traa et al., 2024) indicates that battery-electric inland waterway transport (possibly with battery swapping containers) could play a role, but that not all market segments are suitable for electrification. In these cases, biofuels make up a large share, possibly supplemented or ultimately replaced by hydrogen or e-fuels. The PBL presents two scenarios for 2050: a conservative scenario, in which diesel is replaced by biofuel and a small proportion of electricity, and an innovative scenario, in which more than half of inland waterway transport's energy requirements are instead met by hydrogen or e-fuels, depending on the future availability of these fuels and the balance between costs and usability. The innovative scenario is based on the assumption that technological development will gather pace, leading to an increase in alternative propulsion systems (primarily battery-electric and fuel-cell-electric). Other options include greater reliance on biofuels and/or battery swapping in

combination with electrification, including in hybrid configurations (with an on-board backup generator).

The NPE ([Ministry of Economic Affairs and Climate Policy, 2023](#)) states that ambitious targets have been set, but that the transition has yet to get underway and that multiple technologies and energy carriers will play a role in different segments of the inland waterway transport sector. These include hydrogen and e-fuels, either in fuel cells or in combustion engines (or in a combustion generator powering an electric drive). In a scenario of a full energy transition, hydrogen and e-fuels would account for more than half of the energy requirements of inland waterway transport, comparable to the PBL's innovative scenario. However, as the NPE notes, in addition to the availability of the necessary energy carriers, supplementary policy measures (such as subsidies and regulations) will also be required to achieve such a transition. Given that the inland waterway sector is relatively small, its energy transition is likely to depend on the transition in maritime shipping and heavy road transport, for example on the development of new engine technologies and the availability of energy carriers in those sectors.

The more ambitious scenarios for 2050, from both the PBL and the NPE, show a decrease in total energy demand. This decrease is partly driven by electrification, which is more efficient on a TTW basis.

Limited financial and technical scope for new propulsion technologies

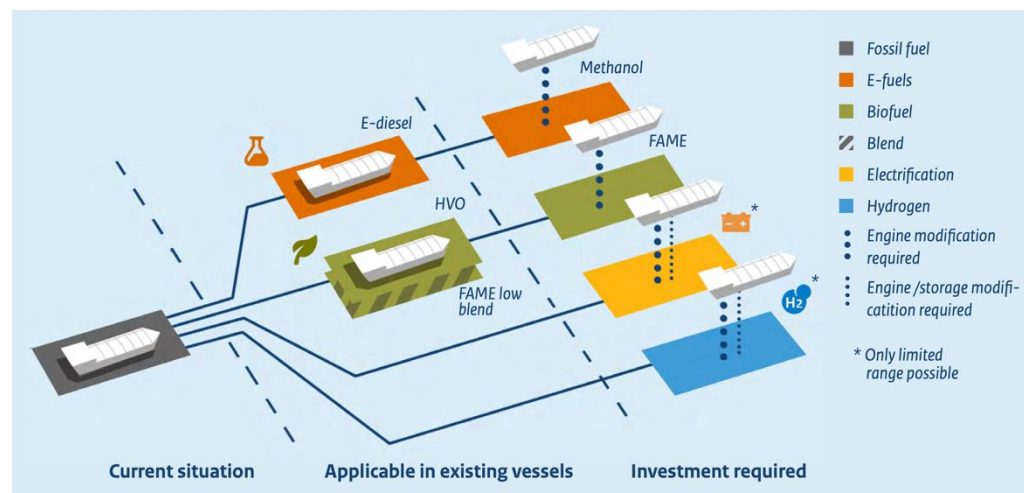
The narrow financial margins and the large proportion of individual owner-operators in inland waterway transport mean that ship owners and stakeholders often have little financial scope for risky investments ([Central Commission for Navigation on the Rhine \[CCR\], 2022](#); [Traa et al., 2024](#)). This also has implications for the choice of liquid fuels used in diesel engines, leading to uncertainties that help explain the differences in the share of e-fuels and biofuels in the energy mix of inland waterway transport across the various scenarios in Figure 4.2. The various business case considerations for a transition to renewable energy carriers in shipping (inland waterway and maritime shipping) are illustrated in Figure 4.3 .

Given its suitability as a drop-in fuel in existing diesel engines, HVO could play a significant role. With an ambitious climate policy and associated carbon taxes, the price of biofuels such as HVO could be comparable to that of fossil diesel by 2040. The price of renewable synthetic fuels such as e-diesel and e-methanol can be two to three times higher than that of biofuels ([Traa et al., 2024](#)).

The investment costs for an alternative engine on board the ship may also be considerably higher than for a standard diesel engine, for example in the case of LNG or B100 (100% FAME). These costs relate not only to modifications to the engine, but also to modifications to the storage of the energy carrier on the ship. Similar barriers also apply to battery-electric ships or ships powered by hydrogen fuel cells. If lower costs for renewable energy carriers offset these higher investment costs, this consideration may change over time. Although investment costs may fall as technologies develop, it is uncertain to what extent and over what timeframe.

Bio-LNG is also a possibility, thanks to technological developments, but faces barriers relating to refuelling infrastructure and on-board storage. As in other cases, policy choices can support the further deployment of biofuels and other renewable energy sources. Although inland waterway transport falls under RED III, apart from the ETS2 there is little policy in place to stimulate the use of renewable energy in the sector after 2030. Policy options are currently being explored for the establishment of a national system for the period after 2030 ([EZK, 2023](#); [CCR, 2022](#); [Traa et al., 2024](#)).

Figure 4.3 Business case considerations regarding the transition to renewable energy sources, illustrated using the choices facing shipowners



Drop-in fuels, such as HVO or e-diesel, are one option for making shipping more sustainable. These can be used without modifications to the engine or storage systems, but there is a risk that these fuels will become expensive. Other energy carriers have potentially lower energy costs, but this is offset by the need for investment in the engine and/or the storage system. Consequently, formulating an investment strategy is involves uncertainties.

Source: KiM.

4.3 Maritime transport

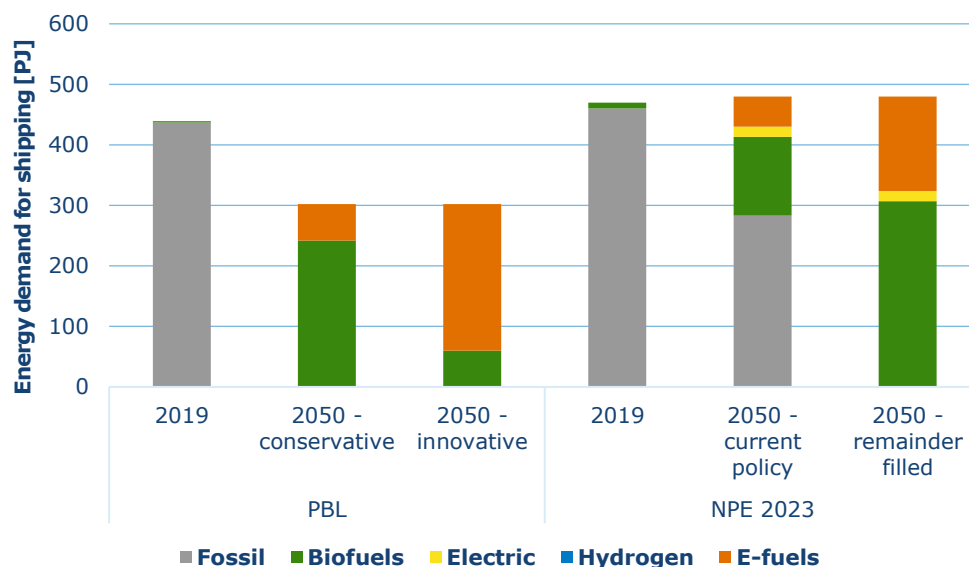
While the energy transition for road transport is primarily focused on electrification and the future energy mix for inland waterway transport remains uncertain, policy and scenarios envisage a greater role for biofuels, hydrogen and e-fuels in maritime transport.

Figure 4.4 presents scenario projections for energy demand in maritime transport in the Netherlands. The majority of energy demand in 2050 is covered by a combination of fossil fuels, biofuels and e-fuels. The balance between biofuels and e-fuels depends on the scenario ([Uslu et al., 2020](#); [EZK, 2023](#); [Det Norske Veritas \[DNV\], 2024](#)). According to these sources, electricity and hydrogen are not suitable for covering long distances at sea, as refuelling or recharging would be required every 1 to 3 days. Electric propulsion is expected to be used only for ships at berth and for entering and leaving ports.

For maritime transport, PBL ([Geilenkirchen et al., 2024b](#)) indicates that hydrogen-powered ships will not have sufficient range for intercontinental routes. Ammonia and e-fuels do, however, have the required energy density and, together with biofuels, will account for the majority of the maritime sector's energy demand by 2050, despite the higher costs and reduced WTT efficiency. Currently, biodiesel, biomethanol and bio-LNG, among others, are considered as potential sustainable biofuels for this sector.

PBL has developed two carbon neutral scenarios for maritime transport in 2050: one in which biofuels (including bio-ammonia) become dominant, and one in which e-fuels (including e-ammonia) become dominant. In both cases, there is no direct use of hydrogen, or only in negligible quantities.

Figure 4.4 Total energy demand and energy mix of the maritime sector in the Netherlands, now and in 2050, in two PBL scenarios and two NPE scenarios



Source: KiM; data from Geilenkirchen et al. (2024b) and EZK (2023).

In the NPE scenarios, a small proportion of electricity is present. This does not relate to battery-electric ships, but to shore power in ports when the ships are moored.

Another projection of the maritime sector’s energy consumption by 2050 is included in the NPE (EZK, 2023). This shows that, under current policy, less than half of the energy demand would shift to renewable sources – of which approximately two-thirds would come from biofuels and one-third from e-fuels. If measures were taken to make shipping fully carbon neutral, the NPE suggests that the sector’s energy demand would be met in roughly the same proportion by biofuels and e-fuels. The IMO framework for net-zero emissions is an example of such a measure. This was due to be finally approved in the third quarter of 2025 (International Maritime Organisation [IMO], 2025a), but this decision has been postponed for the time being (IMO, 2025b).

Like PBL, the NPE indicates that the direct use of hydrogen is unlikely, except for short routes. The direct use of hydrogen is therefore not included in the NPE’s quantitative scenario. This is also in line with the recommendation of the Social and Economic Council (SER), which proposes the use of biofuels in shipping as a bridging (i.e. short to medium term) solution for as long as other sustainable alternatives are not sufficiently available (SER, 2020).

Both PBL and the NPE indicate that there is still no legislation governing the use of ammonia, hydrogen and e-fuels, whether in internal combustion engines or in fuel cells, in the maritime sector. This is partly due to the fact that there are no specific requirements under the FuelEU Maritime Regulation – which focuses on greenhouse gas emissions (EU, 2023c) – and that the IMO Net-zero framework is still awaiting formal approval. However, significant progress is being made on technical standards to enable the use of ammonia as an energy carrier in shipping, and the FuelEU Maritime Regulation includes incentives for hydrogen-based e-fuels (European Hydrogen Observatory, 2025). The level of ambition of the FuelEU Maritime Regulation is likely to require major shifts in the maritime fuel supply. At the same time, this regulation is complemented by other policy measures, for example those arising from the funds made available by the Hydrogen Bank and the Innovation Fund, to stimulate investment in alternative, hydrogen-based fuel supply

infrastructure ([European Commission: Directorate-General for Climate Action \[DG CLIMA\], 2025](#)).

TNO has also published results pointing to various alternative options which – in different variants of the TRANSFORM scenario – compete with one another in international long-distance shipping. These include biofuels, biomethane, synthetic methanol and synthetic LNG ([Scheepers, 2022](#)).

Developments in propulsion technologies for new ships

The scenarios discussed for an energy mix based on biofuels and e-fuels are based on the expectation that maritime shipping will still be using almost exclusively internal combustion engines in 2050. The business case considerations in Figure 4.3 also apply to maritime shipping.

At present, the vast majority of ships still use fossil fuels. Some of these, particularly the newer ones, run on LNG (which reduces air and water pollution, but this only leads to a limited reduction in greenhouse gas emissions). In new orders, there is growing interest in LPG, methanol (for larger ships) and battery-electric propulsion (for smaller ships), which together account for around 10% of the order book for 2023 ([Geilenkirchen et al., 2024b](#)). The number of ships operating directly on alternative fuels, e-fuels or hydrogen remains low. However, an increasing number of ships capable of running on multiple fuels are being ordered. Given that ships have a long lifetime, the transition may proceed more slowly than in other sectors, meaning that retrofits will likely also be necessary to meet the ambitions of the Paris Agreement. The Dutch government is promoting pilot and upscaling projects for zero-emission ships through the Maritime Master Plan. Under the Maritime Master Plan Frontrunners Scheme, grants are awarded for such projects, focusing on the construction or retrofitting of ships powered by hydrogen or methanol, or LNG-powered ships equipped with carbon capture technology. In the 2024 round, 9 projects were selected (5 hydrogen, 2 methanol and 2 LNG with carbon capture projects) from 17 applications ([Netherlands Maritime Nation, 2025](#)). New rounds for this grant will be launched in 2026 and 2029.

Despite some uncertainty regarding the role of certain biofuels and the feedstocks capable of supporting large-scale supply to the maritime sector – with its high biofuel consumption – sustainable biofuels offer concrete opportunities to play a significant role in shipping. To make this possible, and in close alignment with the demand for sustainable aviation fuels in the aviation sector, it is crucial that the production capacity of renewable biofuels for these sectors is scaled up and that the necessary feedstocks become available ([DNV, 2024](#); [Geilenkirchen et al., 2024b](#); [EZK, 2023](#)), see also Chapter 6.

Technical development and commercial availability are crucial prerequisites for the upscaling of sustainable biofuels for maritime transport. Currently, only FAME, HVO and bio-LNG can be used as biofuels. Biomethane production is growing, as Maersk and other companies are operating an increasing proportion of their fleets on gas engines. Other options, such as e-methanol or the use of other renewable e-fuels, to supplement or replace bio-options in the future, are still at an earlier stage of technological development. Furthermore, most e-fuels are constrained by the lack of surplus renewable electricity and renewable hydrogen production, which are necessary to achieve reasonable costs. The technology chosen also depends on factors such as the type of vessel, the cargo and the sailing profile. The availability of renewable energy and the necessary raw materials is a key prerequisite in this regard ([EZK, 2023](#); [Geilenkirchen et al., 2024b](#)).

As with biofuels, there are still challenges in reducing the risk profile of investments in the production of low-carbon hydrogen and e-fuels for maritime transport, partly

because this requires a high availability of renewable, low-cost electricity.¹¹ Policy instruments to support investment, including models such as dual auctions currently used for hydrogen ([H2Global Stiftung, 2025](#)), can complement obligations to enable structural changes.

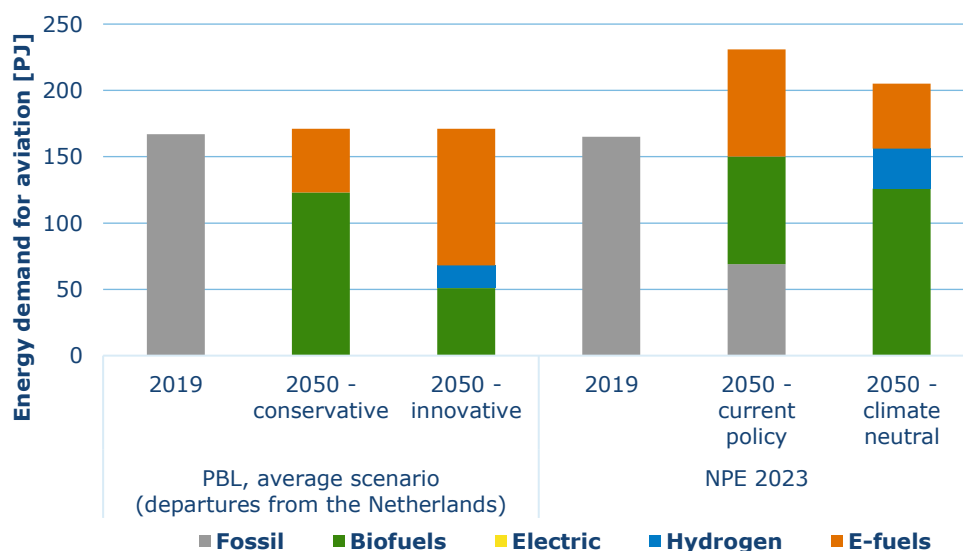
The bunkering function of the Port of Rotterdam

With the Port of Rotterdam, the Netherlands has one of the largest bunkering ports in the world. The Netherlands accounts for nearly 30% of the European bunkering market. Around 99% of seagoing vessels currently run on diesel or heavy fuel oil. Making shipping more sustainable is highly complex due to the sector’s global nature. As seagoing vessels travel long distances, there are usually many alternative locations for bunkering fuel. An international approach is therefore needed to make shipping more sustainable. With the EU ETS and FuelEU Maritime, the European policy framework now provides greater clarity on CO₂ reduction and pricing, while also promoting the increasing use of renewable fuels. A similar policy framework from the IMO could also facilitate the transition in global maritime transport, but the adoption of this framework has been postponed ([Geilenkirchen et al., 2024b](#)).

It should be noted that the future role of the Port of Rotterdam as a bunkering port is uncertain (see also sections 6.7–6.9). The NPE scenarios assume that the Port of Rotterdam will retain its current key position and adapt to a new energy mix, resulting in future total energy demand that is comparable to current levels. The PBL scenarios do, however, include a reduction in total bunkering volume, partly because ships sailing outside the EU will bunker elsewhere to avoid future higher taxes on fossil fuels ([Geilenkirchen et al., 2024b](#)). This also applies to the WLO scenarios.

4.4 Aviation

Figure 4.5 Total energy demand and energy mix of the aviation sector, now and in 2050, in two PBL scenarios and two NPE scenarios



Source: KiM; data from Davydenko et al. (2024) and EZK (2023). In both studies, electricity is mentioned as a potential energy carrier, but as electric aviation is not yet commercially viable, electricity is either not included quantitatively or considered to have a negligible share.

¹¹ This is based on the rules determining what can be classified as renewable hydrogen ([European Commission: Directorate-General for Energy \[DG ENER\], 2025b](#)). This is supplemented by rules defining low-carbon hydrogen ([European Union, 2025](#)).

Figure 4.5 shows scenario results relating to energy demand in aviation, highlighting the relevance of biofuels, e-fuels and hydrogen as potential low-carbon energy carriers that can reduce greenhouse gas emissions and the demand for fossil fuels.

Both the PBL scenarios ([Davydenko et al., 2024](#)) and the NPE ([EZK, 2023](#)) project a significant increase in aviation energy demand. PBL presents two possible energy mixes for 2050, in which either biofuels (in the form of bio-kerosene) or e-fuels (e-kerosene) will predominate. In the latter case, there is also a limited role for the direct use of hydrogen, for example in aircraft with fuel cells, which would only be suitable for relatively short distances. According to the PBL, the concepts currently being developed aim to transport 200 passengers over a distance of up to 3,700 km using a hybrid FC/ICE engine. Similarly, the NPE indicates that current policy will result in the energy mix for aviation in 2050 consisting of roughly equal parts biofuels and e-fuels, while a third of demand will still be met by fossil fuels. If this remaining portion is also supplied by carbon-neutral energy, this is likely to come from a further upscaling of biofuels, alongside a limited role for hydrogen fuel cell aircraft on shorter routes. TNO's TRANSFORM scenario focuses more on biogenic sustainable aviation fuels, while the international work of the International Civil Aviation Organisation (ICAO) includes decarbonisation scenarios that focus either on biofuels ([Scheepers, 2022](#)), or on a mix of biofuels and hydrogen-based e-fuels ([International Civil Aviation Organization \[ICAO\], 2022](#)).

Energy consumption in the aviation sector is expected to increase in the coming decades ([Uslu et al., 2020](#); [Davydenko et al., 2024](#)). This means that – in order to meet the ReFuelEU mandates – more renewable aviation fuels will also be needed, particularly bio-kerosene, but also e-SAF. Biokerosene made from used oils and fats (HEFA) is currently the only process operational at commercial scale. This biokerosene can be used as a drop-in fuel and, apart from ASTM certification, requires no modifications to aircraft or airports. However, due to the limited availability of oleochemical waste streams, the HEFA route can only meet a limited portion of future demand for SAF. The other promising routes for bio-kerosene production, such as the ethanol-based alcohol-to-jet (ATJ) process using advanced bio-feedstocks like agricultural waste streams, do not yet have a commercially viable business case. In Europe, this is also hampered by the requirement that SAF must not rely on feedstocks used for food and animal feed. This necessitates that advanced feedstocks become available and more cost-effective. The barriers are primarily linked to the need to scale up sustainable bio-feedstocks and create conditions that mitigate investment risks. Additional policy measures, such as targeted subsidies, financing instruments and carbon pricing mechanisms, can stimulate the production and use of bio-SAF ([Van Dyk & Saddler, 2021](#); [Davydenko et al., 2024](#)).

Direct use of hydrogen and electricity in aviation

The transition pathways for the aviation industry are primarily based on SAFs, e-fuels that can be used as drop-in replacements for kerosene, requiring no modifications to the aircraft themselves. However, a recent study on the climate impact of aviation shows that, of all alternative aviation fuels, hydrogen is likely to deliver the greatest reduction in both CO₂ and non-CO₂ emissions ([Arblaster et al., 2025](#)).

However, for the direct use of hydrogen or electricity, specific aircraft technologies need to be developed, including specialised engines, fuel tanks and refuelling systems. The main advantages lie in the high energy content per unit weight of hydrogen. Challenges associated with hydrogen include its low volumetric energy density, the need for very low temperatures (close to absolute zero) to store hydrogen in liquid form, and the need to fill tanks while hydrogen remains in this

state. Other problems stem from the additional weight of batteries, storage tanks and fuel cell systems, and the need to provide sufficient power for take-off and landing. Furthermore, hydrogen-powered aircraft would initially likely be used primarily for regional flights. Both the PBL and the NPE indicate that the development of hydrogen-powered aircraft is still at an early stage and that even small battery-electric aircraft (which are not expected to play a significant role in the sector's overall energy transition) are currently at a more advanced stage of development than hydrogen-powered aircraft.

Furthermore, aircraft designs have evolved considerably over recent decades, with the jet engine becoming the standard propulsion system. Given that other propulsion systems, such as battery-electric or fuel cells, require radical changes to aircraft design and airport infrastructure, it is unlikely that these will be used on a large scale before 2050 ([Van Dyk & Saddler, 2021](#); [Destination 2050, 2025](#); [Davydenko et al., 2024](#)).

The impact of EU and international policy

In the European aviation sector, the share of sustainable aviation fuels (SAFs) is set out in the ReFuelEU Aviation Regulation. This contains specific mandates for renewable fuels of non-biological origin (RFNBO), i.e. hydrogen and hydrogen-based e-kerosene. Compared to maritime and inland waterway transport, the share of the various types of renewable fuel in the aviation energy mix in 2050 is therefore more certain. ReFuelEU Aviation stipulates that by 2050, 35% bio-kerosene and 35% RFNBOs (hydrogen or e-kerosene) must contribute to the sector's energy mix.

Other policy measures – such as the deployment of funds made available from the Hydrogen Bank – complement ReFuelEU Aviation to stimulate investment in alternative, hydrogen-based fuel supply facilities ([DG CLIMA, 2025](#)). At the international level, the ICAO has adopted a long-term goal (LTAG) of net-zero CO₂ by 2050, which includes a scheme for CO₂ offsetting and reduction for international aviation (CORSIA) and a framework for promoting cleaner energy, including options based on low-carbon electricity.¹² Although these targets are voluntary and only partially binding (as they depend on national implementation and mutual accountability), they nevertheless contribute to political unity, inclusiveness and stability in a fragmented global sector.

As with shipping, there are still challenges in managing the risk profile of investments in the production of bio- and e-SAFs. As with biofuels and hydrogen derivatives for shipping, investment support mechanisms, including models such as dual auctions currently used for hydrogen ([H2Global, 2025](#); [Bundesministerium für Wirtschaft und Energie, 2025](#)), can complement regulatory requirements to enable structural changes in aviation.

¹² The ICAO's LTAG report includes a scenario in which hydrogen and e-fuels are increasingly used to supplement biofuels in the aviation energy mix, within a context where the sector is becoming fully low-carbon ([ICAO, 2022](#)).

5 Electric vehicles

Electric cars have evolved from a niche option into a central pillar of innovation in automotive strategies worldwide. In 2024, global sales of electric passenger cars (battery electric vehicles and plug-in hybrids) reached 17.5 million units, meaning that more than a fifth of global passenger car sales were electric. By the end of 2025, the Netherlands had reached 41% fully electric ([RVO, 2026](#)), a figure roughly double the market share in France and Germany.

Global sales of battery-electric trucks reached nearly 100,000 units in 2024, accounting for 1.7% of total truck sales ([IEA, 2025b](#)). In the first half of 2025, 90,000 battery-electric trucks were sold, which is almost equivalent to total sales for the whole of 2024, putting sales figures on track to reach 4% of total sales in 2025 ([Soulopolos et al., 2025](#)). China accounts for more than 90% of total global sales of electric lorries: half of the lorries sold in China are already electric. In the Netherlands, 940 e-trucks were sold in 2025, accounting for around 7% of new sales ([Nijenhuis, 2026](#)).

5.1 Various factors contribute to the increased acceptance of EVs

Battery electric vehicles (BEVs) offer significant operating cost savings, mainly due to higher powertrain efficiency and lower energy costs, particularly when using renewable energy sources. The cost of batteries, which accounts for the largest difference in the purchase prices of BEVs, has fallen dramatically over the past decade ([Delgado et al., 2025](#); [BloombergNEF, 2025](#)), as a result of significant technological and industrial developments.

The opportunities and risks associated with the transition have also prompted governments to adopt various policy and fiscal measures to stimulate both demand for electric vehicles and investment from the industry. Despite differences between regions around the world, these dynamics are contributing to a general decline in the purchase prices of EVs.

Thanks to cost reductions combined with high energy efficiency at the end-use stage, the total cost of ownership (TCO) of EVs – particularly cars, light commercial vehicles, buses and now also trucks – has almost reached the same level as that of internal combustion engine vehicles (ICEVs) ([Jayanthan, 2025](#), [McKerracher, 2021](#), [BloombergNEF, 2025](#) and [IEA, 2025b](#)), even though significant differences remain between different vehicle types and regions.

Vehicles that cover long distances on a daily basis – buses, trucks and light commercial vehicles – benefit most from the economic advantages of EVs, as operational savings add up quickly and investments in charging infrastructure can be spread across intensive use. However, as battery costs fall, private passenger cars and two-wheelers will also increasingly benefit, thereby broadening the societal reach of the benefits of EVs.

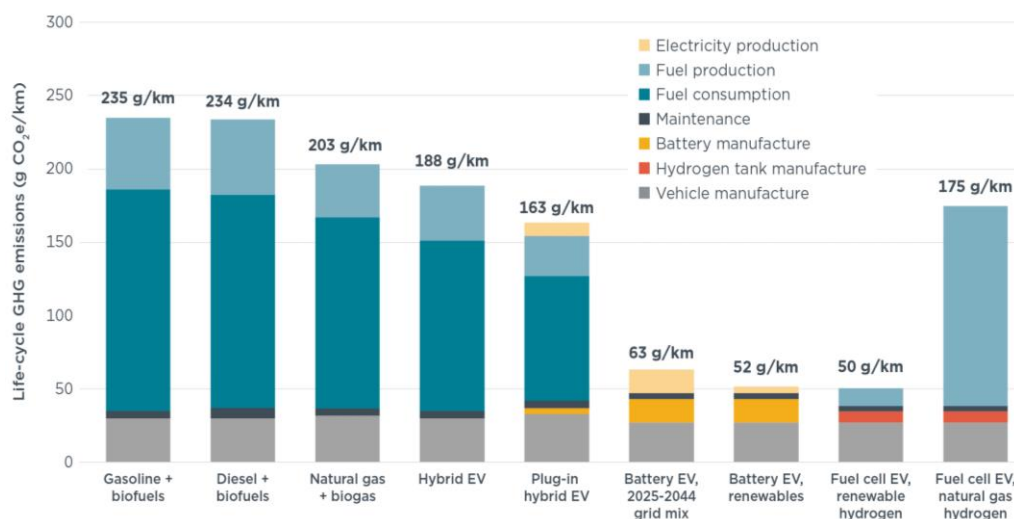
The economic competitiveness of BEVs also depends on specific conditions relating to both vehicle purchase and electricity prices (as both influence the TCO).

In China in particular, BEVs have been brought to market at lower purchase prices than comparable ICEVs, especially in smaller car segments ([IEA, 2025b](#) and [BloombergNEF, 2025](#)). Furthermore, compared to other countries, China has low electricity prices for households and businesses ([GlobalPetrolPrices, 2025a, 2025b](#)).

5.2 The climate benefits of EVs reinforce the case for the transition

Figure 5.1 shows that the greenhouse gas benefits of electric cars over their lifecycle have been extensively documented. BEVs running on the projected average EU electricity mix for 2025–2044 emit significantly (two-thirds) fewer greenhouse gases over their entire life cycle than petrol ICEVs ([Negri & Bieker, 2025](#), [Vieira et al., 2025](#)).

Figure 5.1 Greenhouse gas emissions over the life cycle of mid-range passenger cars sold in the European Union in 2025



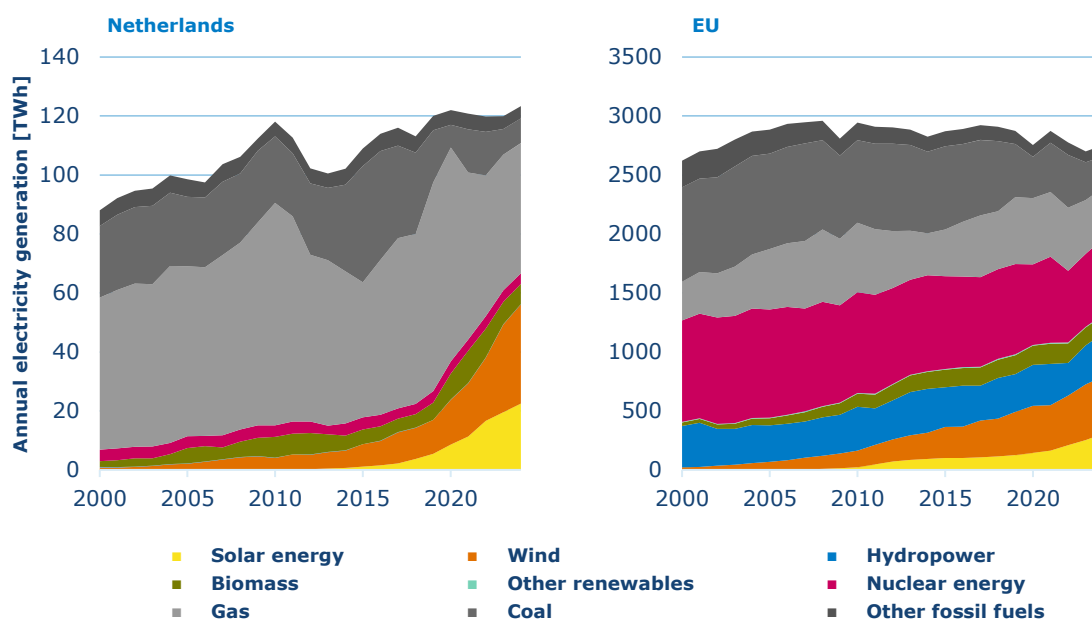
Source: Negri and Bieker (2025), based on 12,000 km/year and an average vehicle lifespan of 20 years.

This remains true even if the transition to a renewable electricity mix proceeds more slowly than currently anticipated, or if unfavourable assumptions are made regarding the lifespan or fuel and electricity consumption of EVs ([Negri & Bieker, 2025](#)). Although the production of electric cars entails approximately 40% more initial CO₂ emissions (and potentially even more for vehicles with particularly large batteries), mainly due to battery production, these additional production emissions are typically offset within a few years of driving.

The climate benefits are greater for heavy-duty vehicles ([DG CLIMA & Ricardo Energy & Environment, 2020](#); [O'Connell et al., 2023](#)), due to the greater impact of emissions during the vehicle's operational phase (for example, approximately 80,000 km/year for heavy-duty trucks compared to 12,000 km/year for passenger cars). Given the current European electricity mix, battery-electric buses and trucks have at least 63% lower greenhouse gas emissions over their lifetime than the cleanest diesel alternatives, even without taking into account an increasing share of renewable electricity ([O'Connell et al., 2023](#)).

The benefits in terms of greenhouse gas emission reductions and energy efficiency in the Netherlands largely correspond to the EU average (the current share of electricity from fossil fuels is slightly higher than the European average).

Figure 5.2 Electricity generation by source in the Netherlands and the European Union, 2000–2024



Source: EMBER (2025).

5.3 Opportunities and challenges as e-mobility evolves into a self-reinforcing technological transition

Unlike many low-carbon fuels – biofuels, synthetic fuels – whose production costs are generally higher than those of fossil fuels, the use of electricity entails structurally lower operating costs. This crucial difference presents opportunities in road transport, enabling EVs to become a self-reinforcing technology, and gradually reducing the need for (financial) support.

Additional opportunities may also arise, as there is considerable scope for further technological developments in a number of areas. Key examples include battery technology (Box 5.1), product design and marketing (from micromobility to the development of new, software-based services for both passenger and freight transport), improved manufacturing techniques for vehicles and batteries, proper management of batteries during and at the end of their life cycle, the development of the circular economy, and the integration of EV batteries into the electricity system (for example, for grid balancing).

Box 5.1 Impact of battery technology development on EV use and energy

Battery technologies are currently still under development. The production of battery packs and cells and the upstream processes in battery supply chains, particularly in countries where significant investments have been made in this industry, continue to improve. Economies of scale, product design, process developments, automation and shifts in the chemical composition of batteries are contributing to this development.

Lithium iron phosphate (LFP) batteries have gained market share in recent years, thanks to lower costs, easier access to raw materials and improvements in design. Nickel-based batteries, which are more commonly used in the premium segment of the automotive market, are now also being used for more batteries with higher energy density.

In addition to improvements in existing battery technologies, new technologies are also becoming increasingly common, for example in the form of solid-state batteries (SSBs) and sodium-iron batteries.

SSBs are expected to have a significantly higher energy density per unit of weight, surpassing that of the best nickel chemistry. This could lead to a greater range, but also to a lower weight. The costs are higher than for other technologies, suggesting that SSBs will initially be used in high-end car models ([Ali & MacRae, 2024](#)) and that industrial-scale production is needed to reduce costs. Some manufacturers have announced measures aimed at the mass production of SSBs. Examples include Toyota ([Toyota, 2023](#)), NIO, despite some setbacks ([Randall, 2025](#)), and Gotion ([Westerheide, 2025](#)). However, large-scale, cost-effective production of SSBs is not yet commercially available.

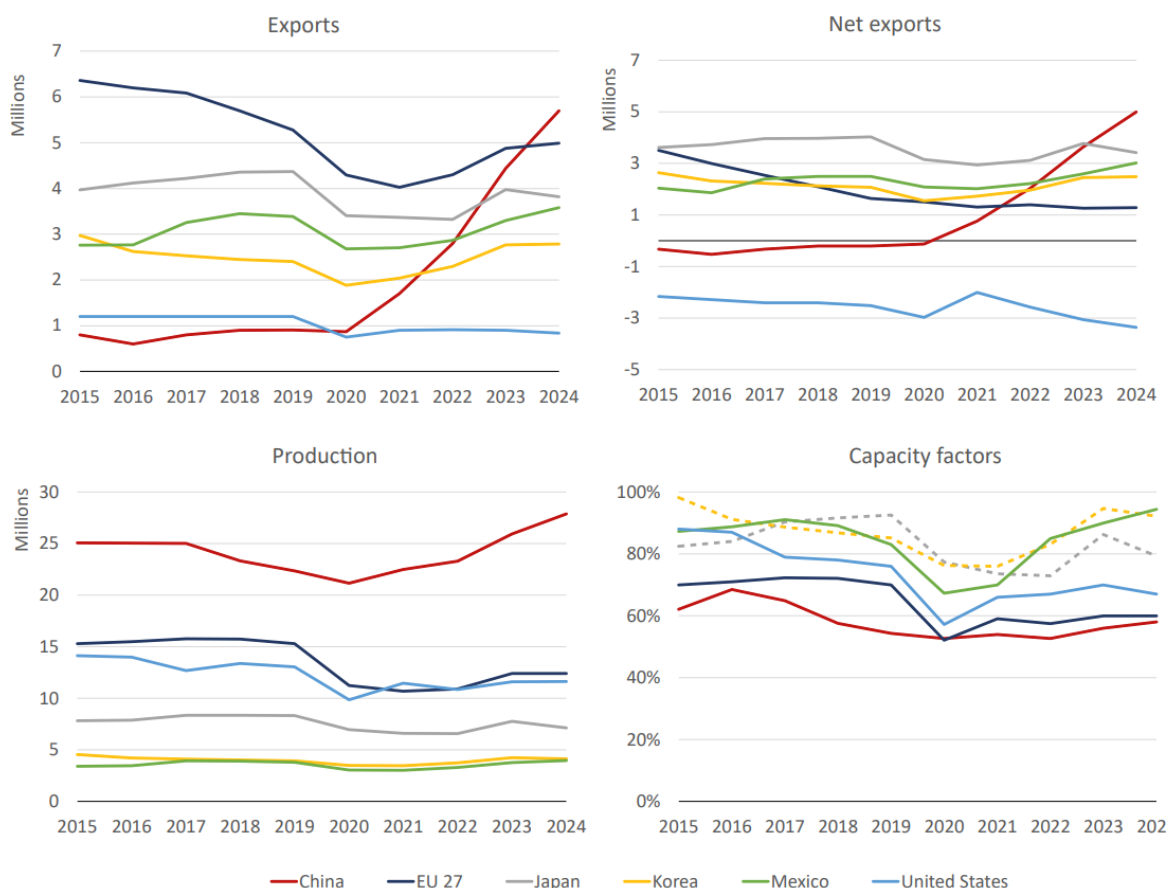
Sodium-ion batteries (SIBs) utilise raw materials that are easy and relatively inexpensive to extract, and are widely available. Their production process is comparable to current technologies. This offers opportunities for low-cost production ([Ali & MacRae, 2024](#)). It may also be an advantage in terms of strategic independence, provided that SIB technology is also developed and scaled up in the relevant regions. Further cost reductions are possible through additional economies of scale and technological development. Due to its low energy density compared to other battery materials, this technology faces greater obstacles in applications requiring high battery capacity in a small volume. Consequently, this technology is primarily seen as suitable for small, low-cost EVs (which may have a shorter range) and potentially in certain truck configurations.

Another development in the field of EV battery technologies relates to high-voltage fast charging. BYD recently unveiled its Super e-Platform, which enables megawatt-scale charging ([BYD, 2025](#)) and charging at a rate of 2 km of range per second. The manufacturer plans to roll out this fast-charging system in Europe. However, this could cause higher peak loads on the electricity grid and lead to high infrastructure costs. Technical solutions – such as stationary batteries and coordinated, smart charging – or policy measures may therefore be necessary alongside price signals to steer charging towards practices that reduce impacts on the electricity grid.

The extent to which these opportunities have been exploited has not been uniform across the globe to date. China, in particular, has succeeded in positioning itself very competitively in the technological race to acquire industrial capacity for the production of batteries and EVs. China's competitive advantage is clearly evident from the fact that it is the only major global market where EVs are cheaper than ICEVs ([IEA, 2025b](#)).

Although China has built up this position by utilising its domestic market, it must now focus on exports to remain successful. This shift towards foreign markets, which is visible in the growth of Chinese car exports since the COVID-19 pandemic (Figure 5.3), could lead to a significant erosion of industrial capacity in other countries.

Figure 5.3 Exports, net exports, production and capacity factors¹³ for the main exporting countries of light commercial vehicles, 2015–2024



Source: Cazzola et al. (2025).

5.4 Policy options to support the EV transition and the further development of the European industrial system

Despite the opportunities highlighted in previous sections, a number of challenges remain. Even as the share of EVs in the EU increases, the transition to alternative, more diverse supply chains for EVs and batteries remains a challenge for traditional European car manufacturers. This reflects a desire to achieve returns rather than take risks with new investments to diversify European industrial capacity, pointing to risks of *stranded assets* and differences in industrial competitiveness.

The slowdown in Europe’s transition to electric vehicles (compared to China) is due to several factors (Draghi, 2024):

- greater resistance to the modernisation of existing automotive production assets;
- differences in labour costs;
- the need to mitigate the impact of rising energy costs on the EU’s industrial competitiveness following the Russian invasion of Ukraine.¹⁴

¹³ Capacity factors are the ratios between the number of vehicles produced and the number of vehicles that could have been produced if the industrial facilities had been used at full capacity.

¹⁴ This is due to losses that occur when replacing existing industrial facilities, which do not occur when building new facilities. During a major technological transition, such as that brought about by electric vehicles, the likelihood of these losses—which are not welcomed by car manufacturers as they reduce their profitability—is greater in replacement markets (where sales of new vehicles are largely linked to older

The risk of losing market share has also prompted legacy car manufacturers (who still require long-term financial health and stability) to seek higher margins on every vehicle sold. These choices have led to larger vehicles and a reduced offer of vehicles in smaller segments ([Cazzola et al., 2025](#)).

The negative consequences of this lag in the transition risk being exacerbated if the protection of existing assets is prioritised over timely investments to respond to this significant technological shift.

The difficulty Western car manufacturers (with the exception of Tesla) have in embracing the transition to EVs potentially points to a continuing need for policy support, such as targeted requirements for a faster transition of vehicle fleets and other incentive mechanisms – such as differentiated taxation based on environmental performance – to steer consumer choices towards EVs.

Although incentives are still necessary, they would be better combined with measures aimed at leveraging European capital for the development of an EU-based EV and battery industry. This is essential to ensure that the market share of EVs continues to grow, while at the same time enabling the EU to realise cost savings through mass production, technology learning and a strengthened environment of EV component and battery supply chain industrial actors ([Cazzola et al., 2025](#)).

Specific examples of policy instruments that could be effective in this regard include ([Cazzola et al., 2025](#); [Sinha et al., 2024](#); [ITF, 2025](#)):

- Differentiated taxes based on the environmental performance of vehicles: this can not only boost the uptake of EVs, but also be implemented in a way that does not reduce tax revenue from vehicle registrations.
- Differentiated circulation taxes (e.g. annual road tax), growing with vehicle age, as these can also reinforce the technological transition and encourage faster fleet renewal.
- Reducing exposure to unexpected changes in the residual value of electric vehicles through government support for capital recovery guarantees. These are also relevant for commercial vehicles and are, moreover, more cost-effective for governments than purchase incentives, while delivering comparable benefits in terms of total cost of ownership (TCO).
- Incorporating requirements for greenhouse gas emissions from battery production into the definition of legal requirements for low-emission vehicles and into the aforementioned instruments, such as policies that set a lower limit for lifecycle emissions per kWh of battery capacity to qualify for incentive measures.
- Include certain non-discriminatory, non-price-based requirements, such as criteria based on the greenhouse gas emission intensity of batteries or criteria using social, environmental and safety standards established under the EU "Battery Passport", in the minimum legal requirements that vehicles must meet.
- Establish criteria that utilise existing rules on corporate sustainability reporting (for example, by making this a condition) to make vehicles and/or batteries eligible for incentives and/or full accountability under the legal requirements.
- Introducing specific, more ambitious regulations in cases where the total cost of ownership is already favourable, i.e. for intensively used vehicles

vehicles reaching the end of their life cycle), such as the EU, than in growth markets (such as China over the past two decades). The reason for this is that, given the same shifts in the overall share of powertrains (and a growing market share for EVs), the risk of a net decline in ICEV sales is lower in growth markets than in replacement markets. This, combined with differences in energy and labour costs, means that market forces threaten to destroy industrial capacity in established markets (such as the EU and North America, for the automotive sector), while investment is being made in new production capacity in growth markets (such as China).

(including commercial vehicles and government fleets), as these are best suited for a cost-effective transition.

- Introducing infrastructure-related support measures aimed at reducing the costs of installing charging points and facilitating investment in the deployment of public charging points.
- Applying exemptions from traffic restrictions for EVs (such as in the case of zero-emission zones) and reduced parking fees and access charges (where applicable) for EVs.

An increase in vehicle production can also create opportunities for new, diversified investments, with positive effects on employment and value creation ([International Labour Organisation, 2020](#); [Tamba et al., 2022](#); [Organisation for Economic Co-operation and Development \[OECD\], 2024](#)). Scaling up electric vehicle production in the EU could also contribute to greater diversification of investment in battery manufacturing, battery material processing and mining ([Cazzola et al., 2025](#)).

5.5 Supply chain options for batteries and semiconductors

China's remarkable rise as a global leader in electric vehicles (EVs) and battery technology is also closely linked to its strategic investments in mineral extraction and processing. This approach has ensured a stable and cost-effective supply of critical raw materials, enabling domestic industries to grow rapidly and attracting foreign investors, including Tesla ([Pistilli, 2025](#)).

China's advance extends beyond raw materials to mineral processing and battery recycling, underscoring that world EV battery supply is currently vulnerable to disruptions in China, for all relevant chemistries ([Cheng et al., 2024](#)).

Concerns about EV battery supply chains are further heightened by the implications of unilateral restrictions on the export of raw materials from China ([Kashyap, 2024](#)), with clear headwinds for the development of battery manufacturers elsewhere – as illustrated by the case of graphite exports to Sweden ([The Economist, 2023](#); [Björling, 2024](#)).

Other supply chain challenges were clearly exposed by the COVID-19 pandemic, especially for firms that have a strong reliance on globalised supply chains. In particular, shortages of semiconductors and chips had significant impacts on the automotive industry contributing to a drop in production and increase in vehicle sales prices.

Threats are very significant for incumbent car manufacturers located in the EU, the US and elsewhere, as they embraced globalisation. On the other hand, drawing upon this strong presence in electronics, China's automotive industry has embraced its integration into vehicles, including for battery management systems, vehicle connectivity and self-driving technology. This helped put Chinese OEMs at the forefront of the ongoing transition towards software-defined vehicles. It is now being followed by similar developments in the realm of artificial intelligence, where China already has a leadership position, globally, alongside the US ([Omaar, 2024](#)).

Synergies between the automotive and electronics industries have helped China reduce its dependence on foreign suppliers whilst simultaneously promoting domestic innovation. Companies such as BYD now serve as examples of how Chinese firms have integrated advanced electronics, software and battery technology into their vehicles.

Ensuring that the transition to electric vehicles leads to industrial development, not only for China but also for other regions, is crucial for strategic reasons, given the importance of the automotive, battery and semiconductor industries for both civilian

and military applications ([European Commission: Directorate-General for Research and Innovation \[DG RTD\], 2024](#)).

Key policy choices, primarily at EU level, can help steer this course:

- Providing long-term, stable policy frameworks, so that investors can be confident that investments in the extraction, refining and recycling of batteries will not be undermined by changing regulations ([Moerenhout, 2024](#)).
- Improving permitting regimes for mines and processing facilities, enabling faster and more predictable timelines for their opening ([Moerenhout, 2024](#)).
- Introducing production incentives in the form of tax breaks or similar measures to attract capital for investment in battery assembly, component manufacturing and the production of cathodes/anodes ([Mehdi & Moerenhout, 2023](#)). Tax incentives must be coordinated at EU level ([Draghi, 2024](#)) within the framework of competition rules and to avoid the risk of a 'race to the bottom', whereby different EU Member States compete with one another and thereby jeopardise their tax revenues (as has already been seen in the past in the context of the establishment of EU headquarters of multinationals in the digital economy).
- Strengthening cooperation on trade and investment with partner countries rich in critical minerals or processing capacity, including the conclusion of trade agreements (such as in the case of the EU/Mercosur), as this can support investment in a more diversified supply chain for battery minerals, to improve access to primary resources ([Cárdenas & Cazzola, 2023](#) and [Moerenhout, 2024](#)).
- Leveraging the competitive advantage of lower greenhouse gas emissions in the EU by reserving public procurement, research, innovation and industrial demonstration/upscaling funds for low-emission EV batteries and related supply chain activities ([Cazzola et al., 2025](#)).
- Supporting research and innovation initiatives aimed at diversifying battery chemistry (such as sodium-ion or lithium-air), technologies for mineral extraction and processing (such as direct lithium extraction), as this can contribute to reduced dependence on critical/rare metals, greater geographical diversification of mineral supply and increased competition ([Brunelli et al., 2024](#)).
- The use of conditions when approving foreign direct investment (such as requirements regarding technology and intellectual property transfer, local content, labour or value added), in cooperation with the European Commission and EU Member States ([Ahamad Madatali & Torlai, 2024](#)), while remaining open to the development of joint ventures or the use of licensing agreements with companies that have gained a competitive advantage in specific countries, with the aim of ensuring that investments in the EU battery value chain build industrial capacity within the EU and do not remain exposed to implicit, undesirable dependencies ([Cazzola et al., 2025](#)).
- Consider the use of temporary countervailing duties or negotiated price undertakings (also to prevent retaliatory measures) for vehicles and batteries produced in countries that have used production incentives not in line with World Trade Organisation rules ([Cazzola et al., 2025](#)).

5.6 Efficient and equitable distribution of policy support for e-transport

Equity concerns arise from the fact that fiscal support schemes for electric cars, such as differentiated taxation schemes can have regressive impacts (amplifying existing inequalities in mobility access), as car ownership rates tend to be lower among lower-income groups across Europe ([European Environment Agency \[EEA\], 2021](#)), including in the Netherlands ([Zijlstra & Durand, 2025](#)).

In contrast, measures to promote electric public transport (such as e-buses) or affordable micromobility (e-bikes, e-scooters/mopeds) may have broader

distributional benefits. They may also increase the accessibility of clean and affordable transport options for households that have less access to them.

Incentives for electric cars and commercial vehicles remain important not only for industrial development and resilience, but also for reasons of equity, for households and businesses (including small and medium-sized enterprises) that require vehicles for their transport.¹⁵ Such incentives are particularly effective for households and businesses with limited disposable income.

In other cases, supporting collective and shared forms of electric transport can lead to fairer outcomes from both a social and environmental justice perspective than support that is primarily focused on private EV ownership.

5.7 Increasing diversity in the offer of EVs across all car market segments

The market for electric cars in Europe has also developed in a way that disproportionately focuses on premium models, thereby raising the barrier to entry for low-income households. There is a risk that higher purchase costs will slow down the replacement of older, more polluting vehicles, thereby delaying the renewal of the vehicle fleet ([Cazzola et al., 2025](#)).

There are also equity issues because the market for second-hand EVs remains relatively small, meaning few affordable EVs are available. This is particularly the case in markets where car manufacturers have prioritised larger and more profitable segments for the early adoption of EVs. These markets include the EU/UK and the United States, but not China, where EVs are also readily available in smaller and cheaper segments.

Various policy choices can help steer the aforementioned instruments in this direction. A differentiated tax could be introduced based on the size, weight and environmental performance of vehicles (see also Chapter 8), resulting in a more favourable economic picture (from the perspective of both manufacturers and car buyers) for smaller, more affordable and more environmentally friendly vehicles ([Cazzola et al., 2025](#)). A similar differentiation could also be applied to measures such as parking charges.

Redistributional measures can be overlaid with differentiated motor vehicle circulation taxes, growing with vehicle age, to ensure access to clean vehicles for parts of society that face constraints to change their vehicle without placing disproportionate penalties on them. Social leasing programmes, such as the one launched in France (Ministère de la Transition écologique, de la Biodiversité et des Négociations internationales sur le climat et la nature et al., 2023), can be particularly well suited to help low-income households access EVs without having to buy it outright, while also being targeted to more affordable model, helping scaling up their demand (Wappelhorst, 2025). Their idea is therefore to combine support for the ecological transition (reducing carbon emissions, cleaner transport) with social equity (helping households that otherwise could not afford a new EV), improving access to mobility (especially where alternative transport options are limited).

Regulatory requirements can also integrate specific features promoting the reversal of vehicle footprint and weight increases, promoting a shift towards a more affordable offer of EVs. These include caps, corporate-average reduction in footprint and/or weight and the use of footprint, rather than (only) weight as a discriminant for the way CO₂ emission regulations apply across vehicles, to enable weight reduction as a compliance strategy (Cazzola et al., 2023). Specific regulations on battery capacities can also complement those applied to vehicles to limit increases

¹⁵ One in three Dutch citizens regards owning a car as a necessity rather than a choice, and 6% experience 'forced car ownership', i.e. car ownership forces them to cut back on other expenditure ([Zijlstra et al., 2022](#)).

in battery size, and, with it, parallel growth in EV weight, size and upward pressure on costs (Cazzola et al., 2023).

Specific policies can also target the second-hand vehicle market, where the choice of EVs is still limited, particularly for smaller vehicle classes (Terwindt et al., 2023). In this context, it is not only important that EV owners do not pay more road tax than ICEV owners, but also that financial incentives are introduced for second-hand EVs. Retaining second-hand EVs can also be relevant to stimulate the emergence of a local EV battery recycling industry, fostering better resource and energy efficiency through circularity. The proposed revisions to end-of-life vehicle policy, currently being developed in the EU, move in this direction (European Commission: Directorate-General for the Environment [DG ENV], 2023; Council of the European Union, 2025). Drawbacks include the risk of widening the existing gap between Northern and Western Europe on the one hand, and Southern and Eastern Europe and emerging economies on the other, as countries with lower income levels are typically more dependent on trade in second-hand vehicles from higher-income countries. Policies aiming to retain second-hand cars may lower trade volumes for these vehicles, opening up opportunities for emerging exporters – including China – to gain influence in emerging markets.

5.8 Access to convenient and affordable charging options, including for underserved communities and the logistics sector

The economic and environmental benefits of EVs depend to a large extent on the availability of charging points and on electricity prices. In many cases, the necessary infrastructure for charging EVs can utilise the existing electricity grid. Competitively priced electricity for EVs also requires investment in infrastructure (charging infrastructure and additional grid investments) needed to make the transition to EVs accessible and affordable, including for the logistics sector. High utilisation rates of this infrastructure (or capacity factors) are also necessary to enable low-cost EV charging. This is particularly relevant for capital-intensive infrastructure, such as DC fast chargers.¹⁶

The performance of business models for the deployment of EV chargers varies depending on the situation. Charging buses and lorries at depots or charging cars and vans at home or at work generally results in lower costs due to higher utilisation rates and lower power requirements per vehicle. There are greater challenges for publicly accessible chargers, due to higher costs for hardware, installation, infrastructure and networks, and investments that are harder to recoup.

Households and businesses with access to private parking spaces can benefit from lower charging costs; those reliant on public charging points pay more. As low-income households and small businesses are more likely to have limited access to private chargers, this situation can lead to inequality in access to the cost benefits and competitive advantage of EVs.

At EU level, the Energy Performance of Buildings Directive (EPBD) seeks to accelerate progress in the installation of charging points in buildings (European Union, 2024a). This is achieved by promoting the use of effective measures to introduce targeted requirements to support the roll-out of charging infrastructure in car parks of residential and non-residential buildings, to remove barriers to the installation of charging points and thus effectively move towards a right to connection. However, the specific rules or practical procedures enabling

¹⁶ Home and workplace chargers require lower investment compared to DC fast chargers. For heavy-duty vehicles, charging at depots offers better opportunities to combine with higher utilisation rates than roadside charging with high power ratings (MW scale). However, both also require investment to strengthen the electricity grid.

owners/tenants to install chargers remain fragmented at present ([Transport & Environment, 2025](#)).

Bridging remaining cost gaps will be particularly important for groups struggling to access private charging points, such as those without access to private parking spaces and who are also poorly served by public transport ([Ministère de la Transition écologique et solidaire & Ministère de l'Économie et des Finances, 2019](#)). This may include residents of multi-occupancy dwellings and/or tenants who do not have their own driveway or fixed parking space, and people in urban neighbourhoods where there are few public parking spaces (although they generally have better access to alternative mobility options).

Targeted policy choices will also be needed to protect low-income groups from the unintended consequences of time-of-use tariffs (which are used for smart charging), without removing the incentives these provide for efficient use of the electricity grid.

At EU level, funding from sources such as the ETS2 and the Social Climate Fund can play a key role in supporting public investment for vulnerable groups. Public funding can also provide support in cases where private capital alone is insufficient to enable both the deployment of chargers and low electricity tariffs. In the EU, public-private partnerships and concession models have been used to attract public support while simultaneously attracting private capital for the deployment of chargers.

Grid congestion is a limiting factor in the roll-out of charging infrastructure for both passenger cars and trucks, meaning that for some people and businesses, electric driving will remain less attractive for some time to come. Technical developments in battery technology can alter range and charging capacity, thereby enabling users to change their charging patterns. This could have a significant impact on charging points and the electricity grid in the future, should many people start charging at high power simultaneously. At the same time, electric vehicle batteries could also be part of the solution if they can be used as temporary storage to balance electricity supply and demand. The government may decide not to take any further action on grid congestion beyond what is currently being done and to accept some delay in the transition. An alternative is to focus more on, for example, smart charging, whereby EVs can actually contribute to grid balancing (for example, charging at times of surplus solar/wind power) and reducing grid congestion. This also includes a focus on *vehicle-to-grid*, by accelerating standardisation so that cars, charging points and energy grids are properly compatible, and by promoting market access and remuneration schemes for feed-in. This does, however, require large-scale digital management systems and behavioural change among users.

5.9 Policy to counteract reducing tax revenue from EVs

Adaptive policy instruments can be developed to anticipate the challenges to the stability of government revenue from transport taxation. These include, for example, differentiated taxation for vehicle registration and use, as well as fuel taxes that reflect the differences in CO₂ intensity of fuel production and supply. In addition, a gradual shift from an energy-based tax to a road-use-based tax is important ([Cazzola & Santos Alfageme, 2023](#); [ITF, 2021](#); [ITF, 2018](#); [Van Dender, 2019](#); and [ITF, 2019](#)),

Such a transition to distance-based charges is complex. It requires foresight and striking a balance between stimulating innovation and addressing revenue shortfalls and social equity. Equity challenges are not limited to road pricing, but apply more broadly to energy price reforms that enable the phasing out of fossil fuel subsidies, with significant economic welfare gains ([Black et al., 2023](#)). These reforms are crucial for sending price signals that are conducive to creating a level playing field for sustainable, low-emission technologies. However, they must also be

accompanied by robust and effectively targeted support for low-income households and small businesses. Targeted support programmes focusing on vulnerable groups in society can alleviate potential concerns about fairness, with limited implications for budget balances ([ITF, 2018](#)).

In the EU, the revision of the Eurovignette Directive ([EU, 2022a](#)) is one of the most concrete EU-wide steps for introducing or expanding road user charges (tolls, distance-based charging, environmental variation), even if it falls short of harmonising road user charges across the Single Market, leaving discretion to Member States on whether or not they should adopt road user charges. The revised Directive allows the phasing out time-based vignettes for heavy goods vehicles on the core TEN-T network, moving to distance-based tolls. Allowing the variation of road/user charges based on CO₂ emissions for heavy goods vehicles, extending some of those features to lighter commercial vehicles and buses, it also helps introducing operational cost advantages (which will need to be transitional, to maintain government revenues) that support the technology transition towards EVs.

If a government objective is to offset declining government revenue from excise duties with other revenue from car use, there are various options for adapting the system of car taxes. These options have different effects on other policy objectives such as affordability, congestion, accessibility and the living environment. No single policy option is beneficial for all objectives; a trade-off will need to be made ([Knoope et al., 2025](#)).

5.10 Conclusion

Academic sources and international and national (policy) analyses show that, compared to ICEVs, BEVs lead to significant reductions in greenhouse gas emissions, higher energy efficiency, and often cost savings as well. Through a combination of technological progress, falling battery prices and integration with renewable electricity, EVs, unlike many other renewable energy carriers, can form a self-sustaining development.

However, challenges remain: tax revenue, industrial competitiveness, supply chain security, grid congestion and equitable access to both vehicles and charging infrastructure. For the EU, striking a balance between competitiveness, the importance of supporting industrial resilience in times of major challenges, inclusivity and sustainability will be crucial to ensuring long-term success, not only in the field of electric transport.

6 Biofuels

Biofuels are fuels produced from biomass. This can include crops as well as waste streams from agriculture, forestry, or other sectors. There are various types of biofuels with different types of feedstock and production techniques, and different applications. Some biofuels can be blended into existing fuels, such as bioethanol in petrol, while other biofuels are suitable for use as 100% fuel in existing internal combustion engines.

As mentioned in Chapter 3, biofuels play an important role in the transition to a carbon-neutral transport sector, and there is already significant use of biofuels in the transport sector. To meet climate targets by 2050, the use of sustainable biofuels will need to be scaled up, even if net energy demand falls and hydrogen or e-fuels also make a supplementary contribution (see Chapter 7). Although the prospects for increasing demand are well supported by research, a number of important questions remain regarding biofuels. What quantities of biofuel can we expect in the future, and in which modes of transport? Is the availability of sustainable bio-feedstocks sufficient? Is there sufficient production capacity or potential for upscaling? And is sustainability certification robust enough? This chapter addresses these and related questions.

6.1 Role of biofuels in the energy transition

Biofuels are currently used primarily in road transport. This is likely to remain the case in the short term, as biofuels are currently more cost-effective than e-fuels and road transport fuels are subject to higher taxes than aviation and marine fuels. However, there is already some (limited) use of biofuels in the international transport sectors (maritime, inland waterway and aviation).

Renewable electricity is an efficient energy carrier that can save both energy and CO₂; and large-scale electrification is expected to take place, particularly in road transport (see Chapter 5). However, batteries and electric motors are not (yet) a suitable solution for all modes of transport. As explained in Chapter 4, various studies show that even in 2050, the internal combustion engine will still be present in international mobility sectors (maritime shipping, inland waterway transport and aviation), where electrification is not competitive or technically feasible. To a lesser extent, this also applies to sectors such as heavy road transport – where a transition to electrification has already begun – and mobile machinery. The existing vehicle fleet may also require renewable fuels in the coming decades, during the phasing out of fossil fuels (see section 4.1).

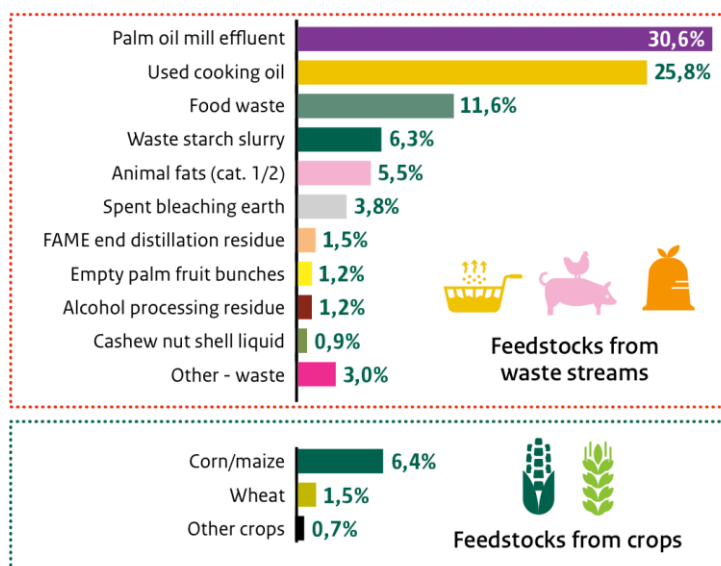
6.2 Current use of biofuels and biofeedstocks

In the Netherlands, biofuels are used to meet the annual renewable energy targets for transport, with the aim of achieving an annually increasing percentage. In 2024, approximately 60 PJ of biofuels were blended or used as a standalone fuel in the Dutch transport sector ([NEa, 2025](#)).

The current feedstock base for sustainable biofuels in the Netherlands consists almost exclusively of waste streams listed in Annex IX of RED III. Due to national and European restrictions, food and feed crops are scarcely used in Europe. Over the past decade, used cooking oil (UCO) and animal fats have been the main feedstocks used to meet the growing demand for biofuels in the Netherlands. With the RED III limit on feedstocks from Annex IXb (waste streams from vegetable or animal oils and fats), we have recently seen a rapid rise in the use of palm oil mill

effluent (POME), a feedstock from Annex IXa. The rapid increase in the use of POME has led to concerns about sustainability, which are currently being investigated by the European Commission. Feedstocks from Annex IXa are used for the production of diesel substitutes such as biodiesel (FAME) and HVO, currently the most widely used biofuels in the Netherlands (Figure 6.1; [NEa, 2025](#)). Compared to the European average (41%), the Netherlands has a higher share waste and residual materials for biofuels (76% in 2024). With a share of over 25% across Europe, rapeseed is the most widely used feedstock ([NEa, 2025](#)).

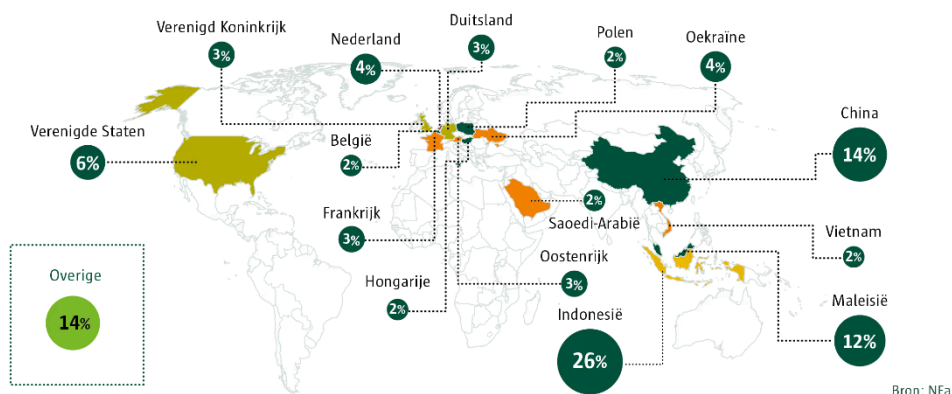
Figure 6.1 Feedstock for biofuels used in the Netherlands, 2024



Source: NEa ([2025](#)), translation by authors.

At present, most of the feedstock for biofuels come from abroad, particularly from Asia. Only 31% of biomass feedstock come from Europe, of which 4 percentage points come from the Netherlands itself (Figure 6.2; [NEa, 2025](#)). As primary agricultural production in the Netherlands and the EU is currently mainly intended for food and animal feed, only a very limited quantity is available for energy applications. This means that most advanced bio-feedstocks must be sourced from outside the EU via international supply chains ([Van Minnen et al., 2024](#)).

Figure 6.2 Main sources of raw materials for biofuels used in the Netherlands, 2024



Source: NEa ([2025](#)).

However, due to growing sustainability ambitions, the Netherlands and other European countries are becoming increasingly dependent on biomass. This creates tension between the growing demand for biomass in the EU and a simultaneous decline in production resulting from the set-aside of agricultural land. Furthermore, the question arises as to the extent to which the Netherlands and the EU wish to be dependent on other countries through the import of biofeedstock.

6.3 Potential future shift from oil-rich to cellulosic biomass

This growing gap between supply and demand for sustainable biomass draws attention to the extent to which EU production can be increased to boost European self-sufficiency. In order to meet the growing demand for biofuels and maintain their position as major EU trading hubs in the long term (see 6.7), Dutch ports will need large-scale access to competitively priced bio-feedstocks for biofuels. Due to the limited potential for domestic production, continued reliance on imports is likely to be necessary, but the bulk of these imports could largely be met by the EU.

Currently, most bio-feedstocks in the Netherlands and the EU are imported, easily convertible waste oils (Figure 6.1). These feedstocks originate mainly from Asia, which means there is a complex global supply chain that requires close monitoring. Furthermore, both the Netherlands and the EU are dependent on imports of feedstocks listed in Annex IX of the RED (NEa, 2025). A shift from oleochemical (oil-based) feedstocks as the main source for biofuels to lignocellulosic (woody) feedstocks (see 6.4) may offer opportunities to reduce this dependence on imports and broaden the feedstock base within the EU. However, such a shift requires a transition to conversion technologies which, in the past, despite policy support, faced significant barriers in terms of investment and economic viability.

6.4 Potential availability of sustainable bio-feedstocks in the EU

The potential availability of sustainable lignocellulosic feedstocks for biofuels in Europe could be sufficient if we were to decide to switch to cellulosic feedstocks and, more broadly, to shift from food and feed crops to energy crops and agricultural waste streams. This could be achieved, for example, by repurposing abandoned agricultural land in the EU, without triggering the need for additional land (Van Minnen et al., 2024; Panoutsou & Maniatis, 2021).

Given the expected high prices of e-fuels at least until 2040 (Van der Veen et al., 2024; Van Kranenburg et al., 2020), the demand for renewable fuels could be met primarily by biofuels. PBL projects that demand for biofuels from the transport sector in the Netherlands may rise to approximately 111 PJ by 2030 (PBL et al., 2024). This translates into an expected demand for 110 to 250 PJ of bio-feedstocks in 2030, depending on the conversion factor from biomass to fuel. This factor is close to 1 for the conversion of waste oils into oleochemical products, but may also be considerably lower, depending on the methods of biofuel production and the raw materials used (Van der Veen et al., 2024). Based on a recent estimate by PBL, demand for biofuels for transport could grow to between 200 and 500 PJ by 2050 to achieve a carbon-neutral sector. Although this range depends on the growth of electricity, e-fuels and the total volume of bunker fuels, this means that the need for biofuels in 2050 will at least triple and may even be eight times greater than in 2024 (PBL, 2024). Depending on the shift away from waste oils as the main source of biogenic carbon, this results in a requirement for approximately 450 to 1,100 PJ of biomass for transport in 2050.

In addition to its analysis of future demand for biomass, PBL has carried out a detailed analysis of the supply potential of advanced bio-feedstocks for biofuels in the Netherlands. PBL estimates that by 2030, between 5 and 6.8 exajoules (EJ) of

'tradable'¹⁷ sustainable bio-feedstocks could be available in the EU27 for energy applications and the production of hydrocarbons. By 2050, this will have increased to between 5.9 and 11.5 EJ. Based on a proportional distribution among Member States according to gross domestic product, between 219 and 243 PJ will be available to the Netherlands in 2030 and between 682 and 1304 PJ in 2050 ([Van Minnen et al., 2024](#)).¹⁸

Imperial College London (ICL) has conducted a similar study and estimates that by 2030, the EU and the United Kingdom will together have between 126 and 262 Mtoe (5.3 to 11 exajoules (EJ))¹⁹. This is projected to increase by 2050 to between 101 and 252 Mtoe (4.2 to 10.5 EJ)²⁰ of sustainable bio-feedstock available for biofuels, primarily derived from agricultural waste streams (e.g. cereal straw and maize stalks). This takes into account an increasing policy shift towards cellulosic feedstocks for advanced biofuels (Annex IXa) with good agricultural and forestry management practices, and also accounts for an increasing use of waste-based cellulosic feedstocks. If we look specifically at advanced bio-based feedstocks derived from agricultural waste streams, the expected volume is approximately 46 to 97 Mtoe (1.9 to 4 EJ) in 2030 and 71 to 176 Mtoe (3 to 7.4 EJ) in 2050 ([Panoutsou & Maniatis, 2021](#)). Based on both PBL and ICL, this means that the Netherlands may be able to meet its demand for biomass within the sustainability criteria of RED III through domestic production and imports from other EU countries.

The largest contribution to this potential availability of biomass is expected to come from agriculture. This potential contribution from agriculture will consist, to a small extent, of biomass from primary cultivation (a crop grown specifically for energy biomass), but will mainly consist of agricultural residual and waste streams ([Strengers & Elzenga, 2020](#); [Panoutsou & Maniatis, 2021](#); [Van Minnen et al., 2024](#)). Biomass from primary cultivation will mainly result from increased crop yields due to improved techniques, to avoid the need for more land.

In addition to higher yields, the cultivation of dedicated energy crops such as *Panicum virgatum* (finger grass), *Phalaris arundinacea* (reed canary grass) (both woody), *Camelina sativa* or *Brassica carinata* (both oilseed crops) can have a significant impact ([Van Minnen et al., 2024](#); [Concawe, 2025](#)). This can be achieved by utilising abandoned and degraded land, which must meet strict sustainability criteria, to prevent additional land from being brought into use and to promote the use of crops that restore soil quality ([Strengers & Elzenga, 2020](#)).

In many parts of Europe, agricultural land is being abandoned due to socio-economic and environmental factors (e.g. falling incomes and soil degradation) ([Perpiña Castillo et al., 2018](#)). Incentives for the cultivation of biomass (energy crops or the collection of residues from food and feed crops) on this land could lead to an increase in production. This concerns approximately 20 million hectares (roughly seven times the land area of the Netherlands excluding water) between

¹⁷ The term 'tradable' refers here to bio-based raw materials that are economically viable to trade (internationally). Local flows (such as manure) are not included.

¹⁸ The majority (around 80% in 2050) of tradable bio-based raw materials for energy and hydrocarbons will be distributed among Member States in proportion to their primary production of hydrocarbons based on the EU reference scenario for 2020. PBL has allocated the remainder of the tradable bio-based raw materials for direct energy applications (which will have fallen to 20% by 2050) to the Netherlands based on the size of the Dutch economy (GDP). For both 2030 and 2050, this amounts to approximately 5.5% of the EU27's GDP.

¹⁹ 1 Mtoe is 41.8 petajoules. 1 exajoule is 1,000 petajoules.

²⁰ The main reasons why the potential remains comparable in 2030 and 2050, despite improvements in biomass mobilisation and increased research and innovation for higher yields, are:

- Stricter policies and regulations for the sustainable use of land and water resources, including a 30% reduction in agricultural land by around 2050.
- Major improvements in forest management are slow to materialise due to the long growth cycles of forests, preventing rapid changes in potential growth.
- Greater awareness of waste reduction and stricter regulations and requirements for recycling by 2050.

2015 and 2030, as calculated by the JRC. If energy crops are grown on this land (possibly as catch crops alongside food crops), significant yields can be achieved without the need for additional land ([Van Minnen et al., 2024](#); [Panoutsou & Maniatis, 2021](#)).

The recently published Sustainable EU Bio-economy Strategy aims to establish European value chains and to strengthen European strategic autonomy through stimulating sustainable and competitive developments regarding bio-based raw materials. Simultaneously the strategy looks to reduce European vulnerabilities through the reduction and diversification of energy imports. Bio-based technologies are central to scaling up the bioeconomy and expanding Europe's industrial base. These enable the conversion of primary and secondary biomass into materials, chemicals, fuels and other high-value applications. Moreover, in this strategy, the EU acknowledges the future need for sustainable biofuels in transport modes where electrification is not feasible ([DG MOVE, 2025](#)).

As set out in the Sustainable Transport Investment Plan (STIP), this strategy will support a coherent, circular and sustainable value chain for these purposes. The STIP states that sustainable raw materials for the production of advanced biofuels, such as lignocellulosic agricultural residues, agri-food residues, manure residues and waste, are currently underutilised and could be used on a larger scale. Furthermore, emphasis must be placed on synergies between sectors and modes of transport, which will also contribute to an increase in volume and a reduction in price. By identifying feedstocks not utilised by other sectors, costs and price volatility can be limited, and other sectors can be prevented from being forced to switch to non-sustainable biomass. Efficient collection and processing of raw materials, sustainability verification and traceability throughout the value chain are essential to ensure a net reduction in emissions ([European Commission, 2025b](#)).

6.5 Mobilising the biofeedstock potential

The cost-effectiveness of biomass mobilisation is influenced by various factors, such as inflation, labour market dynamics and technological developments (e.g. automation). Advanced collection systems, for example, can increase the availability potential of agricultural waste streams suitable for the production of advanced biofuels, thereby reducing prices due to economies of scale. At the same time, prices for sustainable biomass in competitive markets may rise significantly if there is competition between sectors with sufficient purchasing power to secure the supply of biomass ([Concawe, 2025](#)).

Roadside costs (the costs of harvesting and collecting raw materials prior to transport) and transport costs to the biocrude or biofuel production facility account for a significant proportion of the total cost of bio-based raw materials. In particular, the high roadside costs currently mean that agricultural waste streams, for example, cannot yet be used cost-effectively for biofuels. The economic viability of such feedstocks could be improved by introducing long-term obligations that ensure a stable market, which could provide an incentive to scale up the production of bio-feedstocks to meet the demand for biofuels. Furthermore, targeted subsidies can support technologies still in the early stages of development, such as techniques that improve the efficiency of field collection ([Van Minnen et al., 2024](#); [Concawe, 2025](#)).

By 2030 and 2050, the cost competitiveness of sustainable biomass will also depend on geographical factors, particularly the location of biomass sources and demand from the sectors. As cheap, easily accessible biomass sources are depleted, the system will increasingly have to rely on more expensive or logistically complex feedstocks, which in turn will drive up prices. The costs of sustainable bio-feedstocks are expected to fall in a scenario of high demand and high availability ([Concawe,](#)

[2025](#)). By repurposing abandoned and marginal agricultural land, the need for more expensive and hard-to-reach bio-feedstocks can be reduced, as these lands have previously been cultivated and can be reused for energy crops or to supply agricultural waste streams. Furthermore, a high level of mobilisation combined with (expected) high demand for biofuels is likely to lead to an improved capacity to distribute biomass more widely across Europe, as raw materials are more likely to be procured and transported in a more economically efficient manner. However, this requires consistent policy to ensure a level playing field for sustainable bio-feedstock applications, streamline logistics chains and create economies of scale ([Strengers & Elzenga, 2020](#); [Panoutsou & Maniatis, 2021](#); [Van Minnen et al., 2024](#); [Concawe, 2025](#)).

To mobilise the bio-feedstocks needed for an economically and ecologically sustainable energy transition, timely policy choices aimed at both ensuring a sustainable supply and preventing shortages are essential. It is necessary to formulate a consistent policy with clear and measurable objectives regarding the role and use of biomass and biofuels in the long term. In addition, structural shifts in the types of biomass used must also be considered, as these can have direct implications for the technologies and investments required to enable biofuel production.²¹ Through the EU's Common Agricultural Policy (CAP), circular and sustainable approaches can enhance soil fertility and reduce costs. The current and future CAP will support farmers who adopt bio-economic innovation and sustainable and regenerative practices, diversify their sources of income and collaborate in emerging value chains. As part of the EU's bioeconomy, the CAP offers various models for cooperative investment in innovative processing technologies and new value chains, thereby creating value from unused biomass (such as advanced agricultural waste streams). The CAP also aims to link primary production to industrial investment, thereby contributing to growth and employment in rural areas ([EC, 2025b](#)).

At the land management level, the benefits and risks depend on good agricultural and forestry practices, such as fertilisation, harvest timing and crop or ecosystem type. These largely determine the balance between biomass production, biodiversity and carbon sequestration. Measures such as extending crop rotation by adding crops – such as *catch and cover* crops used to maintain and improve soil quality – are agricultural measures regarded within the CAP as key instruments for sustainable agricultural practices aimed at improving soil health, reducing nutrient loss and mitigating climate change. This type of active management can not only contribute to nature restoration and local employment, but also provide usable biomass as an alternative to imported supplies ([EEA, 2023](#)). The improvement of sustainable agricultural practices on abandoned and degraded land across the EU is in line with the European Nature Restoration Regulation. This regulation sets targets to restore the ecological value of agricultural land by improving various indicators, including increasing the biodiversity of pollinators and farmland birds, rewetting peatlands, and improving soil quality through both minerals and organisms ([Halleux, 2024](#)).

Furthermore, long-term investments, economic viability, clear objectives and implementation strategies for biofuels, and coherent sustainability requirements that determine whether certain feedstock streams are excluded or not (see Annex B), are essential. These are conditions that can facilitate the upscaling of sustainable bio-feedstock production by reducing uncertainties and creating a level playing field with a stable market.

The same applies to investments in biomass conversion facilities, as these can vary significantly depending on the raw materials used. Instruments such as targeted

²¹ In particular, oleochemical conversion processes – which are currently the most common – do not rely on the same conversion facilities as biochemical and thermochemical biofuels.

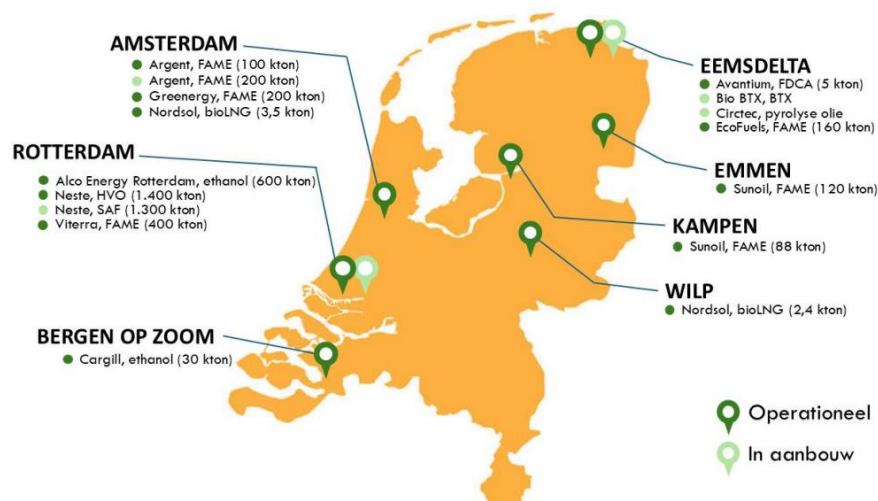
subsidies can stimulate both the sustainable production and the high-value application of bio-based materials, which contributes to greater confidence in the market for bio-based materials. Without an attractive business case, large-scale production of bio-based materials is not feasible. Yields from crops for bio-based materials are currently often lower than those of conventional agricultural crops, and innovations are often still at an early stage. Market stimulation and support for greater value creation are therefore necessary. This includes, for example, improved logistics, such as more efficient collection of waste streams and large-scale processing facilities, to reduce costs along the value chain. Industrial applications also require robust technology capable of processing various biomass streams and producing multiple products, including sustainable biofuels (EEA, 2023; Van Minnen et al., 2024; Panoutsou & Maniatis, 2021). This is a challenge, given the history of investment difficulties associated with bioenergy facilities that rely on lignocellulosic resources. Furthermore, this can only happen if it is accompanied by the establishment of good agricultural practices that support the maintenance or restoration of good soil values (water, resilience, etc.) and meet ecological requirements.

6.6 Current and future production of biofuels in the Netherlands

The Netherlands has a large refining sector. Around 10% of European refining capacity is located in the Netherlands, and Europe's two largest refineries are situated in Rotterdam. Production capacity stood at approximately 3,400 PJ/year in 2023, while Dutch demand for petroleum products in the same year amounted to approximately 1,100 PJ (RVO, 2025b). The Dutch refining sector has made progress in the field of renewable fuels (Figure 6.3): in terms of installed capacity, the Netherlands ranks eighth in the world.

The Dutch refining sector is strongly internationally oriented and has been able to develop over the past decades thanks to the strategic location of the port of Rotterdam for the supply of raw materials and the delivery of fuels and chemical products to north-western Europe. The supply of bunker fuels for (international) aviation and shipping is also exceptionally large in the Netherlands; see also Chapter 3.

Figure 6.3 Biofuel production facilities in the Netherlands in 2025



Source: RVO (2025b).

6.7 The refining sector under pressure

However, this strong international position is under increasing pressure. The transition to carbon-neutral transport poses major challenges for the Dutch refining sector, namely falling demand for fossil oil products and rising production costs (for example, as a result of ETS prices). Without policy measures, it is expected that a significant portion of European refining capacity will largely disappear in the coming decades as a result of falling demand due to the electrification of road transport. Furthermore, for maritime shipping – the largest fuel consumer in the Netherlands – there remains considerable uncertainty as to which type of renewable fuel will become dominant.

The climate targets for transport do not impose requirements on the origin of renewable fuels, meaning that the production of bioenergy in the Netherlands or Europe is not necessary. Furthermore, the Netherlands and European countries that are heavily reliant on electricity generation based on natural gas are facing rising electricity prices, with negative consequences for the competitiveness of their industry. In the EU, carbon pricing has also been introduced via the ETS, which encourages a shift from fossil fuels to other energy sources in order to reduce CO₂ emissions. However, this may lead to an uneven playing field with refineries in countries with lower energy prices and CO₂ costs, and thus to a weakened competitive position ([Wimmer & Neuhausen, 2025](#); [PBL et al., 2024](#)). Policies such as the Carbon Border Adjustment Mechanism (CBAM) aim to protect EU industry from competitors not subject to CO₂ pricing, but challenges remain for exports, as the CBAM currently falls short of creating a level playing field in this regard ([Draghi, 2024](#)).

6.8 The potential shift towards biorefining

The Netherlands has the technical potential to develop a refining sector focused on renewable (bio)fuels, which would serve as a springboard for the chemical cluster's transition to sustainable products. In order to meet the expected growth in demand for biofuels, it is important to establish sufficient production capacity for suitable fuel pathways in time.

Existing installations and infrastructure can largely be used for biorefining. The existing infrastructure and large import facilities for raw materials via the port of Rotterdam make the Netherlands an attractive location. In the event of a complete switch to bio-based raw materials, system adjustments will be necessary. In some cases, these will only relate to specific components. The potential for this depends on the configuration of the current refinery. Adapting the production process from fossil to renewable fuels entails costs and takes time. The extent to which this is the case depends on the specific refining process and the feedstocks used.

A conversion to biorefining is often still faster and cheaper than building new production facilities, but remains technically complex and costly.²² Refineries can also adjust their final product mix. This applies to the production of fossil fuels, but also to renewable fuels. An example of this is the production of HVO and HEFA, where the ratio between the two fuels from a single refinery can be adjusted as required, without the need to modify installations ([Uslu et al., 2024](#); [Geilenkirchen et al., 2024](#); [EZK, 2023](#)).

A European Commission survey found that European technology suppliers possess the knowledge and personnel required to build the advanced biofuel industry, and

²² For oil-based bio-feedstocks, converting an existing refinery is simpler than for bio-feedstocks that require, for example, gasification or methanol synthesis. The physical properties of the bio-feedstocks determine the purposes for which they are used as biofuels and the process required for this. Generally, oil- and fat-rich feedstocks are processed into diesel substitutes and sugar- and starch-rich feedstocks into petrol substitutes.

that refinery operators do not anticipate a shortage of suitable equipment to construct advanced biofuel production facilities, nor do they expect a shortage of raw materials and processing materials. However, several industry stakeholders noted that, although the equipment is available within Europe, it may be cheaper to source it globally. Components typically sourced from outside Europe include catalysts and pressure vessels. The supply of catalysts could become critical, as they may require specific additives such as nickel, molybdenum and potentially specific additives. Furthermore, cheap renewable electricity is only available in specific locations across Europe. Furthermore, there is a severe shortage of experienced project developers in the EU to build advanced biofuel production facilities in the coming years. So although most of the conditions for the development of a European biorefinery sector are thus met, a number of significant challenges remain ([DG RTD et al., 2026](#)).

The establishment of a biorefinery sector in the Netherlands fits well within the European bioeconomy strategy. Bio-based technologies are central to scaling up the bioeconomy, in which biorefineries play a central role. Biorefineries convert biomass – including woody biomass and agricultural residues – into a range of products, including biofuels. Biorefineries can also produce alternatives to critical raw materials, such as bio-based anodes used in batteries. They often require significant capital investment and coordinated planning for the supply of raw materials and infrastructure. Improved industrial symbiosis can optimise the use of raw materials across different sectors, stabilise the supply of raw materials, reduce waste and production costs, and support industrial clusters. Therefore, the Commission and the European Investment Bank Group can use financial instruments to accelerate the development of biorefineries and mitigate risks in order to attract more private capital. The European Commission supports the emergence of strong regional biorefinery clusters, which coordinate raw materials, infrastructure and investment planning at the territorial level ([EC, 2025c](#)). A transformation of the Dutch refining sector into biorefineries could become such a regional cluster if policy measures are taken ([Wennink, 2025](#)).

To achieve climate targets consistent with a carbon-neutral transport sector, it is also important to take into account the controlled reduction of Scope 1 and 2 emissions from the refining sector (i.e. direct emissions from production facilities). A gradual transition of the refining sector can minimise the risk of carbon leakage and offers the possibility of negative emissions via bio-CCS pathways. If the production of fossil fuels in the Netherlands and Europe is scaled back at an accelerated pace, there is a risk that part of the production will shift to regions outside the EU with less stringent climate policies. This could lead to higher CO₂ emissions globally, compared to maintaining refining activities in low-carbon facilities within the EU ([Uslu et al., 2024](#)).

In addition to clear EU regulations, there are other strategies for adapting refineries and chemical plants to changes in climate policy and geopolitical developments (which are leading to rising energy prices in the EU). These may include a rapid shift towards greater electrification and increased reliance on renewable electricity, partly through power purchase agreements. However, the industry will only implement these changes if it is certain that its investment will be profitable. If not, it will continue to operate the current production facilities for a few more years and then close them in the Netherlands and the EU and invest elsewhere. The risk of relocation in the context of the refinery transition is linked to the availability of biomass, production costs and transport. Although a complete shift of the value chain from biomass supply to biofuel production is technically possible, this may not be the most favourable option for a refinery from a strategic perspective. Furthermore, biorefineries offer various benefits for countries, including improved security of supply, the supply of raw materials for the chemical industry, and the

supply of CO₂ to refineries using renewable electricity (*power-to-X*) ([Uslu et al., 2024](#)).

Synergies could emerge between European biomass chains and the establishment of a competitive biorefinery sector, with positive spillover effects for the wider use of domestic sustainable bio-feedstocks. Furthermore, the establishment of European value chains for both advanced biofeedstock and biofuels facilitates better coordination and oversight in the area of sustainability, as these remain within the European policy framework. To follow this path, however, biomass supplies, conversion technologies and end products must be competitive on the global market.

The development of a resilient and globally competitive biorefinery sector also offers social and economic opportunities, even if the overall size of the Dutch refining sector declines due to reduced demand for fuels (for example, due to the electrification of road transport). The Dutch refining sector currently accounts for nearly 4 billion euros per year in the Dutch economy, contributes to competitiveness, employment and investment in research and development in the Netherlands, and forms a strategic basis for gradual replacement by biorefining. The production of renewable fuels is knowledge-intensive and requires more conversion steps than the production of fossil fuels. This results in higher added value when these production steps take place in the Netherlands. As far as personnel are concerned, the availability of skilled labour in the EU is not considered a major problem. Biorefineries expect to be able to recruit staff from conventional ethanol production facilities, traditional refineries and other chemical industries ([Wimmer & Neuhausen, 2025](#); [DG RTD et al., 2026](#)).

Maintaining a refining sector is seen as important for the strategic autonomy of the Netherlands and Europe (see, for example, the Wennink report ([Wennink, 2025](#)) and the STIP ([European Commission, 2025b](#)), as well as Rijksoverheid ([2025](#))). Energy and chemicals have been designated by the government as vital processes and are recognised as crucial to the functioning of society ([National Coordinator for Security and Counter-Terrorism \[NCTV\], 2025](#)). Although the Netherlands advocates free and open trading systems (and currently imports many raw materials and fuels), recent geopolitical developments show that certain high-risk dependencies can also lead to instability (see also Chapter 2). The current structural dependencies on imports of biogenic carbon could be replaced by European production chains, provided that the potential for sustainable biomass (see 6.5) can be utilised in a cost-effective manner. The shift towards greater European self-sufficiency in advanced bio-based materials can help to reduce the strategic dependencies arising from imports, while maintaining industrial capacity within the EU. Utilising European bio-based raw materials, investing in the country's own climate resilience, establishing biorefineries for the production of biofuels, and increasing reliance on European supplies (with stricter CO₂ reduction requirements and ensuring security of supply) contribute to the strategic autonomy of both the Netherlands and the EU ([EC, 2025c](#); [Wimmer & Neuhausen, 2025](#)).

6.9 Challenges and policy options for scaling up biorefining

Various policy conditions are needed to facilitate a controlled phase-out of fossil refining and the development of biorefining, and this is something that has not yet been implemented in policy. To this end, stable supply and demand at both national and European level is essential, as is a gradual greening of refineries to prevent carbon leakage effects. To ensure the future-proofing of investments and competitiveness, the supply of biofuels must be directed towards sectors where fuel demand is also relatively certain in the future, particularly aviation and shipping.

Currently, there are no large-scale biorefineries operational in Europe for the production of advanced biofuels from feedstocks listed in Annex IXa of the RED, indicating a critical gap between current capacity and future demand. One way to bridge this gap is to integrate future biorefineries with existing industrial facilities, such as oil refineries and biofuel plants, which can offer significant cost advantages. These advantages stem from synergies in infrastructure, shared utilities and the ability to reuse existing processing units. Gasification and Fischer-Tropsch in particular benefit greatly from integration with refineries, as they deliver both economies of scale and cost savings through the reuse of existing facilities. According to the literature, this configuration within existing refineries appears to be the most cost-effective option compared to the construction of new, decentralised plants. The construction or conversion of existing facilities into biorefineries differs from the construction of biomass processing plants, which are ideally built close to the source of sustainable biomass. These plants produce biocrude, which is then shipped via sea routes to biorefineries with access to a port ([Concawe, 2025](#)).

The availability of biomass is a key factor in determining the optimal structure of the supply chain. Although there could be sufficient bio-feedstocks available in Europe to meet the demand for advanced biofuels, ensuring a continuous supply of sufficient feedstocks can be a challenge. Mobilising a variety of advanced bio-feedstocks across the EU is therefore essential for establishing a competitive biorefinery sector ([DG RTD et al., 2026](#)).²³ As demand for advanced biofuels increases between 2030 and 2050, the biomass supply network will expand and is likely to become geographically more complex, with different regional roles potentially developing across Europe. Industrialised coastal countries in Western Europe, such as the United Kingdom, Belgium and the Netherlands, have limited domestic biomass resources but possess a strong port and refinery infrastructure, making them competitive hubs for upgrading imported biocrude into biofuels. In contrast, biomass-rich regions such as Scandinavia and the Iberian Peninsula are well-positioned for decentralised production and export of biocrude. The transport of liquids (such as biocrude) is more cost-effective than the transport of solid biomass, due to higher energy density and better logistical efficiency. The export of biocrude from biomass-rich countries and its import to industrial biorefinery hubs with access to ports, such as in the Netherlands, could form the backbone of future long-distance trade flows within the EU. Investment decisions in biofuel production technologies are therefore not based solely on process performance or maturity, but should rather be based on an integrated assessment that takes into account geographical factors and supply chain logistics ([Concawe, 2025](#)).

To meet the targets for carbon-neutral transport, dozens of new biorefineries must be brought into operation in the EU by 2030, and as many as several hundred by 2050. Timely investment decisions and coordinated policy measures are essential to establish a sustainable, EU-wide advanced biofuel supply system with a potential biorefinery cluster in the Netherlands ([Concawe, 2025](#); [DG RTD et al., 2026](#)). In response to this challenge, the European Commission has published a report in which it acknowledges that a significant increase in the production capacity of biofuels based on Annex IX feedstocks is needed between now and 2030 to meet the RED targets for sustainable biofuel production. Furthermore, the Commission states that financial support will be needed to bridge the gap between the production costs of biofuels and the market price of fossil fuels ([DG RTD et al., 2026](#)).

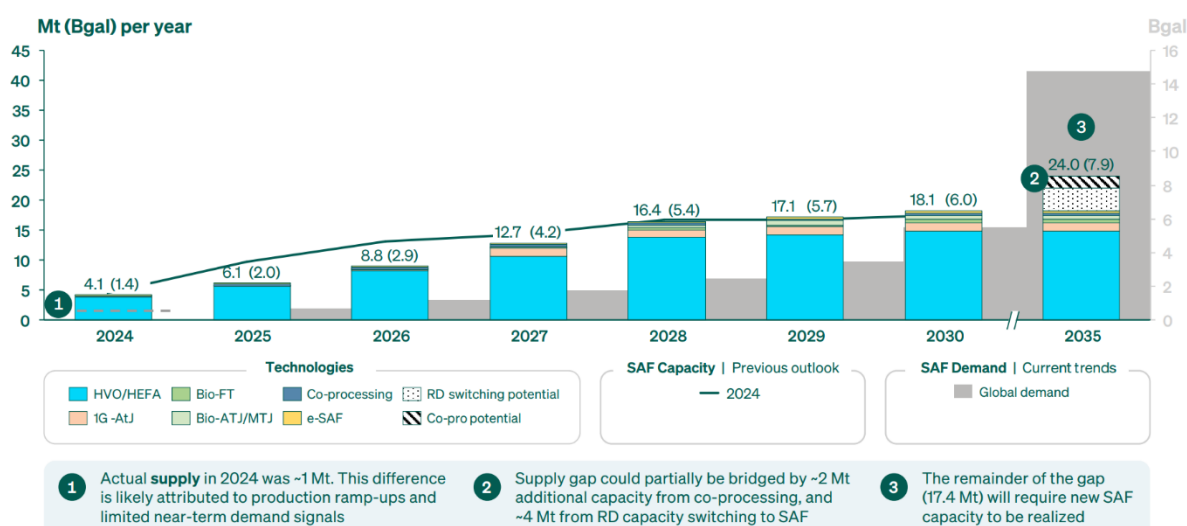
²³ The study by DG RTD et al. highlighted, in particular, challenges relating to the availability of feedstocks for the extraction of waste lipids for hydroprocessing. For the alcohol-to-jet and all gasification-based routes, the main challenge was organising the large-scale production and collection of biomass residues from agriculture and forestry, or developing new supply routes from intermediate crops or severely degraded land. Finally, for RFNBOs, the lack of market maturity for biogenic CO₂ and green hydrogen was cited.

The level of financial support required to bridge the gap between the levelised cost of production of biofuels and the market price of fossil fuels is expected to vary across different industrial value chains. This depends heavily on which feedstock is used and which biofuel is produced, as well as on market dynamics, which in turn depend on EU policy. Two key forms of financial support are considered necessary: (a) financial support for industrial units (e.g. biorefineries), and (b) financial support to mobilise farmers, also in the form of FiPs or production subsidies. Both are estimated at several billion per year (DG RTD et al., 2026).

Current policy instruments are insufficient to increase demand for biofuels in The Netherlands and create a stable market that offers investment certainty for the construction or conversion of biorefineries. The *Fuel Transition Obligation* (BTV, the national implementation of the RED III obligation in the Netherlands) plays only a minor role in stimulating demand for biofuels to promote domestic production of renewable fuels. Investment plans for domestic biofuel production are currently being postponed or halted due to policy uncertainty regarding the future use of biofuels and the setting of targets. This leads to high financing costs for high-risk investments in new production facilities (e.g. biorefineries). In addition, there is uncertainty regarding permits due to the nitrogen crisis, as well as uncertainty regarding the availability and price of renewable electricity for electrolysis projects, grid congestion, fluctuating policy, and cheaper supplies of renewable electricity and biofuels for the production of renewable fuels abroad (Voulis et al., 2025).

Currently, production capacity for renewable fuels exceeds the volumes required to meet national and European obligations, meaning that the business model for many biorefineries is not viable. For example, the obligations set out by ReFuelEU will only stimulate additional investment in SAF production from 2035 onwards (Figure 6.4). Until then, SAF production capacity will exceed demand by a significant margin.

Figure 6.4 SAF production capacity by technology



Source: SkyNRG & ICF (2025).

Due to the short-term surplus of SAF production capacity, producers consider it risky to invest in additional capacity now, solely to make a profit after 2035. Due to the lack of investment in production facilities at present, a shortage of SAF supply is expected to arise after 2035. Furthermore, the limited availability of feedstocks means that growth in HEFA capacity is constrained, but the current oversupply offers no incentives to explore new feedstocks (SkyNRG & ICF, 2025). Higher short-term renewable fuel obligations – harmonised at EU level – could help to stimulate investment in renewable biorefining and SAF production. The recently published EU

Sustainable Transport Investment Plan (STIP) includes a new set of instruments aimed at mobilising at least €2.9 billion in investments by the end of 2027 ([DG MOVE, 2025](#)).

The introduction of carbon pricing is also useful for supporting investment in sustainable biofuels and enhancing their cost competitiveness relative to fossil fuels. Investment support mechanisms, including double auctions currently used for hydrogen ([H2Global Stiftung, 2025](#) and [Bundesministerium für Wirtschaft und Energie, 2025](#)), can also complement regulatory requirements to enable structural changes and voluntary markets, as in the case of the Sustainable Aviation Fuel Buyers Alliance (SABA). Simplified permitting procedures can also help to support investment in new industrial capacity, while ensuring quality standards, safety and environmental safeguards. To ensure a level playing field, it is also important to establish this at European level. This ensures that products are compatible with existing technologies and infrastructure and facilitates the international exchange of knowledge ([Wimmer & Neuhausen, 2025](#)).

Furthermore, it is important to consider the Dutch and European refining sector in the context of the global economic system. Given the global nature of the refining sector, it is not only important for the Netherlands to keep a strong competitive position within Europe, but also for Europe as a whole to remain competitive on the world market, while at the same time recognising that the total demand for fossil fuels will decline. Additional financing options and cost-effectiveness are decisive factors in this regard. The latter is coming under increasing pressure in the Netherlands and Europe as a result of high energy prices caused by geopolitical tensions. Furthermore, it is important that the EU maintains a level playing field vis-à-vis competing economies worldwide, particularly in a context where many countries outside the EU use state subsidies to attract industrial capacity, whilst some countries can also benefit from a large amount of renewable energy sources (giving them access to energy-efficient and clean forms of energy at low cost).

6.10 Conclusion

Renewable fuels are essential for the decarbonisation of transport, and sustainable biofuels will play a key role in making the transport sector carbon neutral by 2050. Where electrification is not possible, biofuels are currently the most cost-effective alternative to fossil fuels.

By 2050 and beyond, the main demand for biofuels in the Netherlands will come from maritime shipping and aviation, although demand from road transport could also be significant. To meet the demand from these sectors, the availability of sustainable bio-feedstocks must be increased. The EU has the potential to be self-sufficient in the production of advanced bio-feedstocks, primarily through the upscaling of agricultural waste streams. To mobilise this demand, timely policy measures can help make it attractive for European farmers to produce this biomass. There are also other challenges. To ensure a sufficient supply of advanced feedstocks, a robust sustainability framework is needed that covers the entire chain, from the initial collection of waste streams to integration with agricultural production, to prevent the need for additional land (see Annex B).

The current Dutch refining sector provides a basis for establishing a biorefinery cluster capable of producing sustainable biofuels. Despite falling demand for road transport fuel due to electrification and the potentially changing bunkering position of the Port of Rotterdam, shipping and aviation will still constitute a major market for biofuels.

The conversion of fossil fuel refineries into biorefineries requires substantial investment, the securing of a reliable and competitively priced supply of raw

materials, time and policy support. However, it also offers economic opportunities, helps meet the demand for renewable fuels and contributes to strategic autonomy. Taking sustainability criteria into account, the Netherlands has the opportunity – including at European level – to utilise the presence of the (petro)chemical industry and the associated knowledge base to scale up the production of sustainable biofuels, alongside other chemical production that relies on the same feedstock. This also presents an opportunity to build a portfolio of sustainable biomass for the future to meet the demand for all carbon that must no longer be fossil-based from 2050 onwards. With advanced bio-based materials from Europe and a domestic cluster of biorefineries, European value chains for sustainable biofuels can be developed.

7 Hydrogen and e-fuels

Hydrogen (H₂) is a gaseous energy carrier. When hydrogen is used without combustion (for example, in fuel cells), it emits only water vapour (H₂O) and no greenhouse gases.²⁴ Hydrogen can be produced in various ways, including from natural gas or from water using electricity as an energy source (electrolysis). The possibility of producing renewable hydrogen (through electrolysis using only renewable electricity) makes it a potential renewable fuel in the energy transition. At the same time, interest in hydrogen has waned in various sectors, mainly due to challenges in (scaling up) the production of renewable hydrogen and high costs, for example as a result of energy losses in the production chain and difficulties in the transport and storage of hydrogen.

Box 7.1 Types of hydrogen

Different forms of hydrogen are often given colour-based names depending on the production process. For this report, the most relevant types are: renewable, low-carbon **green hydrogen**, produced by electrolysis using renewable electricity; low-carbon **blue hydrogen**, produced from natural gas while the emitted CO₂ is captured and stored (CCS); and fossil **grey hydrogen**, produced from natural gas without CCS. In addition, **white hydrogen**, which occurs naturally, is also mentioned later in this chapter.

The main sectors focusing on hydrogen are those where hydrogen is, or can be, used as a feedstock ([Madeddu et al., 2020](#)), such as the chemical sector (fertilisers, certain refining processes) and possibly also primary steel production, where hydrogen can be used to extract iron from ore (other technological alternatives for this production process include the use of biogenic carbon and/or the deployment of CO₂ capture). Hydrogen may also be applicable in sectors facing technical challenges with direct electrification, meaning that the use of fuels in these sectors will remain necessary. In the transport sector, this means that shipping and aviation are the most likely candidates for hydrogen. Hydrogen may also be an option for heavy long-distance road transport.

E-fuels are synthetic fuels produced from renewable hydrogen and nitrogen (from which e-ammonia is derived) or carbon (from which synthetic hydrocarbons are derived), which can be used as a substitute for fossil fuels. E-fuel made from hydrogen and carbon is a renewable fuel, provided it is produced from hydrogen derived from low-carbon electricity and captured CO₂.²⁵ E-fuels have a high energy density comparable to that of conventional fuels, and many e-fuels are just as easy to store and transport, which is an advantage over the direct use of hydrogen. However, there are two major challenges: the high energy intensity and high costs of the raw materials and the production process, combined with the difficulty of further reducing these production costs, which makes e-fuels even more energy-intensive and expensive to produce than hydrogen. E-fuels are therefore most

²⁴ Burning hydrogen as a fuel also leads to the emission of nitrogen oxides, as their formation depends on the presence of nitrogen in the atmosphere and on the temperature rise that occurs during combustion. After-treatment technologies are required to manage nitrogen oxide emissions, just as with other combustion processes.

²⁵ CO₂ can originate from industrial process emissions, such as in cement production, or be captured from the atmosphere. For CO₂ capture and utilisation (CCU), there are limitations if the CO₂ is not of biogenic origin, as the combustion of e-fuel would still lead to a net increase in CO₂ in the atmosphere. For capture from the atmosphere, direct *air capture* (DAC) is required, an energy-intensive process that is not yet available on a commercial scale.

effective where there is a surplus of renewable electricity that can be utilised for this purpose.

These two challenges mean that the use of e-fuels is most relevant for sectors such as aviation and shipping, as these two modes of transport will be the most difficult to electrify. These sectors will therefore, despite the higher costs, require an alternative fuel with high energy density. E-fuels are also of interest in scenarios where the production and upscaling of alternative options – particularly sustainably produced biofuels – are hampered by, for example, limited availability of raw materials ([ITF, 2024c](#)). Because e-fuels are produced from hydrogen, they are often discussed alongside hydrogen in national hydrogen strategies.

In this chapter, we discuss recent developments and some challenges regarding energy intensity and production costs, and we look at the future of hydrogen and e-fuels in the transport system.

7.1 Hydrogen production is increasing slowly

Currently, hydrogen production is still largely based on fossil fuels, primarily natural gas and coal ([IEA, 2025c](#)). Sectors that have traditionally consumed hydrogen include, in particular, oil refining and the chemical industry, for example for the production of ammonia and fertilisers. The production of low-carbon hydrogen accounts for less than 1% of the global total. Key factors hindering the production of renewable hydrogen include high costs and uncertain future demand, both within and outside the sectors that already use it.

The production of renewable hydrogen via electrolysis is an energy-intensive process that requires a significant amount of renewable electricity and electrolysis capacity. To illustrate: if all trucks and passenger cars in the Netherlands were to switch to hydrogen, a total of 8 GW of electrolysis capacity would be required. This translates not only into a demand for renewable energy that exceeds the current total production of renewable energy in the Netherlands, but also into significant land use for production facilities and infrastructure ([Bakker et al., 2022](#)).

An alternative to hydrogen from electrolysis is producing hydrogen from sources other than renewable electricity. The main competitor is producing hydrogen from natural gas via steam methane reforming (SMR). To limit the climate impact, the CO₂ released during SMR can be captured and stored (CCS). Together with other specific processes (autothermal reforming), emissions can be kept sufficiently low to also use this hydrogen as a low-carbon energy carrier ([Howarth & Jacobson, 2021](#); [Romano et al., 2022](#); [Howarth & Jacobson, 2022](#)). CCS faces challenges in terms of cost and scalability. Furthermore, some authors argue that a focus on SMR with CCS could lead to a counterproductive 'lock-in' effect, as this could perpetuate the energy system's dependence on fossil fuels and slow down the development of renewable hydrogen from electrolysis, unless policies are implemented to prevent such a situation ([Van Cappellen et al., 2018](#)).

In 2025, the expected production capacity of low-carbon hydrogen by 2030 (based on announced projects) fell for the first time. This applied to both electrolysis projects and projects involving SMR and CCS. The cancellation, scaling back or postponement of future electrolysis projects accounted for 80% of this decline in expected capacity ([IEA, 2025c](#)).

Additional challenges for hydrogen include the difficulty of storing and transporting it. Compressing and/or liquefying hydrogen to facilitate its transport is expensive and energy-intensive. E-fuels are easier to store and transport, but producing e-fuels from hydrogen also entails additional costs and a loss of efficiency. Furthermore, the risk of hydrogen gas leaks – a greenhouse gas with a global

warming potential more than ten times higher than that of CO₂ ([Sand et al., 2023](#)) – may contribute to climate change.

Overall, the well-to-wheel efficiency of renewable hydrogen in hydrogen fuel cell vehicles is approximately 25% ([Bakker et al., 2022](#)), which is about one-third of the efficiency of direct electricity use in battery electric vehicles.

Problems with infrastructure and end-use efficiency contribute to cost challenges and hinder confidence in large-scale future demand for hydrogen, whilst a positive outlook for large-scale demand is, in fact, a prerequisite for a significant increase in hydrogen production and distribution. This is, at least in part, a matter of interdependence (or a 'chicken-and-egg scenario'): some of the challenges facing the hydrogen sector could be mitigated if there were sufficient demand, but demand will not grow without sufficient availability of hydrogen at competitive costs.

7.2 Challenges in scaling up hydrogen in road vehicles

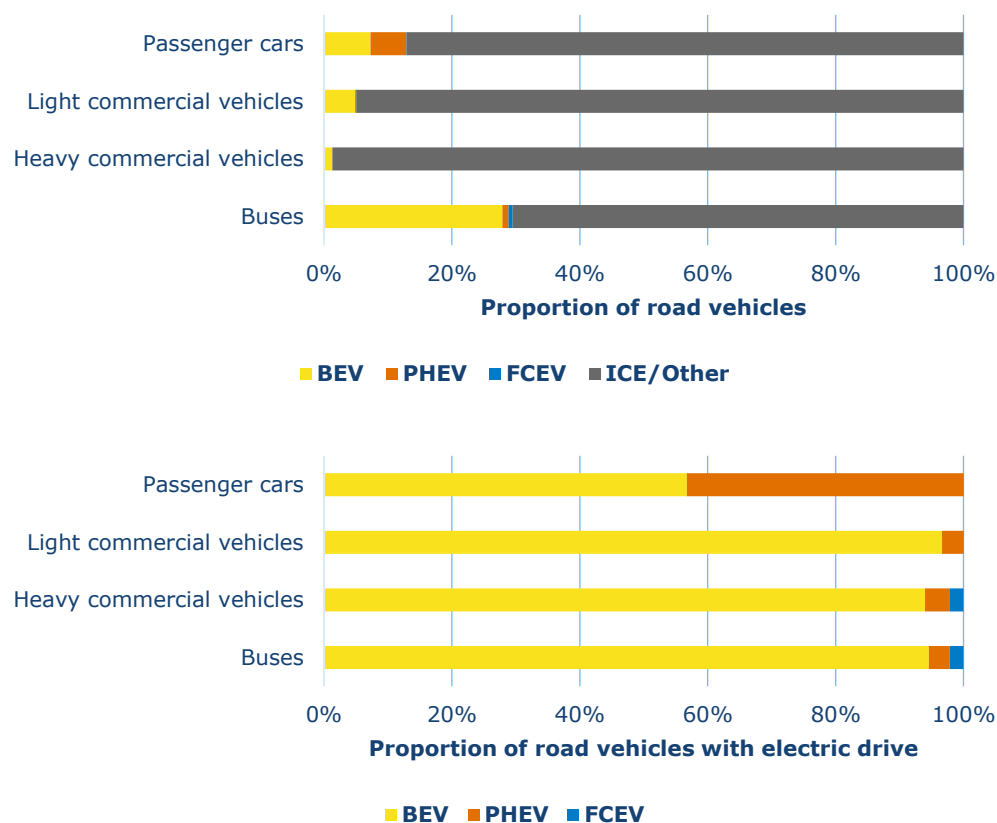
Expectations and scenarios on the use of hydrogen in road transport have changed over time. Before the developments in battery technology and charging infrastructure over the past decade, hydrogen was a promising alternative for fossil fuels, as fuel cell electric vehicles (FCEVs) could be refuelled more quickly than battery electric vehicles (BEVs) and had a greater range that was closer to that of internal combustion engine vehicles (ICEVs). However, recent technological developments have significantly reduced the advantage of FCEVs over BEVs, while the disadvantages of higher costs and lower fuel availability may persist, particularly in the passenger segment ([ITF, 2021](#); [Plötz, 2022](#)).

For road freight transport, hydrogen may be a better option, although recent technology analyses and market signals also point to a growing preference for direct electrification in this sector ([Plötz, 2022](#); [Gründler & Kammel, 2021](#); [ITF, 2021](#); [ITF, 2022](#); [Soulopoulos et al., 2025](#)), just as for lighter road vehicles. A study by Zhang et al. ([2025](#)) shows that for hydrogen fuel cell trucks, both vehicle and fuel costs are higher than for battery-electric or diesel vehicles, and that this is likely to remain the case in the future. According to this review, this higher *total cost of ownership* (TCO), combined with the current lack of large-scale production of renewable hydrogen, is likely to lead to the electrification of local and regional freight transport, leaving only 'long-distance transport' (> 500 km, 25–49 t gross vehicle weight) remaining a potential viable option for hydrogen, due to potential practical limitations to electrification in this segment in the medium term.

The uptake of hydrogen fuel cell electric vehicles (FCEVs) in the Netherlands is slow compared to other low-emission vehicles such as BEVs and plug-in hybrids (PHEVs), partly hampered by the lower availability of both hydrogen vehicles and hydrogen itself.

In January 2026, the number of FCEVs on Dutch roads was approximately 1,000 times lower than the number of BEVs (Figure 7.1). Hydrogen has a greater share in heavy commercial vehicles and buses, but even there the uptake of BEVs is currently much higher (a ratio of approximately 1 hydrogen vehicle for every 30 electric vehicles).

Figure 7.1 Share of the road vehicle fleet powered by different types of electric drivetrains in the Netherlands (31 January 2026)



Note: Hydrogen-powered vehicles with internal combustion engines are not listed separately from conventional vehicles with internal combustion engines.

Source: KiM; data from RVO (2026).

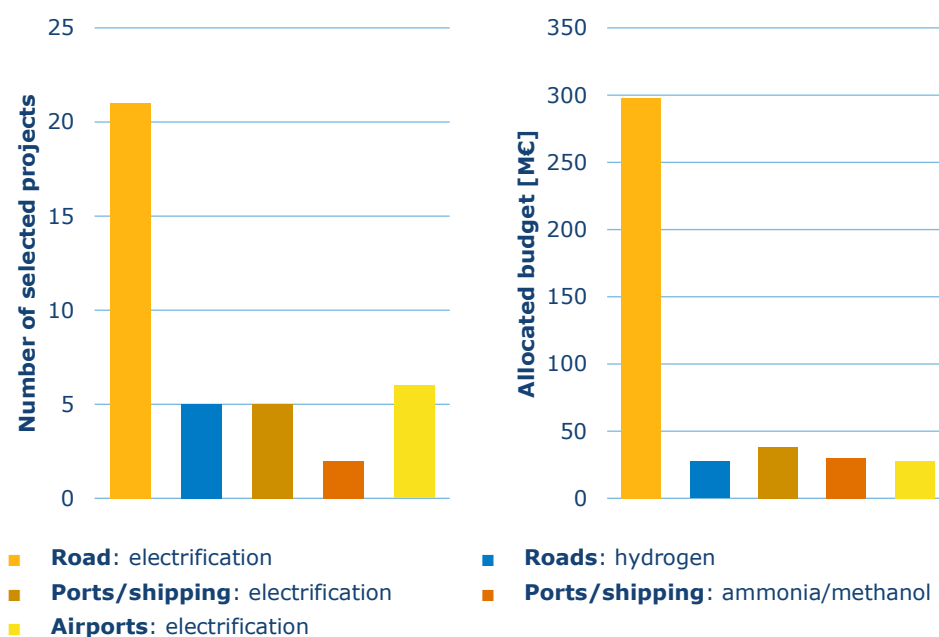
Nevertheless, the number of heavy-duty hydrogen vehicles is increasing. The Dutch government has various policy measures in place to stimulate the development of hydrogen across the entire value chain. With regard to the distribution of and demand for hydrogen, the SWIM subsidy (Hydrogen in Transport Subsidy Scheme) offers financial support to consortia investing in both hydrogen refuelling stations and heavy-duty vehicles. SWIM is open for applications annually and runs from 2024 to 2029. In the 2024 SWIM round, funding was awarded for a further 192 trucks, 10 passenger vans and 9 other light vehicles (National Hydrogen Programme, 2024). In the 2025 round, funding was granted for a further 355 vehicles (RVO, 2025a). SWIM primarily subsidises FCEVs, although heavy goods vehicles and buses equipped with a hydrogen ICE are also eligible for the subsidy.

In their overview of the decarbonisation of trucks, Zhang et al. (2025) indicate that by 2040, battery technology will be sufficiently developed to electrify more than 70% of European road transport, with trucks needing to be charged only once a day. Furthermore, fast chargers and mega-chargers are being installed along Dutch and European motorways, enabling recharging during a trip. This suggests that electrification has great potential for road transport, even in segments where this seemed unlikely just a few years ago. There may still be segments of road transport where electrification is not possible or desirable. In such cases, hydrogen – or e-fuels/biofuels – could be an option. This remaining segment consists mainly of heavy long-distance transport (> 500 km and 25–49 tonnes gross vehicle weight,

according to [Zhang et al., 2025](#)). In one of the scenarios for a pathway to carbon-neutral road transport, PBL considers the possibility that 20% of zero-emission trucks will be running on hydrogen by 2050 ([Van Meerkerk et al., 2024](#)).

Like SWIM, the EU has various schemes and targets to support the development of alternative transport fuels. The Alternative Fuels Infrastructure Facility (AFIF) has been established for energy supply infrastructure along the European TEN-T transport corridors. The projects selected in the first round, which concluded in 2024, are primarily focused on the electrification of road transport, with hydrogen in second place. The allocated budget is also heavily focused on electrification solutions (Figure 7.2). This is also evident from the expected results: “With this selection, the AFIF will support approximately 2,500 electric charging points for light commercial vehicles and 2,400 for heavy commercial vehicles along the European TEN-T road network [and] 35 hydrogen refuelling stations for cars, trucks and buses [...]” ([European Climate, Environment and Infrastructure Executive Agency \[CINEA\], 2025](#)).

Figure 7.2 Types of projects funded in the first AFIF round and associated budget



Source: KiM; data from CINEA ([2025](#)).

Policy scenarios: high costs for hydrogen in scenarios, limiting its role

As described, costs are the main factor making hydrogen FCEVs less viable than BEVs. This is due to the costs of the FCEVs themselves, which are more complex than BEVs, and of the hydrogen fuel – particularly because of the inherent efficiency losses in producing hydrogen from electricity. European hydrogen production costs are expected to fall to almost half of current levels (e.g. [Frieden & Leker, 2024](#); [Zhang et al., 2025](#)); but even then, the total cost of ownership (TCO) for heavy-duty battery electric vehicles is expected to fall more sharply and potentially reach cost parity with conventional diesel trucks much sooner than hydrogen fuel cell vehicles. As with the development of hydrogen fuel production and infrastructure, this is likely to have a self-reinforcing effect: a mature business case for battery electric vehicles further reduces the likelihood of a breakthrough for hydrogen vehicles in the road transport sector ([Zhang et al., 2025](#)).

7.3 Dutch policy scenarios for hydrogen

In view of the above, various recent studies and policy documents point to a modest role for hydrogen in the future mobility system (see Figure 3.5). The NPE (National Energy System Plan) states that until 2035 there will be little low-carbon electricity available for the production of hydrogen and e-fuels and that choices must be made regarding the production and consumption of these energy carriers ([EZK, 2023](#)).

According to the NPE, by 2050 hydrogen and hydrogen derivatives should primarily be used in (industrial) sectors for which no reasonable alternative to decarbonisation exists. In the transport sector, this amounts to (international) shipping and aviation.²⁶ This is in line with the forecasts by mode of transport from, among others, the NPE and the PBL discussed in Chapter 4.

Even if the focus is on e-fuels, and there is no direct use of hydrogen in sectors such as aviation and shipping, this could mean that hydrogen production will need to be scaled up significantly. This is because hydrogen is a required input for e-fuels. Furthermore, due to the additional losses in the production chain, a large amount of renewable electricity would also be required.

7.4 Hydrogen strategies in some other countries

Similar conclusions have been drawn internationally. For instance, the French government states in its national hydrogen strategy that hydrogen will play a key role in the decarbonisation of industry and 'certain forms of transport'. For road transport, including freight transport, electrification and BEVs are considered more efficient and affordable, except in specific cases, such as very long-distance transport or other energy-intensive purposes. In aviation and shipping, hydrogen is expected to be significant, either directly or as a feedstock for the production of e-fuels. For aviation, these hydrogen-based fuels will be the main renewable energy carrier ([Ministère de l'Économie, des Finances et de la Souveraineté industrielle, énergétique et numérique et al., 2025](#)).

The Belgian hydrogen strategy also prioritises electrification over hydrogen and indicates that light commercial vehicles and passenger cars are likely to run entirely on electricity by 2050, while hydrogen and electricity will compete with each other for heavy road transport. Maritime and aviation will be the main modes of transport where hydrogen will be used, albeit in the form of hydrogen-based ammonia and methanol or in the form of hydrogen-based e-kerosene, in maritime and aviation respectively ([Federal Public Service Economy, 2022](#); [Commission for the Regulation of Electricity and Gas, 2024](#)).

The German hydrogen strategy also states that hydrogen and e-fuels "will be needed primarily in the aviation and shipping sectors" and that hydrogen will play a role primarily in industry, aviation, shipping and heavy road transport only. The potential of liquid hydrogen or e-fuels, particularly for short and medium-haul flights, is specifically mentioned ([Federal Ministry for Economic Affairs and Energy, 2024](#)).

In Italy, a document commissioned by the Ministry of Infrastructure and Sustainable Transport under the Draghi government also pointed in the same direction: maritime and aviation will be the main modes for the application of hydrogen. The Italian guideline for the decarbonisation of transport focuses on improvements in energy efficiency and fuel switching, is open to the electrification of short flights in

²⁶ Long-duration energy storage could be another application. In this case, hydrogen competes with established technologies (interconnectors and pumped storage plants, which are already in use in Scandinavia) and emerging technologies (such as liquid and/or compressed air storage, long-duration energy storage in batteries, or thermo-mechanical energy storage).

aviation, and highlights a number of remaining challenges for hydrogen as an energy carrier for aviation ([Armaroli et al., 2022](#)).

7.5 New developments in the hydrogen sector: naturally occurring hydrogen and direct electrolysis

Several recent developments in the hydrogen sector may potentially shed new light on some of the arguments against the use of hydrogen or e-fuels in transport.

One such development is the discovery of, and growing interest in, [naturally occurring hydrogen](#). If it were possible to extract, transport and store sufficient quantities of it efficiently, naturally occurring hydrogen could supplement the supply of other forms of hydrogen. Recent studies suggest that a large quantity of white hydrogen may be available ([Ellis & Gelman, 2024](#)). Other analyses indicate that the production levels achieved to date are far too low in relation to global energy demand ([Centre national de la recherche scientifique, 2024](#)). Large-scale extraction would also only be feasible under certain geological conditions, but to date no source of hydrogen has been found that meets these conditions ([Everts et al., 2025](#)). The actual availability and commercial viability of naturally occurring hydrogen, as well as the underlying natural mechanisms of its formation and storage, are also still the subject of research ([Katz, 2025](#)).

The available research on naturally occurring hydrogen does not yet suggest that this will be a major factor in the energy system. Even in cases where extraction is feasible on a large scale and at low cost, the implications of naturally occurring hydrogen, particularly for the Dutch transport sector, are still subject to challenges regarding the costs of transport, distribution and storage (at filling stations and on board). Should naturally occurring hydrogen become widely available and find applications in large stationary end-users (such as industry), it could also become more attractive for applications in the transport sector. The benefits could be greater if naturally occurring hydrogen could be obtained (relatively) locally, thereby avoiding costly transport and conversion processes.

Renewable hydrogen is usually produced from electricity generated by wind or solar farms and transported via the electricity grid to an electrolysis plant. This means that conversion losses occur and that factors such as grid capacity play a role. Initiatives are being developed for [direct electrolysis](#), whereby hydrogen is produced on-site (for example, at a wind farm) without the need to transport electricity over long distances. This can significantly reduce the costs of producing renewable hydrogen ([Groenemans et al. 2022](#)), but requires the construction of infrastructure to transport hydrogen to the point of use and, consequently, large-scale off-take agreements to cover the investment risks. The Dutch government had plans to support the development of two pilot projects. However, these have been suspended for five years under the 2025 Climate and Energy Policy Document, due to lower expected demand and higher expected costs ([KGG, 2025](#)).

7.6 Summary and conclusions on hydrogen and e-fuels

Hydrogen and e-fuels remain an important part of the future energy system. Hydrogen is an energy carrier that can be produced in a renewable manner without dependence on fossil fuels and with fewer practical drawbacks than electrification. E-fuels produced from hydrogen can be used more easily than hydrogen itself in existing types of engines.

On the other hand, primary energy consumption and the costs of hydrogen or e-fuels are much higher than for direct electrification, and the heat recovery efficiency is lower. This means that hydrogen or e-fuels should be prioritised in cases where electrification is not practically feasible for economic or practical reasons, such as

physical constraints (as in aviation, due to the extra weight of batteries). This view is shared by various Dutch sources and by the hydrogen strategies of neighbouring countries. In practice, this means that the most likely applications for hydrogen and e-fuels in the mobility sector will be in aviation and international shipping, as well as a (still uncertain) share in the future energy mix for inland waterway transport. For road transport, recent literature suggests that passenger transport and the majority of freight transport are likely to be fully electrified; only in long-distance transport for heavy freight does a potential application for hydrogen remain. It is still uncertain how limited this application is and for which segments of road transport, but at present this cannot be ruled out.

Due to the interdependence of hydrogen uptake and the development of large-scale hydrogen production and infrastructure, there is a risk that neither will get off the ground. This could be exacerbated by waning interest in some sectors, such as the recent suspension of offshore projects for renewable hydrogen in the Netherlands. Furthermore, PBL and the NPE point out that the current policy to encourage hydrogen production and use is insufficient to achieve the policy objectives for hydrogen in the energy system. It is therefore important that policy choices regarding hydrogen and e-fuels are targeted at the right sectors (in line with insights into practical applicability) and take a long-term view of the energy transition in the sectors expected to be supplied by these energy carriers.

8 Energy demand reduction

8.1 Arguments for reducing energy demand

One of the arguments for energy saving is that EU Member States are legally obliged to do so under the Energy Efficiency Directive (EED) (EU/2023/1791). The EED sets out national targets for primary and final energy consumption in 2030. All end-use sectors, with the exception of maritime transport, fall under the EED. The Netherlands has chosen not to allocate the national energy efficiency target across different sectors. PBL (2024) reports that it is unlikely that the Netherlands will meet the 2030 target.

More substantive arguments for energy saving that are frequently cited in policy documents such as the NPE, ministerial letters to the Parliament, etc. ([Bakker & Moorman, 2025a](#)):

- It reduces CO₂ emissions (if the energy sources are fossil fuels). As a result, energy savings contribute to reducing cumulative CO₂ emissions between now and 2050, making it easier to stay within the carbon budget required to limit global temperature rise to 2 degrees.
- The challenge of becoming carbon neutral is reduced because less investment is required in the production, large-scale transport and distribution of energy (affordability of the energy system).
- It reduces the risk of future scarcity (and thus rising prices) of energy carriers, particularly hydrogen (and e-fuels) and biofuels, which could make achieving climate neutrality considerably more expensive.
- It reduces dependence on other countries, for example for the import of raw materials and fuels (security of supply).
- It reduces energy bills for citizens and businesses (affordability).
- It reduces land use because there is less need for raw materials and the production of energy carriers (efficient use of resources).

Despite these benefits, it is not easy to design effective energy efficiency strategies. This may be due, for example, to technical, behavioural or political challenges in policy design. Furthermore, energy savings can be partially offset by an increase in energy consumption resulting from growth in activity. This is also known as the rebound effect. For example, if electric vehicles are cheaper per distance travelled than vehicles with internal combustion engines, electrification can lead to an increase in the total distance travelled and thereby energy consumption.

Energy savings can be achieved through electrification, but also as a result of more efficient vehicle use, a shift towards more efficient modes of transport, or a reduction in demand for transport. This is also known as the Trias Mobilica or 'avoid-shift-improve' approach ([Creutzig et al., 2022](#); Bakker & Moorman, 2025a). In this chapter, we highlight some examples of possible strategies for energy efficiency.

8.2 Electrification has a major impact on primary energy consumption, but particularly in the longer term

As mentioned earlier, electric cars, vans and trucks save around two-thirds of primary energy compared to comparable vehicles with internal combustion engines. As of 2025, around 7% of the 9 million passenger cars in the Netherlands and less than 1% of trucks are fully electric. Given the ongoing policy support and falling battery costs, the transition to electric transport on the roads is expected to continue and eventually become self-sustaining (Chapter 5). However, due to the slow replacement of the vehicle fleet, it will take several more decades before

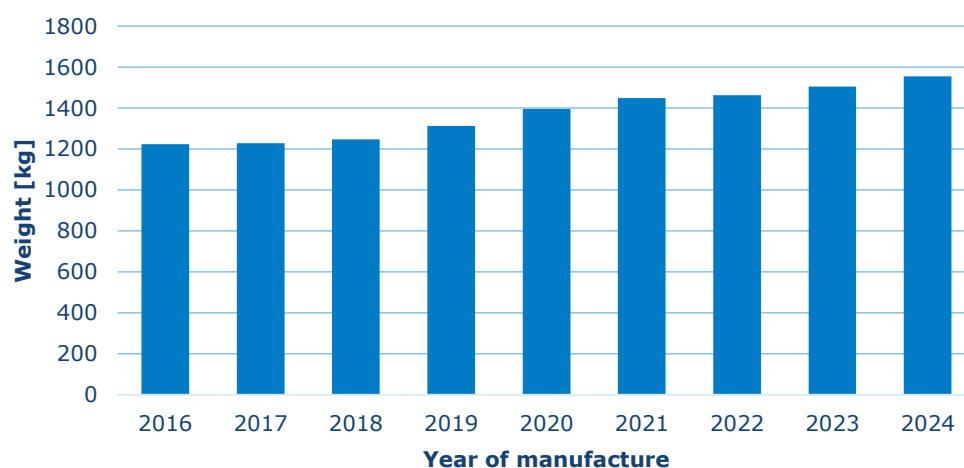
electrification is (almost) complete. Passenger cars in the Netherlands now reach the end of their service life after 20 years ([Auto Recycling Nederland, 2025](#)), while vans and trucks have a shorter lifetime ([Kok et al., 2024](#)). In other words, the energy efficiency of road transport will gradually improve over the coming decades thanks to advancing electrification.

On the other hand, with increasing electrification, government revenue from excise duties on road fuels will decline, as also discussed in Chapter 5. If it is a government objective to maintain this revenue, there are various options for adapting the system of vehicle taxes. These options have different effects on other policy objectives such as affordability, congestion, accessibility and the living environment. No single policy option is beneficial for all objectives; a trade-off will have to be made ([Knoope et al., 2025](#)).

8.3 Cars are getting bigger despite tax incentives for smaller cars

At the same time, passenger cars are becoming heavier and larger (Figure 8.1; [CBS, 2025a](#)). Furthermore, the rise in SUVs is increasing the height of cars, which in turn increases aerodynamic drag and energy consumption.

Figure 8.1 Average weight of passenger cars in the Netherlands by year of manufacture, as at 1 January 2025



Source: KiM; data from CBS ([2025a](#)).

This trend towards larger cars may have arisen due to 1) consumer preferences, combined with 2) car manufacturers focusing on more expensive models that yield higher profits than smaller cars, and 3) a rebound effect from improved engine efficiency and aerodynamics: due to lower fuel costs for the same model, buyers are opting for larger car models that have a similar energy consumption to smaller models from a few years ago.

The shift towards electric vehicles contributes to the increasing weight of vehicles, but the impact of weight on the energy efficiency of electric vehicles is much smaller than that of vehicles with internal combustion engines (see Figure A.2 in Appendix A). Cazzola et al. ([2025](#)) argue that the shift towards the production of smaller electric vehicles may offer opportunities for European industry, alongside other benefits such as energy efficiency and lower material consumption.

According to the WLO scenarios with low economic growth ([CPB & PBL, 2025](#)), the number of passenger cars in the Netherlands remains fairly stable at 9 million vehicles, while in the high-growth scenarios it could rise to 13 million vehicles by 2060. In light of this potential strong growth, trends in car size are even more relevant. In addition to energy consumption, the trend towards larger cars leads to

greater use of parking space, which can be a particular problem in cities where the dimensions of parking spaces are based on car sizes from many decades ago. Other consequences include an increase in the use of raw materials, such as steel²⁷, aluminium and plastic, and rare earth metals and other metals in the case of electric vehicles ([Zijlstra et al., 2022](#)).

This trend is clearly visible despite a progressive tax system: the annual road tax (MRB) rises sharply based on the vehicle's weight, whilst the purchase tax (BPM) also implicitly rises based on weight, as the tax rate depends on CO₂ emissions. Policy makers face a choice: maintain the current tax system or adjust the car tax system (and implement other policy measures) to counter the trend towards larger vehicles.

8.4 The potential of LEVs to replace car and van journeys

On the other hand, light electric vehicles (LEVs) are becoming increasingly popular, ranging from e-bikes and electric cargo bikes to electric scooters and microcars ([ITF, 2023](#)). The fleet of the latter, also known as 'light motor vehicles', has increased by 40% since 2020 to around 24,000 vehicles (electric and ICE)²⁸. There are two categories: L6e up to 350 kg and a maximum speed of 45 km/h, and L7e up to 450/600 kg (passengers/cargo) and 90 km/h.

Currently there is no road tax in the Netherlands, but also no EV incentives for these vehicles. The EU's initiative for small, affordable cars aims to boost the European car industry, but focuses on standard models up to 4.2 metres²⁹ and does not include LEVs.

Smaller vehicles are highly efficient. A micro-EV, for example, consumes just 0.07 kWh per km ([ITF, 2023](#)), while the average for all current EV models is three times higher ([EV Database, 2025](#)). An e-moped is even more efficient, at 0.02 kWh/km ([ITF, 2023](#)).

LEVs currently mainly replace journeys made by bicycle, ICE two-wheelers and public transport, but the proportion of LEV journeys replacing car journeys is also significant, with research findings in the Netherlands reaching up to 40% (Van de Coevering, 2025). According to De Haas & Huang ([2022](#)), there is also potential for e-bikes to replace more car journeys, given that, for example, 30% of commuting trips of up to 9.5 km are made by car. They estimate that e-bikes could potentially replace 2% of the total distance travelled by car in the Netherlands.

As regards logistics, it is estimated that light electric freight vehicles could replace 10–15% of urban van trips, particularly in delivery services and food logistics ([Knoope & Kansen, 2021](#)). A major barrier for businesses is that lower payload capacity may mean more drivers and/or more trips are required, leading to higher costs.

8.5 Truck tolls and road pricing will improve energy efficiency in various ways

From 2026, a distance-based truck toll (heavy good vehicle charge) will apply to lorries on Dutch roads. For a standard EURO 6 diesel lorry (>32 tonnes), the charge is 17 cents per kilometre, but vehicles that emit less CO₂ pay less. Zero-emission trucks, such as electric vehicles, pay just 4 cents per kilometre.³⁰ This is a strong incentive for electrification. Kok et al. (2024) expect, initially as a result of the truck toll and the fall in battery prices, but also due to European CO₂ standards, a 10–

²⁷ In Europe, the automotive industry is the largest consumer of aluminium and the second-largest consumer of steel. For the production of new cars, the majority of materials are extracted from new sources ([Zijlstra et al., 2022](#)).

²⁸ <https://www.autoweek.nl/autonieuws/artikel/aantal-brommobielen-in-nederland-enorm-hard-gegroeid/>

²⁹ To illustrate: a Volkswagen Up is 3.6 metres long.

³⁰ <https://www.vrachtwagenheffing.nl/dit-gaat-u-betalen>

20% share of electric vehicles in the Dutch truck fleet by 2030, 30–55% by 2035 and 60–80% by 2040.

The costs of road transport will rise as a result of the truck toll. This provides an incentive to increase load factors, so that more cargo can be transported over the same distance, and/or to use shorter routes (route choice effect)³¹. Furthermore, rail and inland waterway transport will become more competitive. However, other policy measures are also needed to make inland waterway transport and rail more attractive in order to achieve a 'shift' (push and pull approach), including investments in infrastructure, promoting digitalisation and reducing regulatory barriers ([Bloemheuvel et al., 2020](#)).

Distance-based pricing for passenger cars will have similar effects. A road user charge is expected to lead to fewer car journeys, a lower total distance travelled by all cars combined, and less congestion ([Knoope et al., 2022](#)). If the introduction of a road pricing scheme is accompanied by a reduction in purchase tax or registration fees, this may lead to higher car ownership. If the rate is differentiated based on, for example, specific CO₂ emissions or the size/weight of the vehicle, there is an incentive to purchase more energy-efficient vehicles.

8.6 The reduction of the speed limit from 130 to 100 km/h has saved 4% of energy in road passenger transport

In March 2020, the speed limit on motorways (main road network) in the Netherlands during daytime (6.00–19.00) was reduced from 130 or 120 to 100 km/h. As a result, the average speed of passenger traffic fell by 9–12 km/h to 104 km/h, or 102 km/h when adjusted for changes in traffic volume (due to the COVID-19 pandemic) ([Rijkswaterstaat, 2021](#)).

Lower speeds lead to energy savings thanks to reduced fuel consumption: per kilometre driven, a reduction in speed from 11–14 km/h to 102 km/h results in a 7–9% reduction in fuel consumption, as estimated based on the speed-efficiency relationships in Umwelt Bundesamt ([2020](#)). Passenger cars cover approximately 50% of the total distance driven in the Netherlands on motorways (CBS data in [Knoope et al. \(2020\)](#)). We therefore estimate that the reduction in the maximum speed in 2020 led to a saving of approximately 4% on the total energy consumption of passenger cars.³²

³¹ Furthermore, the toll acts as an incentive for the Super EcoCombi, a combination of a truck and semi-trailer with a tractor unit and two semi-trailers, measuring up to 13.6 metres in length and with a load capacity of up to 72 tonnes. Currently, this combination is not permitted on Dutch roads, but the Ministry of Infrastructure and Water Management plans to carry out tests and pilot projects to assess whether the Super EcoCombi can be authorised in the future. The efficiency gains could be significant for a given journey from origin to destination if it replaces these two standard vehicles. As the new large vehicle cannot be used for all journeys, the energy saving is expected to amount to approximately 1% of total road transport fuel consumption (CE Delft in [Bakker & Moorman, 2025a](#)).

³² It should be noted that this figure may be lower because less than half of petrol consumption may occur on motorways, or higher because 1) driving speed is less dynamic (accelerating and braking), 2) different routes are chosen because shorter routes become more attractive at a speed limit of 100 km/h, and 3) the total distance travelled decreases due to longer journey times.

9 Conclusion

The energy system is changing

The energy transition is no longer merely necessary for achieving climate targets, but also offers opportunities for energy security in an increasingly unstable geopolitical world. This geopolitical uncertainty also creates a greater need for technical expertise and raw materials. This means that Europe, and the Netherlands in particular, is on the cusp of an industrial transformation that will affect the petrochemical industry. The new energy system is evolving and will take decades to develop, a process accompanied by significant uncertainties.

Scaling up the production and application of renewable energy carriers

What is certain is that all renewable energy carriers – electricity, hydrogen, biofuels and e-fuels – will need to scale up further, both in terms of production and application across the various modes of transport. This scaling up will not happen automatically: it represents a major policy challenge. Partly, this will be achieved through the implementation of existing policy; partly, additional measures will be required.

Electric transport is often preferred due to higher efficiency and lower total running costs: electrification wherever possible. However, given the large share of bunker fuels for aviation and shipping in the Dutch energy mix, where electrification will (for the time being) be very difficult to implement, a significant amount of biofuels and e-fuels will also be required.

Potential tension between government objectives

The various targets in the energy transition for transport often reinforce one another but can also conflict.

When we look at energy supply security, we see opportunities for improvement through diversification of energy sources towards electricity and biomass, particularly if the sources for these are found within the EU. When importing raw materials from outside the EU, a broad base of suppliers is a key consideration for the government, in order to limit strategic dependencies. For electricity, the variability of supply and demand and the increase in grid congestion are areas of concern – although electric vehicles (EVs) can actually play a positive role through *smart charging* and *vehicle-to-grid*.

When it comes to the goal of industrial competitiveness, the picture is mixed. The European automotive industry has focused on electric vehicles much later than China. As China is now further ahead and the transition to EVs has clearly begun, including through European policy, the automotive industry in the EU will have to accelerate the shift to EV production. Crucial tasks in this regard include the restructuring of domestic production chains and reducing the cost of batteries. For the petrochemical cluster in the Port of Rotterdam, there are challenges posed by a potential decline in demand for fossil fuels and a changing international competitive position, but also opportunities to make the switch to the production of sustainable fuels.

From the perspective of affordability for citizens, driving an electric vehicle is likely to be cheaper on average in the long term than driving a car with a combustion engine. However, it is a challenge to make this a reality for households and businesses without their own parking space or solar panels, for whom charging is more expensive, and also for those who rely on the second-hand market. Equity, or

the distribution of costs and benefits across different groups and over time, therefore remains a key consideration to maintain public support.

Uncertainties and opportunities: adjusting policy

This potential conflict of objectives, alongside inherent uncertainty in technological and administrative developments ([Geilenkirchen et al., 2024a](#)) and geopolitics, presents a complex task for policymakers. Citizens and investors want long-term certainty, but in practice it will be necessary to make adjustments along the way to keep the various objectives in balance: adaptive policy. This is an approach to dealing with uncertainties and opportunities in a smart and constructive way by explicitly recognising them in the decision-making process ([KiM, 2017](#)). Below, we offer some suggestions regarding the questions that may arise in practice to help monitor this balance.

First and foremost, it is essential to have as clear a picture as possible of the various objectives. In this regard, it is important to prioritise these objectives in relation to one another, possibly through public debate. Which objectives take precedence, and are there, for example, minimum requirements for other objectives? What might a potential shift in priorities lead to?

Next, it is important to define the objectives sufficiently. Climate objectives are clear for the long term and provide a dot on the horizon. For security of supply, the necessary emergency reserves for crisis situations are well established, but this does not apply to limiting risky dependencies. Aiming for 100% self-sufficiency in the EU is not necessarily realistic or necessary. How much dependence on imports from outside the EU is acceptable, and from which countries?

It is not possible to predict when and how adjustments can be made due to uncertainties in technological development and administrative factors such as EU policy. Moreover, goals and priorities may shift – these are a matter of political judgement. However, policymakers can monitor potential ‘tipping points’ and developments in order to make more proactive adjustments. To illustrate this, we provide some examples in Table 9.1. We note that not all bottlenecks or trigger points can be resolved or mitigated through policy. Many developments are the result of market forces, over which policy has only limited influence in the current system. And sometimes, less policy rather than new measures may be desirable.

Table 9.1 Examples of trigger points that may justify adjustments to the policy strategy and possible associated indicators

Policy strategy	Scaling up biofuels	Electrification of passenger cars and vans	Zero-emission lorries	Making internal combustion engine (ICE) vehicles more sustainable
Interim target for energy mix or CO ₂ emissions in the EU	<ul style="list-style-type: none"> • 20% SAF in aviation (2035) • 14.5% CO₂ reduction in shipping (2035) • Potential RED IV targets (post-2030) 	<ul style="list-style-type: none"> • 90% reduction for new vehicles (European Commission proposal) (2035) 	<ul style="list-style-type: none"> • 90% emissions reduction for new trucks (2040) 	<ul style="list-style-type: none"> • Road fuel suppliers with few CO₂ allowances: high share of renewable fuels for ICE vehicles (2040)
Potential trigger points	<ul style="list-style-type: none"> • Scarcity of bio-based raw materials • Risky dependence on non-EU sources • Limited production capacity • Loss of competitiveness of the petrochemical cluster 	<ul style="list-style-type: none"> • Grid congestion hinders electrification • Affordability 	Grid congestion hinders the uptake of BEV trucks	<ul style="list-style-type: none"> • HVO shortage; • Other drop-in fuels are expensive • Limited options for petrol engines • Limited refuelling options (especially in rural areas)
What is needed to address these issues?	<ul style="list-style-type: none"> • Expansion of bio-feedstock production in Europe and import opportunities • Policy consideration: should SAF production capacity be encouraged? 	<ul style="list-style-type: none"> • Addressing grid congestion further • Stimulating the second-hand EV market 	<ul style="list-style-type: none"> • Policy consideration: to what extent should H₂ be promoted for trucks as a backstop option for electrification? 	<ul style="list-style-type: none"> • Policy consideration: what is the risk of high fuel prices for drop-in fuels, and is this a problem? Does it make sense to take action on this by promoting engine modifications?
Possible indicators	<ul style="list-style-type: none"> • What is the expected availability of bio-based raw materials within and outside Europe based on current policy? • How dependent is the Netherlands on a few energy suppliers from outside Europe? • Biofuel prices by mode of transport • Build-up of renewable fuel production capacity in the Netherlands/EU 	<ul style="list-style-type: none"> • Availability and total user costs of second-hand EVs in small segments 	<ul style="list-style-type: none"> • Progress of electrification for the heaviest road transport segment • Price trends and forecasts for renewable hydrogen 	<ul style="list-style-type: none"> • To what extent are vehicles for non-drop-in fuels available? • Interest among vehicle manufacturers in bringing these to market • Road fuel prices • Share of ICE vehicles in the freight and passenger vehicle fleet • Availability of refuelling points, especially in rural areas

The examples are based on the challenges outlined in Chapter 5-7 and the policy objectives shown in Figure 3.1.

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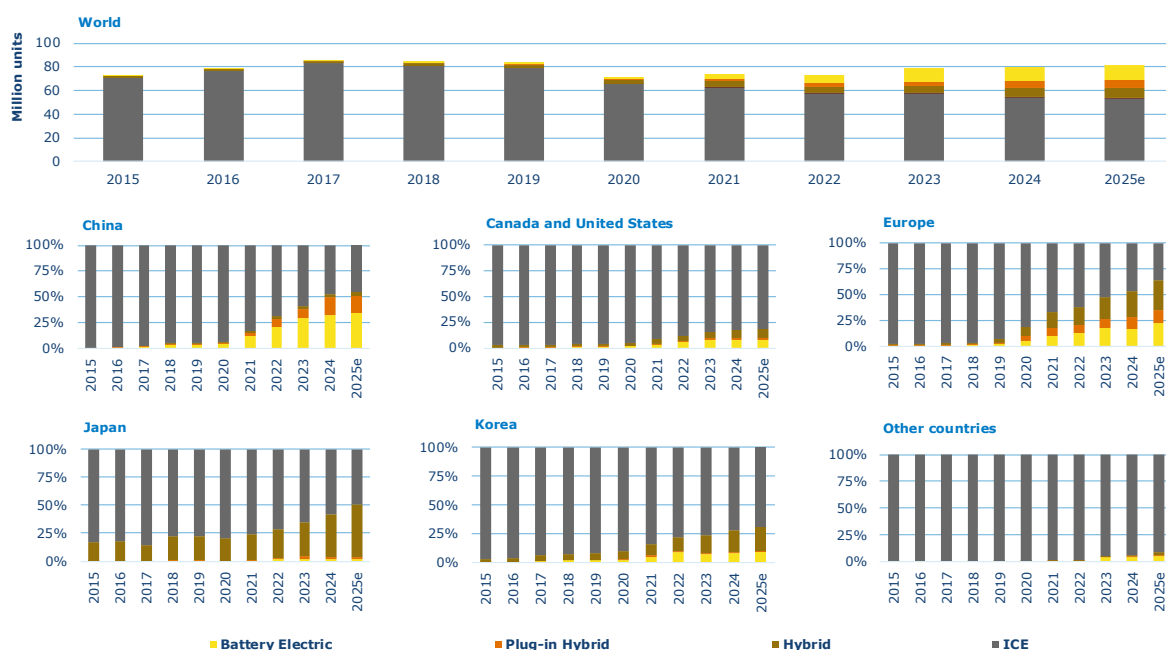
Appendix A Background on electric vehicles

Sales of electric road vehicles are rising across all segments

Electric transport has evolved from a niche option into a central pillar of innovation in automotive strategies worldwide. In 2024, global sales of electric cars (including battery electric and plug-in hybrids) reached 17.5 million units, meaning that more than a fifth of global passenger car sales were electric. Forecasts and estimates for 2025 predict sales of nearly 20 million electric cars ([S&P Global, 2024](#), [IEA, 2025b](#), [EV Volumes, 2025](#), [BloombergNEF, 2025](#)), with an already visible increase in China, the EU and emerging economies, and stagnation or decline in the United States. Around two-thirds of the total consisted of, and is expected to consist of, battery electric vehicles, whilst the remainder consists of various types of plug-in hybrids.

Sales of electric cars in the EU amounted to nearly 2.4 million units in 2024 ([IEA, 2025b](#)) and are expected to rise to 25% of light vehicle sales in 2025 ([European Alternative Fuels Observatory \[EAFO\], 2025a](#)), amounting to 2.7 million units. The Nordic countries are leading the way in terms of electric car sales in Europe, with a share of sales of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) ranging from 35% in Iceland to 95% in Norway (based on a 12-month moving average) in August 2025 ([New AutoMotive, 2025b](#)). The Netherlands stands at 41% fully electric in 2025 ([RVO, 2026](#)), a figure that is roughly double the market share in France and Germany.

Figure A.1 Global sales of light commercial vehicles and regional market shares by powertrain, 2005–2025



Source: estimates based on [Cazzola et al., 2023b](#), [EEA, 2026](#), [European Automobile Manufacturers' Association \[ACEA\], 2022](#), [IEA, 2024](#), [Cozzi & Petropoulos, 2024b](#), [Kuhanathan et al., 2024](#), [Allianz Trade, 2025](#), [New AutoMotive, 2025a](#), [S&P Global, 2024](#), [IEA, 2025b](#), [EV Volumes, 2025](#), [BloombergNEF, 2025](#), [EAFO, 2025a](#), [Luman, 2025](#) and [Wimmer & Neuhausen, 2025](#). The figures for 2025 are estimates.

Globally, sales of electric motorcycles between 2021 and 2024 ranged between 6 and 10 million per year, representing a global market share of 15% compared to motorcycles with internal combustion engines ([IEA, 2025b](#)). If we add electric scooters and low-speed mopeds to this, estimated annual sales of two-wheelers

come to between 35 and 50 million units, with China accounting for the lion's share of the increase compared to sales of motorcycles alone. The global market share and sales figures for electric models, including electric scooters and low-speed mopeds³³, stood at between 40 and 50% of total two-wheeler sales in 2024 ([BloombergNEF, 2024](#), [Honda, 2022](#)). In Europe and the Netherlands, electric mopeds account for around a third of sales, while sales of electric motorcycles are still in their infancy (less than 5%) ([Roetynck, 2024](#), [BOVAG, 2025a](#), [Hackmann, 2024](#)).

Global sales of light electric commercial vehicles (vans) stood at 0.65 million units, 7.1% of total sales ([IEA, 2025b](#)), more than double the figure for 2022. The Netherlands is a global leader in the purchase of electric vans, with a market share of over 80% in the first half of 2025, the highest percentage in the world and well above the EU average of 10% ([Soulopolos et al., 2025](#)). New zero-emission zones in Dutch cities and the registration tax were key drivers behind this development.

Global sales of battery-electric lorries reached nearly 100,000 units in 2024, accounting for 1.7% of total lorry sales ([IEA, 2025b](#)) and nearly 90,000 in the first half of 2025, which is almost equivalent to total sales for the whole of 2024 and is on track to reach 4% by the end of the year ([Soulopolos et al., 2025](#)). China accounts for over 90% of total global sales, with half of the trucks sold domestically being electric. In Europe, sales of electric heavy-duty vehicles (HDVs) in 2025 saw a modest increase compared to 2024, when they stood at approximately 14,000 units, accounting for 4% of the total ([Soulopolos et al., 2025](#), [Mulholland & Ragon, 2025](#)). Heavy-duty trucks (>12 tonnes) accounted for the largest share of total truck sales (275,000 units) in 2024, but only 1.2% of these were electric. Almost 50,000 units of light and medium-duty trucks (3.5–12 tonnes) were sold, with EVs accounting for a larger share of 10%.³⁴ In the Netherlands, the uptake of electric trucks is considerably more advanced. In the first quarter of 2025, EVs accounted for 83% of all medium-duty truck sales, which is three times the total number of medium-duty electric trucks sold throughout 2024 ([Mulholland, 2025](#)). The share of electric heavy goods vehicles in the Netherlands was in line with broader EU figures. Like medium-duty trucks, electric buses had a very high market share in the Netherlands: 54% of all new bus and coach registrations in the first quarter of 2025, including the vast majority of city buses ([Mulholland, 2025](#)).³⁵

The availability of charging infrastructure went hand in hand with, and sometimes preceded, the increase in the number of EVs

The growth in the number of electric vehicles and the increase in the number of charging points go hand in hand. The charging infrastructure for electric vehicles more than doubled between 2022 and 2024, reaching a total of over 5 million charging points ([IEA, 2025b](#)). By 2024, approximately 1.3 million new publicly accessible charging points have been installed worldwide. The charging infrastructure in the EU will have more than doubled between 2022 and 2024 to 880,000 publicly accessible charging points ([ACEA, 2025](#), [EAFO, 2025b](#)). Estimates for 2025 stand at over 1 million units, including 175,000 fast DC chargers ([EAFO, 2025b](#)).

³³ This includes both the Dutch segments of 'mopeds' ("bromfietsen) and 'light mopeds' ("snorfietsen").

³⁴ Sales of buses and coaches in the EU amounted to 35,000 units in 2024, 17% of which were electric. Data from early 2025 point to further growth: sales of electric heavy goods vehicles rose by 45% year-on-year, based on first-quarter sales figures. The share of light/medium-duty lorries in the first three months of 2025 stood at 18% and that of buses at 19% ([Mulholland, 2025](#)).

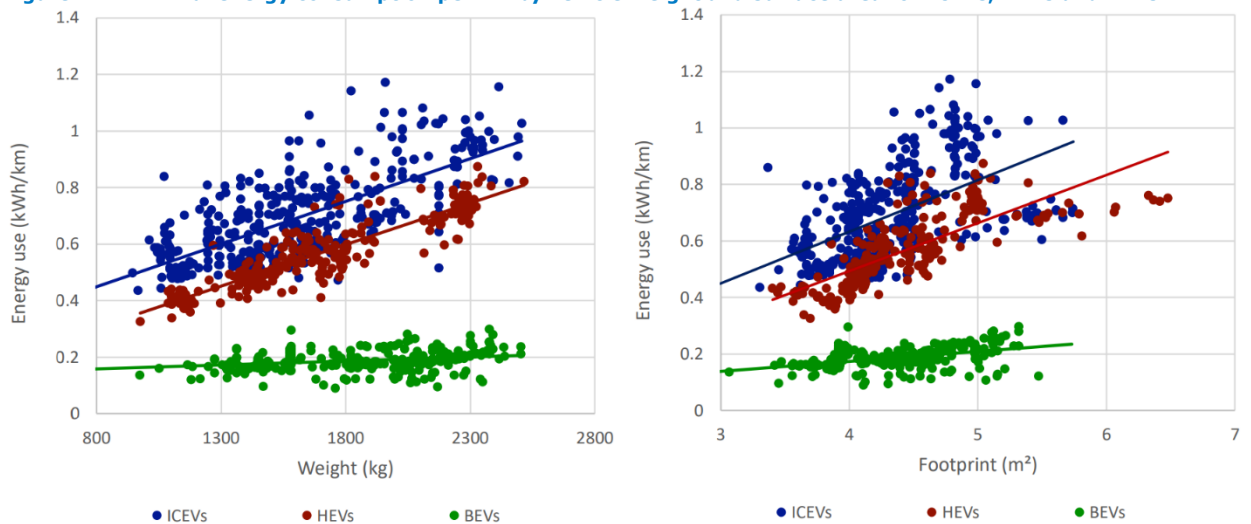
³⁵ Sales of electric buses continued to grow in 2024, reaching 70,000 new sales (6% of total sales), a 30% increase compared to 2023 (IEA, 2025), bringing the global number of electric buses to 0.73 million units. Battery-electric buses far outpaced fuel cell buses by a ratio of 35 to 1 due to their lower operating costs (IEA, 2025).

The Netherlands has more than 200,000 public charging points ([RVO, 2026](#) and [EAFO, 2025c](#)), which is approximately 20% of all conventional chargers in the EU and 4% of all fast chargers.

Energy efficiency benefits of the transition to EVs

BEVs offer significant energy efficiency benefits. This is because the final energy requirement is three times lower compared to ICEVs (Figure A.2), as electric motors convert more than 80% of the energy stored in the battery into motion, compared to a conversion efficiency of 20–30% for internal combustion engines ([IEA, 2023a](#)), and also enable the recovery of braking energy.

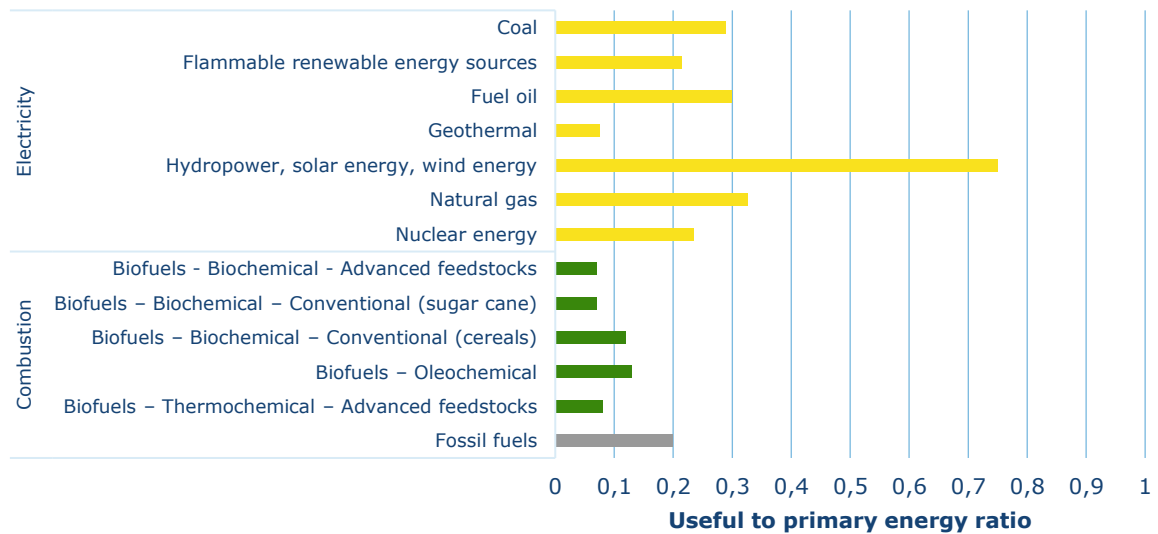
Figure A.2 Final energy consumption per km by vehicle weight and surface area for ICEVs, HEVs and BEVs



Source: Cazzola et al. ([2025](#)).

When using wind, solar and hydroelectric power, BEVs also minimise the primary energy requirement of the entire system, as shown in Figure A.3. This is partly because renewable electricity can be directly counted as primary energy. For BEVs using other forms of electricity, the efficiency gains are less significant, due to the losses incurred in generating electricity using heat (from fossil fuels, nuclear energy, combustible renewable energy sources and geothermal energy). For ICEVs, the relatively poor performance is largely due to losses in the engine, which are further exacerbated by additional losses during refining and other energy conversion processes (for example, in the production of biofuels).

Figure A.3 Ratio of usable to primary energy for EVs and ICEVs



Sources: as indicated in Table A1.1 in [Cazzola et al., 2024](#) for final-to-primary energy for biofuels, [IEA, 2023](#), [IEA, 2004](#), [IEA, 2008](#), [IEA, 2007](#), [Kampman et al., 2010](#) for final-to-primary energy for electricity, and [Serrano-Guevara et al., 2025](#), [Cazzola et al., 2023b](#), [IEA, 2019b](#), [Bieker, 2021](#) for useful-to-final energy ratios for vehicles.

Electric propulsion is also driving a broader transformation of transport

Electric propulsion technologies are not only suitable for cars, motorised two-wheelers, buses or lorries, but also for new forms of transport, particularly light electric vehicles.

The disruptive potential of electric propulsion as a technology capable of supporting a broader transformation of transport, including in combination with digital tools, has become evident in China over the past decade, partly as a result of venture capital injections that led to the mass deployment of shared e-bikes. Similar developments are also taking place in the EU, where new light electric vehicles have come onto the roads.

The range of transport options diversified rapidly, with the result that new products were not (properly) recognised in technical legislation and national traffic regulations; in the case of e-scooters, they were even banned outright for road safety reasons – including in the Netherlands ([Roetynck, 2024](#)). These challenges also led to doubts about the safety and environmental performance of new forms of micromobility, particularly where these had a short lifespan ([ITF, 2020a](#); [ITF, 2020b](#)). This was particularly problematic in the early stages of technological implementation, which were characterised by implementation practices where increasing market share was clearly prioritised over other considerations, a situation that has since improved ([ITF, 2024a](#); [ITF, 2024b](#)).

Despite challenges, including disruptions in the market development of conventional transport vehicles, the increased product diversification enabled by electric propulsion has led to a wider uptake of electric light vehicles – as evidenced by the case of e-bikes, which now account for around half of all bicycles sold in the Netherlands ([BOVAG, 2025b](#)). The further development of these vehicles can help align the transition to electric vehicles with a more efficient, competitive and equitable economy, provided that these new, lighter vehicles can effectively contribute to the replacement of heavier, more energy-intensive alternatives (see also Chapter 7).

Policy support for charging infrastructure

Policy strategies to support the installation of publicly accessible EV chargers have begun with concessions and public-private partnerships (PPPs), combined with strategic investments backed by venture capital. All these measures are reinforced by regulatory requirements, as these help to lower the risk profile of investments in EV chargers. Parallel efforts have also supported open standards, with the aim of reducing prices by promoting competition. These open standards enabled standardised hardware, payment and roaming protocols, whilst also supporting the ability to pass on price signals to end-users and increase grid flexibility, which contributed to lower costs.

As the number of EVs has increased, so too has the demand for fast charging, which has supported the deployment of charging stations on purely market-driven terms, without government funding. Planning became a more relevant part of the strategic development of the charging infrastructure for electric vehicles, as sufficient land had to be reserved for it ([Ministry of Transport, 2023](#)). This is also a development that is expected to gain in importance in the future, as the charging infrastructure for heavy-duty vehicles also requires larger areas and greater capacity from the electricity grid ([Ministry of Transport, 2023](#)).

This phased evolution, from government-stimulated and coordinated infrastructure development to a largely market-driven, self-sustaining ecosystem, with targeted government interventions to address equity or market failures, has also been followed in the Netherlands. In this case, the first phase comprised public-private pilot projects and PPP-style concessions, tenders at bundled locations with government-funded hardware and operating rights granted to private charging point operators. In the next phase, open data and technical guidelines from the EU supported the standardisation of hardware, payment and roaming protocols, alongside an increasing use of usage data and forecasts in planning. In this phase, the share of government financial support declined, investments became increasingly commercial, and additional funding was provided for rural areas or zones with low demand. Open protocols also supported non-discriminatory access and transparent tariffs. Several Dutch municipalities (notably Amsterdam, Utrecht and Rotterdam) adopted an on-demand approach to the installation of charging points, whereby new public charging points are only installed after a resident or business has requested them, in an effort to make funding efficient and support greater inclusivity, whilst also relying on planning tools and promoting ways to install publicly accessible charging points that are less disruptive to the electricity grid.

Current priorities in the Netherlands include shorter lead times for roll-out, accessible information and price transparency, the use and promotion of open protocols, support for renewable energy integration through smart charging and grid flexibility, the development of charging infrastructure that meets the needs and requirements of the logistics sector, safety and cybersecurity ([Nationale Agenda Laadinfrasctuur, 2025](#)). In the future, the Dutch approach to the roll-out of EV charging points could strengthen the focus on equity in-demand approaches and strategic plans by reducing the cost of installing public charging points exclusively for low-income households, by identifying priority areas with low incomes and disadvantaged areas where publicly accessible charging points should be installed at subsidised costs, and by directing the use of public funds towards supporting these investments.

Appendix B Ensuring the sustainability of biofuels in the EU

The production and consumption of sustainable biofuels offer both environmental and climate benefits, but are also associated with potential tensions. Although biomass contributes to CO₂ reduction, the restoration of biodiversity and the circular economy, its use can also put pressure on land use, ecosystems and other sectors that require biomass. The use of sustainable biofuels is therefore subject to sustainability criteria. For instance, biofuels must meet certain land-use requirements, the cultivation of bio-feedstocks must not affect carbon sequestration in the soil (such as in forest and peatlands), and areas of high biodiversity value must be protected ([NEa, 2025](#); [EEA, 2023](#)).

National and European legislative frameworks impose strict sustainability requirements on the production and use of biofuels. Within the European Union, this is laid down in the Renewable Energy Directive (RED). The RED takes into account various factors that influence sustainability, such as greenhouse gas emissions from direct and indirect land-use changes, combating fraud, transparency in the production chain and potential socio-economic impacts. These sustainability requirements apply to both liquid and gaseous biofuels.

One key requirement, for example, is that the greenhouse gas emissions from biofuels must be at least 50–65% lower than the emissions from the RED reference value for fossil fuels, depending on the age of the production facility. This reduction is calculated across the entire chain, from the cultivation of the raw material to the fuel reaching the tank. In Europe, only sustainable biofuels may count towards national renewable energy targets in transport. Member States are obliged to verify that the declared quantities of biofuels are covered by valid sustainability certificates. They must collect this data and report it to Eurostat. To ensure this, companies in the biofuel chain must demonstrate that they meet the sustainability criteria. This can be done through national control systems or through voluntary certification schemes recognised by the European Commission³⁶ ([NEa, 2025](#); [Van Dam & Ugarte, 2022](#); [Muisers et al., 2024](#)).

Certification is an important prerequisite for demonstrating that the biofuels supplied meet sustainability requirements. A voluntary scheme is a certification system for the sustainability of biofuels, typically developed by private parties, such as market participants or stakeholders. These schemes may impose stricter requirements than the statutory minimum standards, for example in the areas of soil, water and air protection. Certificates issued through recognised voluntary schemes are considered proof of sustainability. All Member States accept these schemes, with several often coexisting. As a result, the majority of sustainable biofuel traded in the EU is certified through these certification schemes. For sustainability certification, the entire production chain must be audited: from the cultivation or collection of raw materials to the production and distribution of the biofuel. The voluntary sustainability schemes use independent certification bodies for this purpose. These auditors check whether companies meet the sustainability criteria, both through document checks and on-site inspections. This covers farms, storage sites, oil refineries, biofuel plants and traders. Companies that meet the criteria are certified and may issue sustainability certificates for the biomass in question.

³⁶ The requirements for national monitoring systems are set out in detail in the relevant EU regulation ([EU, 2022](#)).

Sustainability certificates issued under a recognised voluntary scheme are valid in all EU Member States. Both biomass produced within the EU and imported biomass can be certified in this way. Member States may also use national schemes for the certification of domestic biomass. The European Commission is responsible for recognising voluntary and national sustainability schemes at the request of the Member State. Recognition is valid for five years and may be withdrawn if it transpires that the scheme no longer meets the requirements.³⁷ Similar schemes for the certification of sustainable biofuels also exist outside Europe. International frameworks such as ICAO (for aviation) and IMO (for maritime transport) employ comparable approaches to promote sustainable energy in transport. Although the details differ, the core principle is the same everywhere. The common denominator in such systems is the use of sustainability certification as proof of sustainability and CO₂ reduction compared to fossil fuels ([Muisers et al., 2024](#)).

Additional rules apply to the so-called ILUC effect. ILUC stands for Indirect Land-use Change and refers to an indirect change in land use that may occur as a result of biofuel production. For example, when agricultural land used for food production is converted into land for biofuel production, global demand for food must still be met. Although this can be achieved by intensifying current food production, there is also a risk that new land will be brought into use elsewhere. In that case, food production is, as it were, relocated to a new site. The production of biofuels therefore causes a change in land use elsewhere. Where this indirect land-use change leads to the conversion of land with high carbon stocks (such as forests or peatlands), this can result in high greenhouse gas emissions ([NEa, 2025](#)). The RED II sustainability framework aims to minimise the risk of ILUC as much as possible by limiting the share of food and feed crops and by limiting the share of bio-based raw materials with a high ILUC risk by 2030 and gradually phasing it out to 0%. For these fuels with a high ILUC risk, an exemption is possible if certification demonstrates that the ILUC risk is low. Within the frameworks of ICAO-CORSIA, EU RED III and the Dutch policy framework for sustainable biomass, market parties can demonstrate a low ILUC risk through certification. This certification process requires the application of certain mitigation measures, such as improved land management, to minimise the ILUC risk ([Van Dam & Ugarte, 2022](#); [Muisers et al., 2024](#)).

The Netherlands and the EU have implemented measures for sustainability assurance ([EU, 2022b](#)), consisting of an audit system comprising certification (ex-ante) and verification (ex-post). In recent years, several cases of fraud have come to light. The lessons learnt from the detection and handling of these fraud cases have been translated into additional measures, thereby increasing the robustness of the system (European Commission et al., 2021). The sustainability assurance system must be continuously monitored and improved where necessary. For example, due to suspicious activities relating to POME, several investigations have been launched to trace the origin of POME deliveries.

Higher ambitions and associated market incentives are putting pressure on existing vulnerabilities in the system. A larger quantity of biofuel requires a larger group of players to be monitored. As the use of biofuels in transport is set to grow in the coming decades, it is essential that the system is reliable and that potential risks of fraud ([DG ENER et al., 2022](#)) are addressed.

These developments, including the global nature of production chains, place ever-increasing demands on private and public oversight in the Netherlands and the EU ([NEa, 2025](#)). A number of policy options are available to strengthen fraud prevention, some of which have already been implemented. For instance, work is underway to improve the information available to national regulators and to

³⁷ The list of approved voluntary schemes can be found on the European Commission's website ([DG ENER, 2025a](#)).

increase public oversight of private certification bodies and sustainability schemes. Stricter requirements could also be imposed on audits and verification protocols, for example by demanding a higher standard of proof and carrying out more thorough checks at production sites and collection points for bio-based raw materials. Furthermore, work is underway in the EU on the Union Database (UDB), in which all system-related production and transactions worldwide are recorded in a single, verified system. The aim is to ensure the traceability, transparency and compliance with sustainability criteria for bio-based materials and fuels, thereby supporting monitoring and enforcement ([Van Dam & Ugarte, 2022](#); [Muisers et al., 2024](#); [NEa, 2025](#)). This is necessary because sustainable biofuels play a key role in the transition to a carbon-neutral mobility sector.

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