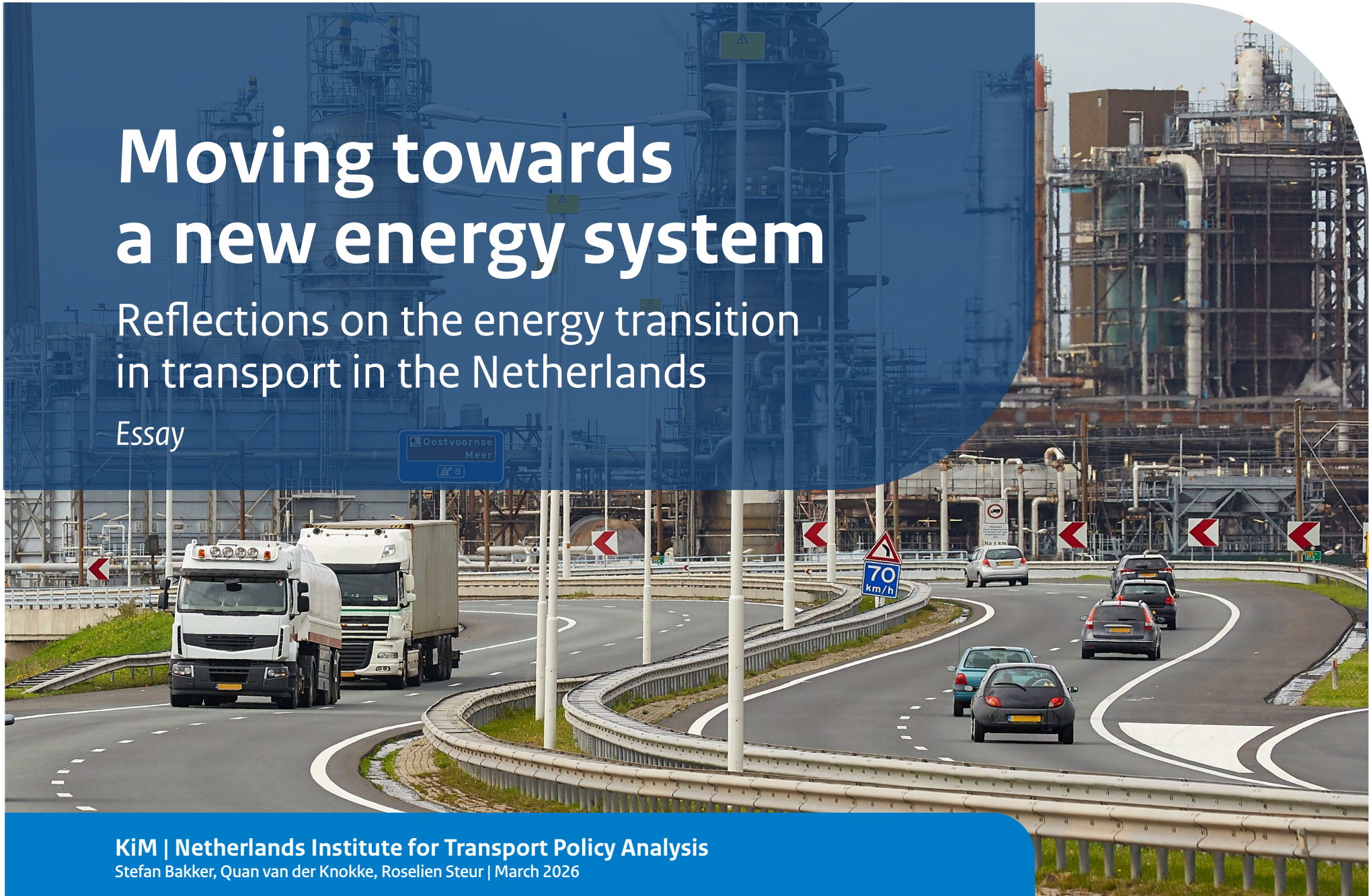




Moving towards a new energy system

Reflections on the energy transition
in transport in the Netherlands

Essay



Summary

The energy transition involves a shift from a fossil fuel-based system to one based on renewable energy. This is a major challenge, including for the transport sector. A rapidly changing geopolitical landscape means that, besides climate, other objectives, such as energy security, strategic autonomy, competitiveness and affordability, are becoming increasingly important, creating a complex puzzle.

Due to technological uncertainties and trade-offs between certain objectives, adaptive policy will be necessary: we must be able to adjust our approach. Electrification is often the most efficient and cost-effective solution where possible, but the majority of energy demand in the Netherlands will still be met by fuels in 2050. For all modes of transport, the transition will not happen by itself: policy support will be needed to ensure a successful transition.

Various objectives highlight the importance of the energy transition

Combating climate change is a key driver behind the phasing out 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, leads to additional objectives becoming at least as important as climate action: energy security, strategic autonomy, industrial competitiveness and affordability. This has only increased the urgency of the energy transition. At the same time, new dependencies regarding critical raw materials and

technology may arise. Furthermore, affordability will not necessarily improve for all groups in society, meaning that a just energy transition is not a given.

The future energy mix varies by mode of transport

At present, fossil fuels form the basis of transport energy supply. Road transport – two-wheelers, cars, buses, vans and trucks – could largely be electrified by 2050. A small proportion of renewable fuels will still be required, and there may also be a limited role for hydrogen in trucks. The energy-saving effect of large-scale electrification will reduce total energy demand. For aviation and shipping – which account for 58% of current transport energy demand in the Netherlands – electrification and hydrogen are, only possible to a (very) limited extent, for the time being. Biofuels and e-fuels will therefore also play a major role in the energy mix.

Large quantity of biofuels needed, but challenges in scaling up biofeedstock and production

Due to the potential cost advantages of biofuels over e-fuels, carbon-neutral scenarios for 2050 project demand for biofuels will be 3-8 times higher than it is today. The current feedstocks, such as used cooking oil, are insufficient to meet future demand. However, there are opportunities for sustainable biomass from intermediate crops or waste streams from European agriculture. Additional policy measures are needed to realise this potential.

Objectives can reinforce one another but may also conflict: adaptive policy is needed

The energy transition offers opportunities to contribute to various policy objectives, but there may also be trade-offs. 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.

Contents

1 Introduction

The energy transition, which aims for a carbon-neutral society by 2050, is a major, cross-sectoral challenge. The Dutch Coalition Agreement 2026–2030 underlines the importance of this transition. It focuses on European cooperation with the aim of achieving 90% reduction of CO₂ emissions by 2040, with possible additional national measures if this target is not in sight. Security of supply, strategic autonomy and affordability are key considerations for these measures.

The energy transition also presents a major challenge for the Dutch transport sector. At the same time, rapid changes are taking place both globally and in the Netherlands, which are reshaping the context of this transition. This makes it important to provide an up-to-date and coherent overview of the energy transition for transport, including considerations for policymakers.

In this publication, we examine the current state of the energy transition for transport and the interrelationships between modes of transport and energy carriers. We demonstrate that, due to geopolitical developments, the energy transition has become even more relevant than it was a few years ago, and that while the challenge is clearly understood, it will still require a great deal of commitment and cooperation from governments and market players. The objectives are clear; the main focus now is on how we will chart the course towards them.

Photo: Shutterstock

What is an energy transition?

A transition is a fundamental and irreversible structural change in which an existing system – whether it concerns 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.

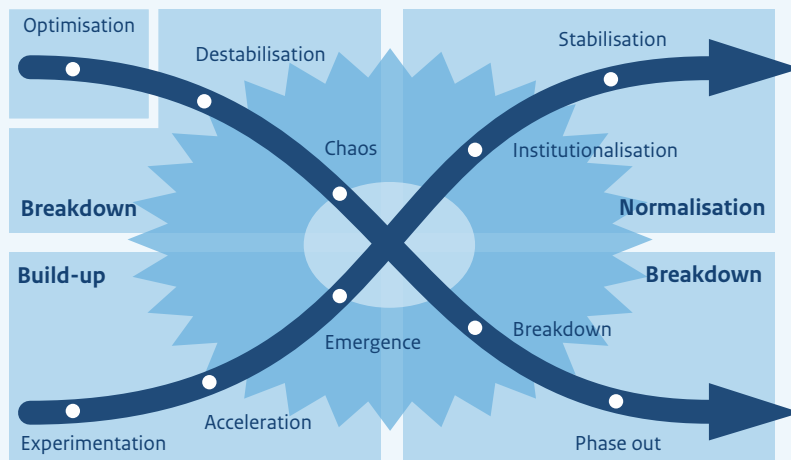
A transition is often accompanied by a period of chaos, resistance and uncertainty, as the established order is challenged by innovative forces, until the new reality eventually becomes the norm.

For the energy system, the (intended) transition means 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 next chapter.

In the 2019 Climate Act (Klimaatwet), the Netherlands set itself the target of becoming carbon neutral by 2050. This means that greenhouse gas emissions must be reduced to (virtually) zero across all sectors, including transport. Until about 10 years ago, the transport sector was almost 100% fossil-fuel-based. In other words, a complete transition to low-carbon energy would have to take place in less than 40 years.

Figure 1

Example of an X-curve used in transition studies



Source: Van Raak et al. (2022)

2 The energy transition in transport offers opportunities for various policy objectives



Photo: Rijksbeeldbank, John Gundlach - Flying Holland

Recent geopolitical developments mean that, in addition to climate action, industrial competitiveness, affordability, security of supply and strategic autonomy have also become key objectives in (policy for) the energy transition. These objectives can reinforce one another, but they can also conflict.



Climate policy has set the energy transition in motion

Since the start of this century, combating climate change has been a key driver for policies aimed at reducing the use of fossil fuels in transport. Policies aimed at reducing energy shortages, such as car-free Sundays in the 1970s and more fuel-efficient vehicles, or policies focused on gaseous fuels, have had a limited impact on the use of fossil fuels in the Netherlands. It is only with instruments such as CO₂ emission standards for new vehicles in the EU and the European Renewable Energy Directive (RED), which obliges fuel suppliers to reduce CO₂ emissions of their energy supplies, that the use of fossil fuels is declining. Dutch policy on the roll-out of charging infrastructure and the promotion of electric vehicles (EVs), through financial instruments as well as, for example, zero-emission zones, is also significant in this regard. For some policy instruments affecting the energy transition, air quality considerations play a role alongside climate.

To date, this policy has resulted in 7% of the passenger car fleet being fully electric, and increasing shares of electric passenger cars, vans and public transport buses in sales in 2025 (RVO, 2026). In addition, renewable fuels play a significant role in road transport, with, for example, diesel being on average 14% from renewable sources (NEa, 2025). In heavy road transport and air transport, sea and inland shipping, we are still at the very beginning of the transition.



Geopolitical factors are now leading to greater focus on energy security...

Ensuring security of energy supply is a key objective of energy policy. Reducing high-risk dependencies contributes to this. Recent international developments have an impact on this, such as the wars in Iran and Ukraine and the sanctions on Russian oil imports, as well as dependence on LNG from the US. These factors create uncertainty regarding the supply and prices of oil and gas and once again highlight the importance of reducing dependencies (Draghi, 2024; IEA, 2025).

Globally, fossil fuels for transport come mainly from a limited number of oil-exporting countries. The Netherlands, too, imports three-quarters of oil from just 7 countries (CBS, 2025). Increasing domestic energy production and expanding the number of countries from which energy is imported (diversification) can improve security of supply (European Commission, 2024). Renewable electricity comes from wind, solar and biomass generation in the Netherlands or neighbouring countries. Hydrogen, e-fuels and biofuels can come from the EU or a wide variety of countries outside the EU, thereby limiting dependence on a few countries (NEa, 2025; European Commission, 2024). A transition from fossil fuels to renewable energy thus offers opportunities to reduce high-risk dependencies, and thereby to achieve a more secure energy supply. The climate and energy security objectives can therefore reinforce one another.



...and dependence on raw materials and technology

The Draghi report on the competitiveness of the European Union acknowledges the global competitive landscape and the risks posed by dependencies in the supply chains for products, raw materials and technology. Slowing economic growth, demographic changes, rising energy prices and international competition are putting pressure on European prosperity. The report explicitly addresses the mobility sector, particularly regarding the declining market share of the European automotive industry and the need for a coherent policy and vision for this sector, which includes, among other things, the development of clean technology and the procurement of critical raw materials.

At the same time, the energy transition also offers opportunities for greater self-sufficiency in this area. We see a focus on strategic autonomy, for example, in European strategies such as the Clean Industrial Deal, the Industrial Accelerator Act and the Battery Booster Strategy. The Draghi report also acknowledges that, if the right measures are taken, Europe can still play a leading role in the development of clean technology, resulting in reduced international dependencies, lower energy prices and greater security of supply.



Industrial competitiveness

The energy transition in transport requires major investments and rapid change from market players. For instance, while European car manufacturers are major and strong players globally, the transition to EVs appears complex for established players, and new manufacturers seem to be rapidly gaining market share (Cazzola et al., 2025).

In the Netherlands, the petrochemical cluster in the Port of Rotterdam has traditionally held a strong position, with the various sectors reinforcing one another. Ships using the port can bunker fuel in Rotterdam, which can be produced there on a large scale by the petrochemical sector, for which the raw materials are supplied by international shipping. This chain may change as the world transitions to carbon-neutral energy (IEA, 2023), and with it the position of the Port of Rotterdam. Depending on how the energy transition progresses elsewhere, and whether industry in the port area can respond effectively to this, both the demand for fuels and the attractiveness of the Port of Rotterdam as a whole, relative to other ports, may change.

At the same time, biofuels and e-fuels offer new opportunities for this cluster (see also Box 4 in Chapter 4). So, to maintain competitiveness, change will be necessary. Only in this way can a threat be turned into an opportunity.



Importance of affordability and fairness

Transport accounted for 12-16% of household expenditure in the Netherlands in 2015. Of the Dutch population, 10% report having difficulty paying for all their trips, spending more on transport than they can afford, or cutting back on other expenditures to cover these costs (Krabbenborg & Durand, 2024).

Accessibility is a basic need for society and the economy, according to the 2026-2030 Coalition Agreement. Affordability of energy and transport are particularly important in order to meet this basic need. It would therefore not necessarily be a problem if costs for (certain forms of) transport were to rise – and sometimes that may even be the aim of a policy instrument – but it is a problem if this means that affordability deteriorates for part of society.

It is important for the energy transition to take affordability into account, not only from the perspective of fairness – which is essential for public support – but also because a successful transition requires everyone to participate. However, there are cases in which the costs of the energy transition are not distributed fairly, which in the long term could undermine the affordability (of car-based mobility) and thus accessibility (Krabbenborg & Uitbeijerse, 2024).

For instance, switching to an EV is currently most attractive for those who can afford to buy a new or second-hand EV with their own funds and can charge it on their own property, particularly when using solar power. Higher purchase costs (and therefore higher depreciation) and lower operational costs mean that an EV is more attractive for people who drive a lot than for those who cover few kilometres. Furthermore, the higher purchase costs of EVs pose a greater financial barrier for buyers on lower incomes (Cazzola et al., 2025). If they have to take out a loan to cover this, the total cost of ownership (i.e. both purchase and operational costs) rises compared to wealthier households. At the same time, the costs of using cars with internal combustion engines are rising. Prices for fossil fuels are expected to continue rising, partly due to policy, and carbon-neutral fuels may also become more expensive. In short, affordability may come under pressure during the transition.

Synergies and trade-offs in policy goals

The increased focus on strategic autonomy and security of energy supply in the EU reaffirms the need to commit to clean alternative energy carriers. At the same time, ensuring the availability of the necessary fuels throughout the transition, which will take several decades, is a challenge. This is despite the fact that declining volumes are making the extraction and production of fossil fuels less profitable, while companies must invest in renewable fuels.

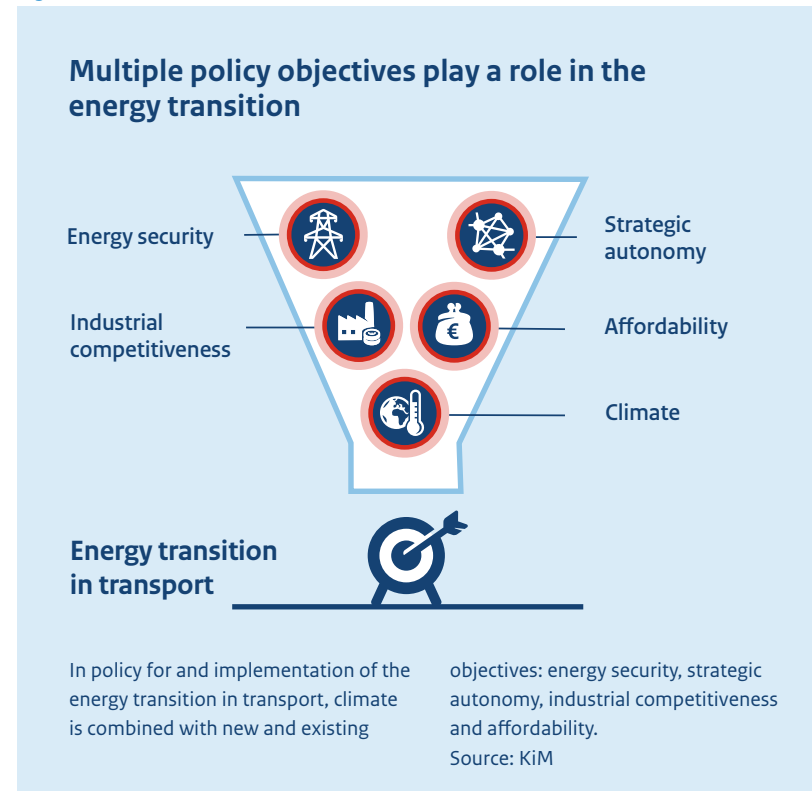
Governments face a dilemma: how to ensure affordable mobility while simultaneously offsetting declining excise duty revenues and promoting EVs. If maintaining this level of revenue is a government objective, there are various options for adjusting the vehicle tax system. These options have different effects on other policy objectives such as affordability, congestion, accessibility and the environment. No single policy option is beneficial for all objectives; a trade-off will need to be made (Knoope et al., 2025).

If car manufacturers wish to become less dependent on Chinese battery producers (autonomy), alternative supply chains will need to be developed with increased production of batteries and components in Europe (Draghi, 2024). This may, however, result in it becoming more difficult to be able to compete with affordable EV models from outside Europe, which could make EVs more expensive (affordability).

Conclusion

This chapter shows that the objectives relating to the energy transition can reinforce one another, but can also sometimes conflict. This makes it necessary to set priorities among these objectives. Not all objectives can be achieved simultaneously; choices must be made. It is also essential to fully understand how the various modes of transport and energy carriers relate to one another and what the sequence of actions might be during the transition. This will provide a clearer picture of the key challenges and how they can be addressed. That is what we aim to contribute to with this publication.

Figure 2




3 A broad sketch of the energy transition in transport





Photo: Methanex / Waterfront Shipping


Renewable energy carriers

There are several energy carriers that can play a role in the energy transition of the transport sector. Each of these energy carriers has different advantages and disadvantages.

 **Electricity** (usually in battery-electric vehicles) is often the most efficient option, but heavy batteries impose limitations on aviation, shipping and possibly the heaviest segment of long-distance road transport. Furthermore, renewable electricity is not always available.

 **Biofuels** are produced from crops and waste streams, but these raw materials are not available in unlimited quantities, and sometimes have to be sourced from far away.

 **Hydrogen** is a renewable energy carrier when produced using renewable electricity, but its production is relatively costly and involves significant energy losses.

 **E-fuels** are produced from renewable hydrogen and CO₂ and are therefore even more expensive to produce, but can be used in internal combustion engines and are easier to store than electricity or hydrogen.

Although these energy carriers are often described as renewable, sustainable or carbon neutral, they still result (indirectly) in emissions of CO₂ or other greenhouse gases, for example during the production or transport of these fuels, or the construction of the infrastructure required for them. However, these indirect emissions are generally significantly lower than the direct and indirect emissions caused by the use of conventional fossil fuels.

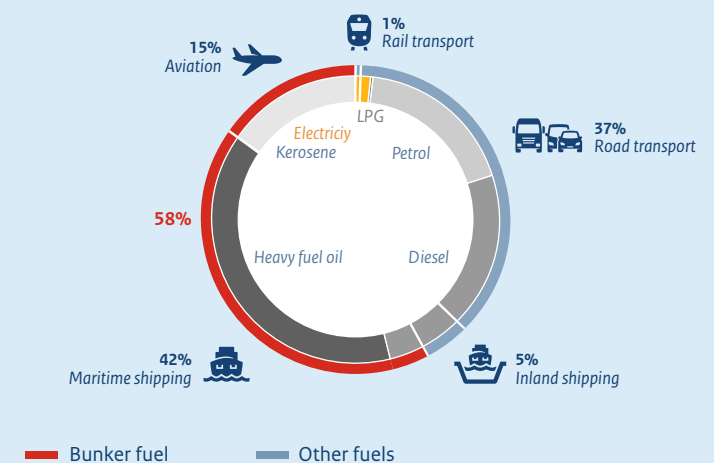
The characteristics of these energy carriers mean that they are not equally suitable for every mode of transport. However, they are all essential to the energy transition.

The energy transition in the transport sector consists of a shift from an energy system based almost entirely on fossil fuels to a mix of multiple renewable energy carriers.

In 2024, only 6% of the Netherlands' energy demand for transport was met by renewable energy (KiM, 2025). The transition is therefore still in its early stages. This is despite the fact that transport accounts for a substantial share of total Dutch energy demand: approximately 40% or around 1000 PJ (Uitbeijerse et al., 2024). This is a high proportion compared with other countries, which is due to the high share (58%) of bunker fuels for international maritime shipping and aviation in the Netherlands' energy demand for transport (Figure 3). These bunker fuels are almost entirely of fossil origin.

Figure 3

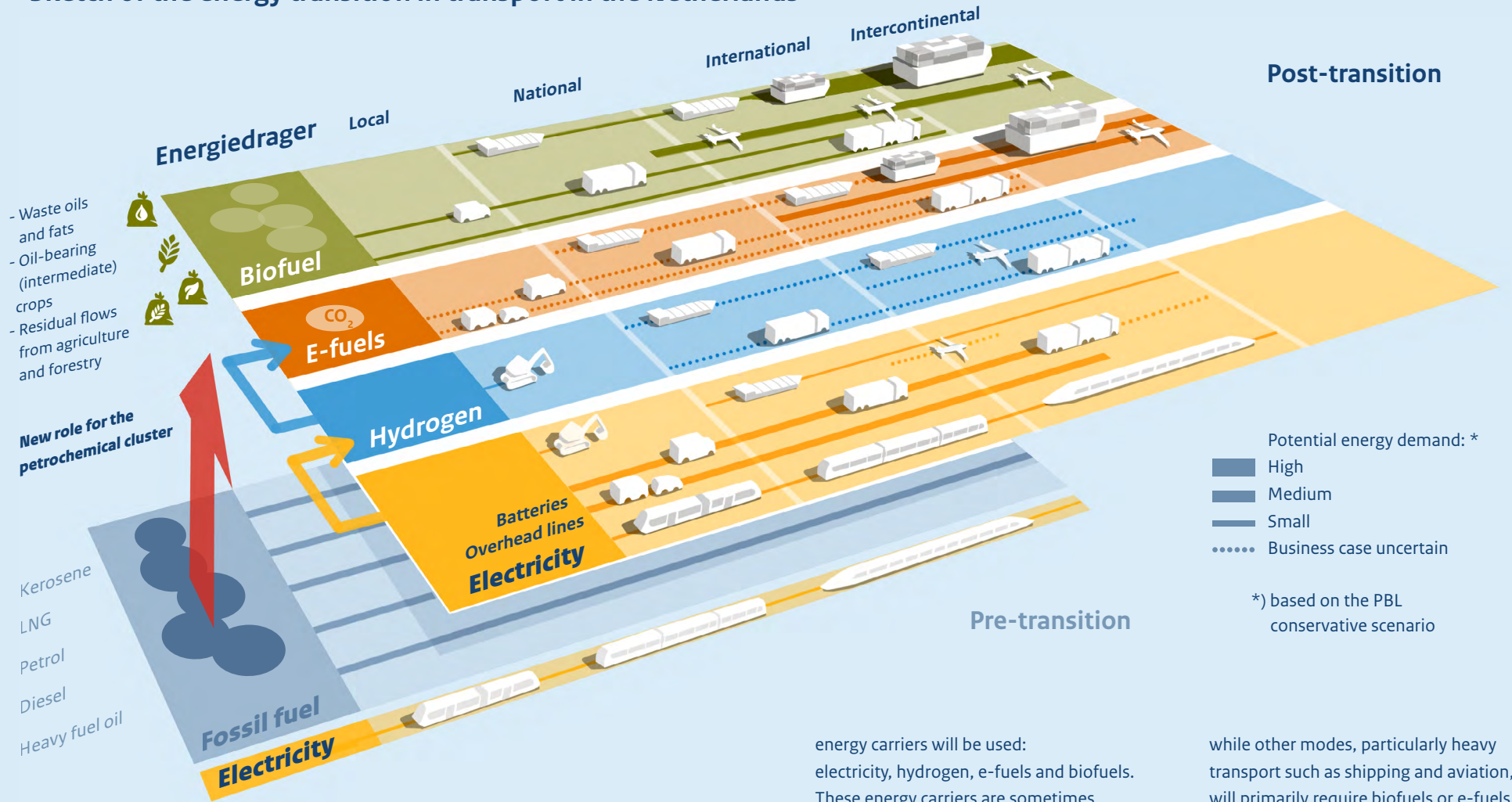
Energy mix of the Dutch transport sector by energy carrier and mode of transport (2024)



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

Figure 4

Sketch of the energy transition in transport in the Netherlands



Overview 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 dependent on electricity, and e-fuels, in turn, on hydrogen.

The use of these energy carriers will also vary: electricity is the most suitable option for a number of transport modes,

while other modes, particularly heavy transport such as shipping and aviation, will primarily require biofuels or e-fuels. For each energy carrier, the potential energy demand is shown in different line widths beneath the modes of transport, broken down by mode and distance travelled. In the transition from fossil to renewable energy carriers, a new role awaits the petrochemical cluster.

Energy supply chains

Figure 6 (page 14) illustrates what energy chains for carbon-neutral transport (in the Netherlands) might look like. These supply chains consist of various stages: extraction of raw materials, production, transport and distribution, and refuelling or charging (well-to-tank). For most of these steps, there are various options, each with their own advantages and disadvantages in terms of costs, production chains and practical applicability across the different sectors. There are therefore still many choices to be made on the path towards the energy system of the future.

We can illustrate this using biofuel supply chains. As we shall see in Chapter 4 (Box 3), demand for biofuels is likely to rise sharply. The feedstocks for these fuels can come from various sources (residual flows, intermediate crops or energy crops) and locations, both within and outside the EU. Furthermore, the conversion of the bio-feedstocks – possibly following a pre-processing step – into biofuel can take place close to the raw material's production site; however, another option is to transport the raw or pre-processed material and convert it into fuel elsewhere, for example in petrochemical clusters.

Under the influence of the policies already in place (see Chapter 5), supply chains will be developed as a result of market forces. However, on various points, it is expected that the energy transition will not take place (sufficiently) without further guidance and policy. We will explore this further in Chapter 5. Moreover, various policy objectives intersect, which may reinforce one another or, conversely, create tension (Chapter 3). That is why there may also be a role for governments here.

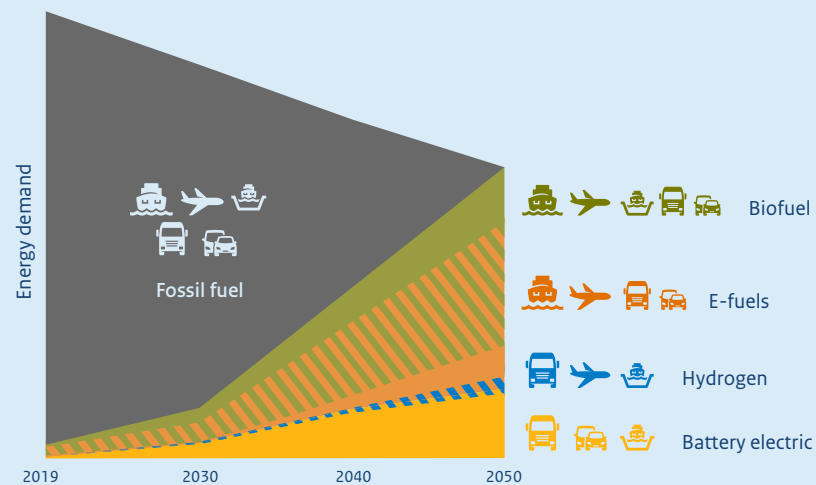
Figure 5 provides a schematic illustration of how the energy mix might evolve if transport within and from the Netherlands is carbon neutral by 2050. The figure is based on an analysis by the Netherlands Environmental Assessment Agency (PBL) for carbon-neutral transport, in which biofuels predominate in the conservative scenario, and in the innovative scenario the costs of hydrogen and e-fuels fall to such an extent that they will cover a large proportion of energy demand. In terms

of petajoules, the total energy demand for transport will decrease, although this downward trend does not apply to all modes, such as aviation. Demand for all renewable energy carriers rises sharply. The decline in energy demand – despite transport demand growth – is mainly due to electric vehicles having much higher energy efficiency than vehicles with internal combustion engines.

Figure 5

Development of the energy mix in transport in the Netherlands

Outline based on the PBL scenarios for carbon-neutral transport in 2050 (conservative and innovative)



Between now and 2050, the share of fossil fuels will fall to 0, while the contribution of other energy carriers will need to grow significantly. Biofuels and e-fuels are competing options (shaded), as part of the energy demand is expected to be met either

by biofuels or e-fuels, depending on the scenario and its specific implementation. This also applies to hydrogen, which competes primarily with e-fuels and electricity.

Source: KiM based on PBL/TNO (2024a).

Figure 6

Well-to-tank overview of the four energy supply chains for carbon-neutral transport (in the Netherlands)

For each energy source, there are various options available within its supply chain for carbon-neutral transport. These supply chains range from raw materials and their

origin, through to production, transport and distribution, storage and, ultimately, refuelling/charging. This figure illustrates some of these options. In this essay, we

focus primarily to the top half of the figure: the origin and production of sustainable energy carriers. Source: Innovatiestrategie luchtvaart

(Ministry of Infrastructure and Water Management, 2023), supplemented at the top and bottom to provide a well-to-tank overview.

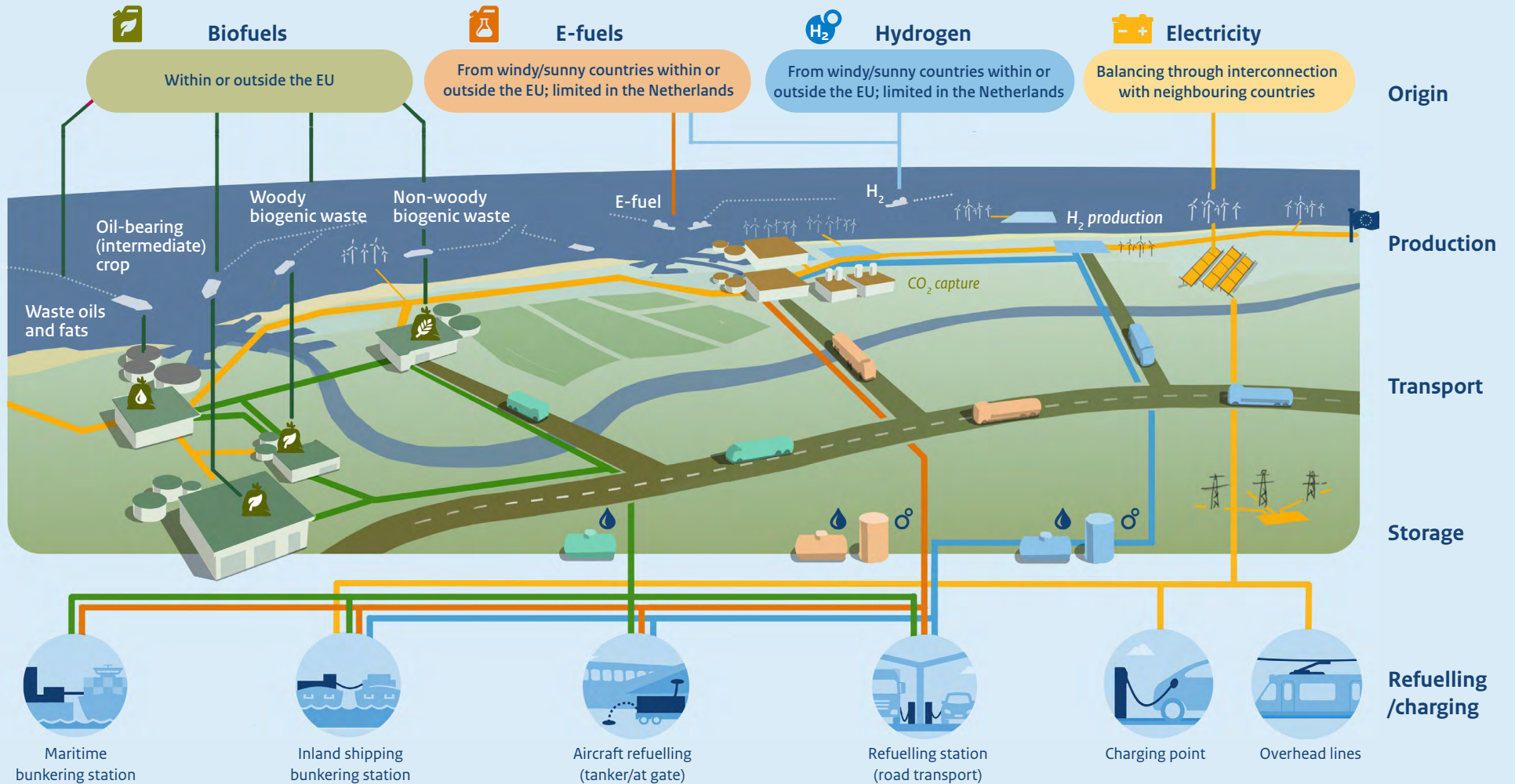




Photo: Tineke Dijkstra

Other strategies that may contribute to reducing energy consumption in transport are to reduce total demand for transport (avoid) and to shift to transport modes that are more energy efficient. Bakker & Moorman (2025) explore policy options for such strategies passenger and freight transport.

Energy saving as part of the energy transition currently receives limited attention, but can reduce the costs of investment in energy infrastructure.

Conclusion

Affordable and widely available energy forms the basis of our current transport system (and other sectors). Over the coming decades, petroleum as a basis for fuels will be gradually replaced by other energy carriers, each with its own production chains. This requires a massive shift in the underlying physical energy infrastructure and the way in which stakeholders collaborate. In doing so, the energy infrastructure for transport becomes intertwined in other ways with, and also dependent on, that of other sectors.

Energy efficiency contributes to various objectives

In addition to the shift from fossil fuels to renewable energy sources, energy saving is also a strategy that contributes to policy objectives such as combating climate change and ensuring security of supply. Furthermore, energy savings lead to lower energy bills, make the challenge of the energy transition less daunting, and conserve space and raw materials.

Electrification is a key strategy for energy saving, given that electric motors are three times more efficient than internal combustion engines. However, the use of e-fuels actually increases (primary) energy consumption, due to the energy losses that occur during the production of hydrogen and e-fuels. While passenger cars currently consume more primary energy than aviation in the Netherlands, the situation is inverted in 2050 in the carbon neutral scenario of the National Energy System Plan (NPE), for example.

4 The potential energy mixes and challenges vary by mode of transport



Photo: Alamy

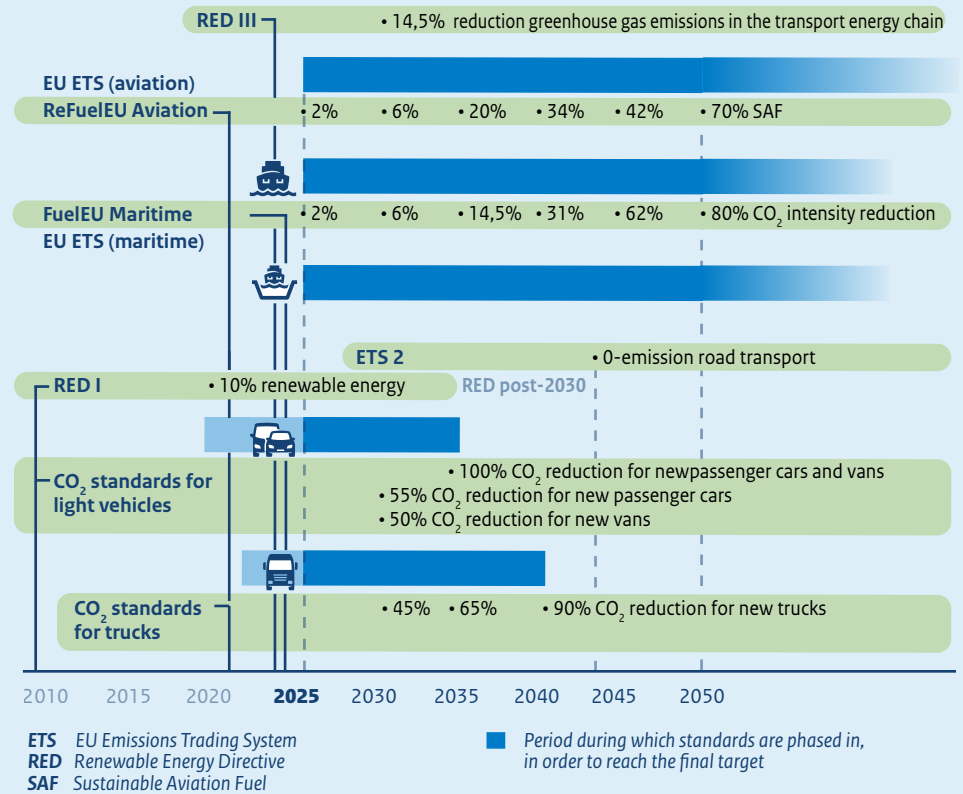
A large-scale shift from fossil fuels to renewable energy will take time and investment. When we consider the different transport modes individually we can fully appreciate the extent of the differences in progress, approach and characteristics. In the section below, we therefore examine the potential energy mix in carbon-neutral scenarios across different modes, and the challenges involved.

Policy plays a crucial role in this regard. As a result of policies introduced since the start of this century for road transport and, later, for other modes of transport, the transition to a new energy system has begun. Figure 7 provides an overview of the key instruments at European level that are in force at the start of 2026 (i.e. excluding the amendments proposed by the European Commission). Policy at national level is also important, and we will discuss this in the various sections.

Figure 7

Timeline for European policy aimed at decarbonising transport

(status: February 2026)



This figure shows 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 in the various policy measures are phased in.

For ETS2, we assume that by 2044 there will be no emission allowances available for fuel suppliers to road transport and inland shipping, nor will there be any offsetting options, and therefore all these fuels must be carbon neutral.

Source: KiM



Photo: Adobe Stock

4.1 Passenger cars, vans and trucks: electrification is taking off

The production and sale of electric cars are continuing to rise in the Netherlands, the EU and the rest of the world. At the European level, efforts are being made to achieve a significant reduction in road traffic emissions, for example through standards requiring 90–100% lower CO₂ emissions from new passenger cars and vans sold in 2035 and for lorries in 2040 (depending on the ongoing decision-making regarding the EU's automotive package). This means that in the coming years there will be a steep increase in the share of electric cars in new car sales, which must rise from 17.4% in the EU and 41% in the Netherlands (2025) to around 90%. This represents a massive

shift for the automotive industry and a challenge for the sector. At the same time, by 2035, a large proportion of all cars already on the road will still be powered by internal combustion engines.

In Dutch carbon neutral scenarios such as the NPE and those developed by PBL, the majority of road transport will ultimately be electrified. This is due to policy measures, such as the Dutch heavy goods vehicle charge (truck toll) and EU CO₂ standards, as well as expected technological developments and falling prices for new electric vehicles. As a result, electric driving is cheaper than driving on fuel

in most cases, either now or in the near future, for both light and heavy vehicles.

The climate impact of electric vehicles in Europe and the Netherlands is around 70% lower than that of vehicles with internal combustion engines in terms of emissions over the entire life cycle (including elements such as the production of the car and battery) (Negri & Bieker, 2025). Electric cars also have other forms of environmental impact due to the extraction of raw materials, particularly for the production of batteries.

The electrification of road transport is leading to a steady increase in electricity demand. As a result, the share of road transport could rise to 22% of total Dutch electricity consumption by 2050 under the NPE's carbon neutral scenario. In addition, a significant upgrade of the electricity grid is required to resolve grid congestion – resulting from the sharp increase in electricity demand across multiple sectors.

Less energy import, but increase in other dependencies

Electrification is causing shifts in vehicle production chains, thereby altering dependencies on international players. For an electric vehicle the battery is the most important component. China currently produces cheaper electric vehicles (EVs) than Europe and dominates the production of batteries or battery components and the materials used in them. For example, the EU imported 22 billion euros worth of batteries from China in 2024 (European Commission, 2025). Recently, China has restricted exports of key materials, such as natural graphite and certain rare earth metals. The EU is imposing import duties on Chinese electric cars, which may offset higher production costs



Foto: Toon Zijlstra

within the EU. This protects the market share of European manufacturers, but also makes the transition to EVs more expensive for drivers. This could slow down the uptake of electric vehicles.

However, the development of new battery technology is progressing rapidly and also offers opportunities to produce better and cheaper batteries in Europe using fewer scarce raw materials, thereby increasing the driving range for a lower price. However, this is no easy feat: building a factory in Europe takes much longer than in China. Furthermore, investors currently consider building battery production plants in Europe too risky because battery prices are low and technology is developing rapidly. There is also a shortage of technical personnel. Coherent policy, purchase guarantees and capital support could reduce the investment risk.

Uncertainties and challenges in large-scale electrification

The transition to (almost complete) electrification of the vehicle fleet will take place over a long period of time. Passenger cars in the Netherlands currently have an average lifespan of 20 years, meaning that completely renewing the vehicle fleet will take several decades. Despite the efficiency of EVs and the potential for lower costs for drivers, there are still significant uncertainties that may require policy intervention in the long term. Are EVs the best and most feasible solution for all road transport applications, and within what timeframe? Is an EV also cost-effective for households without a private charging point? Is the second-hand market for electric passenger cars developing in a way that ensures the transition is affordable?

In addition, electricity grid congestion is a limiting factor in the roll-out of charging infrastructure for both passenger

cars and lorries, meaning that for some people and businesses, electric vehicles will remain less attractive for the time being. Technical developments in the field of batteries may alter driving range and charging power, thereby enabling users to change their charging patterns. In the future, this could have a significant impact on the charging points and the electricity grid, should many people start charging at high power at the same time. At the same time EV batteries could be part of the solution when used as temporary storage to balance the supply and demand for electricity.

Governments 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, which would enable EVs to contribute to grid balancing (for instance, by charging at times when there is a surplus of solar and/or wind power) and reduce 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 incentive schemes for feed-in. This does, however, require large-scale digital management systems and a change in user behaviour.



Foto: Volvo Group

The market for second-hand EVs is still small, and consumers remain cautious because the depreciation and lifespan of batteries in older EVs are still uncertain. Options in the market are still limited in the compact and mid-range segments. Governments could choose to stimulate the second-hand market in these categories through financial incentives, such as tax measures and subsidies.

EU policy is currently being developed to promote the use of electric vehicles. Examples from the Industrial Action Plan for the European automotive sector include encouraging affordable leasing of zero-emission vehicles to reduce transport poverty (social leasing) and setting targets for making corporate vehicle fleets more sustainable. In addition, the proposal for the Automotive Omnibus Regulation makes suggestions to local authorities to offer parking benefits for a new category (M1E) of small vehicles.

Decarbonisation of petrol cars and diesel trucks by 2040-2050

The phasing out of vehicles with internal combustion engines is also an economic issue involving uncertainties in the long term. For example, it may become difficult to find enough trained mechanics for maintenance.

Under current policy, fossil fuels will have been almost phased out by 2040–2050. However, in the Netherlands, petrol and diesel substitutes will still be needed for several million passenger cars and tens of thousands of trucks with internal combustion engines. Drop-in fuels that can be used in existing engines and with existing infrastructure may prove to be an expensive option for this purpose. One example is the diesel substitute HVO, which is already widely used and which may become scarcer if the supply of raw materials fails to keep pace with demand. For the use of less expensive fuels, such as FAME biodiesel or the petrol

substitute bioethanol, in high blends, an engine modification is required (unless a technical breakthrough occurs, for example enabling ethanol – perhaps with an additive – to be used as a drop-in fuel in petrol engines). 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.

Governments may choose to leave the fuel supply and any engine modifications to the market, or to actively promote them, including in an international context.

What role is there for hydrogen in heavy road transport?

Recent literature suggests that direct electrification will provide the best business case for heavy road transport. If this does not prove to be the case, or if grid congestion remains a limiting factor, hydrogen – via a fuel cell or in an internal combustion engine – could also play a role. This could, for example, be the case for very heavy transport over long distances. The production, distribution and storage of renewable hydrogen require significant investment to enable its widespread use in road transport.

At present, the Dutch government encourages the use of hydrogen in trucks by subsidising vehicles and refuelling stations, and through the reduced tax rate for zero-emission vehicles in the heavy goods vehicle charge. The main uncertainty in the long-term business case is the price of hydrogen, with recent literature not painting a favourable picture for most segments compared to direct electrification. Given these uncertainties, adaptive policy appears necessary. A question for governments is to what extent and over what timeframe hydrogen in road transport requires further incentives in the decarbonisation of the truck fleet.



Photo: Daimler Truck AG



Photo: Alamy

4.2 Maritime shipping: mainly biofuels, as well as e-fuels; for inland shipping also other options are available

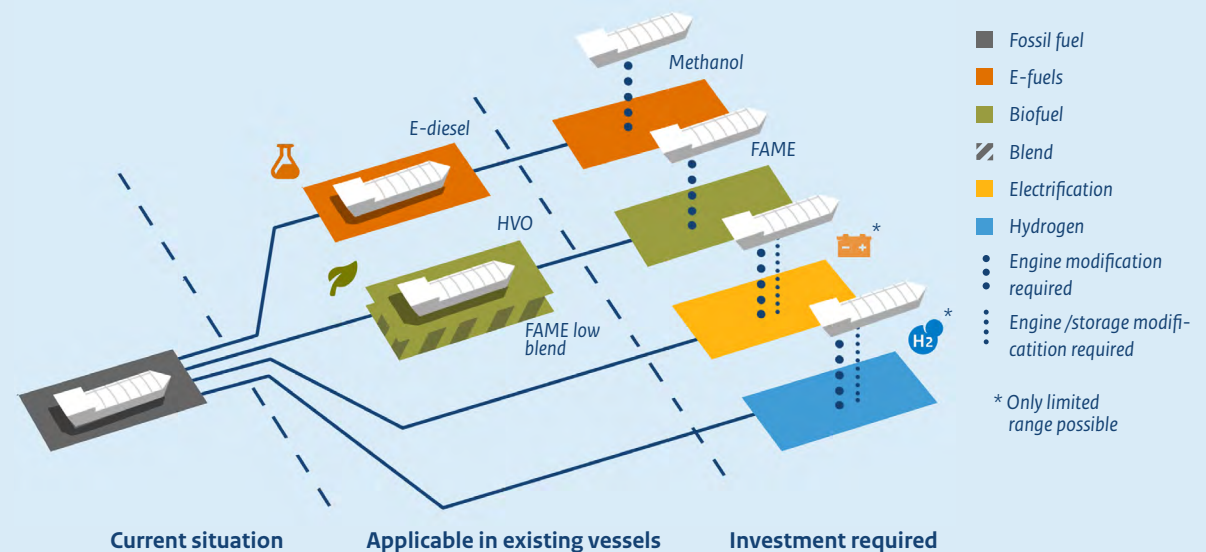
International shipping relies on large quantities of fuel per vessel per voyage. Currently, almost 99% of vessels run on heavy fuel oil or diesel, and the energy mix of the shipping sector consists almost entirely of fossil bunker fuels (PBL/TNO, 2024b).

Electrification or the use of hydrogen may only be viable for ships covering short distances, which consequently require less on-board energy storage. In the carbon-neutral scenarios by PBL and NPE for shipping, biofuels and e-fuels such as ammonia and methanol are therefore the dominant options. For some of these fuels, investments in the engine and/or on-board energy storage are required, as not every existing engine and storage system is suitable for new fuels. Other fuels, which can be used without modifications to the vessel, are also referred to as drop-in fuels (Figure 8).

Figure 8

Business case considerations for the shift to renewable energy

Explained based on the choices facing shipowners



Drop-in fuels, such as HVO or e-diesel, are a possibility for reducing greenhouse gas emissions from shipping. These can be used without modifications to the engine and energy storage systems, but there is a risk that these fuels become an expensive option.

Other energy carriers have potentially lower costs, but require investments in the engine and/or the energy storage system. This means that formulating an investment strategy involves considerable uncertainty. Source: KiM



Photo: Shutterstock

Box 3

Challenges in scaling up the production of sustainable bio-feedstocks

As indicated in Chapter 3, the demand for sustainable biofuels for transport in the Netherlands can grow quickly: in carbon neutral scenarios, by 2050 demand could be 3-8 times higher than at present, due to the expected cost advantages over e-fuels (Figure 5). The current demand of 52 PJ (NEa, 2025) stems largely from road transport. Depending on policy, there may be a slight increase in this demand until roughly 2035–2040, after which electrification will limit demand from road transport. For other transport sectors, such as shipping and aviation, demand is expected to increase particularly after 2035 due to higher blending targets in EU legislation.

Currently, mainly oil-rich raw materials from waste streams, such as cooking oil, are used for the production of biofuels. However, these are not

expected to be available in sufficient quantities to meet the demand for biofuels by 2050. Therefore, other sustainable feedstocks, such as woody biomass or oil-rich crops such as camelina. There is considerable potential for this in Europe (within current sustainability criteria). This mainly concerns intermediate crops, which are planted before and after the main crop (to maintain soil quality) and from waste streams from agriculture and, to a lesser extent, from forestry.

There is potential for synergy with agricultural development. In many parts of Europe, agricultural land is being abandoned due to declining economic yields and soil quality. This land could once again become viable for food production where this can be combined with the production of biomass. In

that case, relevant questions are how and when this scaling up of biofeedstock production in Europe will take place, and who will pay for it. Without policy commitment, it is possible that only limited scaling up will occur, and so there may be a role here for policy. In terms of policy options, instruments such as ETS2 and the Dutch Fuel Transition Obligation (brandstoftransitieverplichting) could be considered to create demand and reduce the price difference with fossil fuels, or financial instruments to bring abandoned land back into agricultural use.

Furthermore, the production process for biofuels from lignocellulosic feedstock is more complex than that for oil-rich feedstock and is not yet commercially viable. Production costs are uncertain but are likely to be higher than those for biofuels currently in use.

Transition to renewable fuels: opportunities and uncertainties for ports and the Dutch petrochemical cluster

Rotterdam offers a range of low-cost bunker fuels through the synergy between the port and the petrochemical industry, supported by an extensive infrastructure and knowledge network. On the one hand, this synergy presents opportunities for a transition to the production and bunkering of renewable fuels, via processes such as biorefining, for instance in Fischer-Tropsch plants.

On the other hand, future demand for bunker fuels is uncertain. It may decline as a result of 1) a global fall in demand for fuels and fossil energy due to climate policy and 2) a potential change in Rotterdam's competitive position as a bunkering port, should ports outside Europe become more attractive than those in Europe in terms of fuel prices due to less stringent regulations.

Investments in new production capacity are therefore not yet being made due to a lack of short-term investment certainty in the market. Converting refineries requires major investments and is not straightforward. In some cases, it may be possible to convert existing facilities.

For other new energy carriers, the existing infrastructure is unsuitable, and new facilities will need to be built, alongside the phasing out of existing, redundant facilities. At present, there is still sufficient production capacity to meet the slowly rising demand for renewable fuels. It is only from 2035 onwards that demand is expected to rise rapidly under the influence of EU policy, particularly from the aviation sector but also from the maritime sector, and may exceed production capacity, both for e-fuels and for biofuels.

The Dutch government can promote the production of sustainable fuels in two ways. On the one hand, it can focus on the demand side across the various modes of transport, thereby reducing the risk for fuel producers. On the other hand, it can focus on the supply side of sustainable fuels through financial instruments for production itself. Examples of this include the Sustainable Aviation Fuels Incentive Programme (Programma Stimulerende Duurzame Luchtvaartbrandstoffen) and the SDE++, and at EU level the Sustainable Transport Investment Plan, the Innovation Fund and the Hydrogen Bank.

In inland shipping, several carbon-neutral options compete with one another in terms of cost and practical feasibility. In addition to the fuels mentioned above, there may also be a role for electrification, and possibly for hydrogen as well. One option may prove more suitable for a particular segment and operational profile than for other segments or profiles: light, small inland vessels, for example, may be suitable for electric propulsion, whilst large vessels covering long distances are expected to be more reliant on biofuels or e-fuels. Furthermore, vessel engines have a long lifespan and small businesses have limited investment capacity.

In the Netherlands, inland shipping is a major sector, but on a global scale it is a niche industry. When it comes to technological developments, this sector must therefore rely in part on advancements in other sectors.





Photo: Rijksbeeldbank

4.3 Aviation: biofuels and e-fuels, minor role for hydrogen and electricity

It is expected that the energy demand of the aviation sector in the Netherlands will continue to rise, particularly as passenger demand continues to grow. The current use of renewable energy in the aviation sector is low, but Dutch and EU policy, particularly ReFuelEU Aviation, is focused on rapidly increasing this. In line with EU policy, the Netherlands has had a 2% blending obligation for sustainable aviation fuel (SAF) in place since 2025.

Electrification would require such a large weight and volume of batteries per aircraft that, from an energy and practical standpoint, it is not a viable option for many routes. Only for certain applications, such as small aircraft on relatively short flights, electrification might be an option, at least in the medium term.

Hydrogen has greater potential as an energy carrier, but still has a lower energy density per unit volume than conventional kerosene. For this reason, hydrogen does not appear to be suitable either for intercontinental flights, which account

for the majority of aviation's energy consumption. The current expectation is that by 2050 hydrogen will account for a small proportion of the aviation energy mix. Biofuels and e-fuels based on renewable hydrogen (SAFs) will therefore account for by far the largest share in a carbon-neutral aviation sector. These fuels have a higher energy density per unit weight and per unit volume than hydrogen or batteries and are suitable for use in existing aircraft with little or no modification, although these drop-in fuels are more expensive, more energy-intensive and/or more complex to produce.

The (potentially substantial) non-CO₂ climate impacts associated with the combustion of fossil fuels in aviation – such as contrails, ozone and methane formation – are virtually absent in battery-electric flight. These effects are also reduced with hydrogen. With biofuels and e-fuels, however, this reduction is limited, and significant non-CO₂ effects continue to occur.

Various policy instruments already exist at both national and European level to bring about the energy transition in aviation. For example, the blending

obligation for SAF is set to rise to 6% by 2030 and 70% by 2050. However, compared to other modes of transport, the energy transition in aviation remains a major challenge. There are various ways in which governments can further stimulate this transition (Uitbeijerse et al., 2024), including by correcting market failures, thereby making the development of new technologies more fiscally viable. Other recommendations include fostering a culture of innovation through improved infrastructure for new energy chains, collaboration and institutional aspects, and helping to create new markets in which the supply and demand for sustainable energy carriers become economically viable and attractive.

4.4 Cross-modal and cross-sectoral considerations

The implementation and pace of the energy transition vary by mode of transport, but some considerations affect all modes. Furthermore, the production and transport chains of the various energy carriers for different modes are intertwined (Figures 4 and 6) and will be integrated with those of other energy end use sectors such as industry and buildings.

Looking across sectors in the Netherlands, we see that in carbon-neutral scenarios such as the NPE, electricity demand will increase by a factor of 2-3 by 2050 compared to the present. Scaling up production, for example through 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 any domestic production of e-fuels. On the other hand, electric vehicles can also help reduce grid congestion by acting as temporary storage for electricity and feeding it back into the grid during periods of shortage. When it comes to electricity, the main challenge ultimately lies in balancing supply and demand at the right time and in the right place. In the long term, calm and cold winter days remain a particular challenge that still needs to be addressed.

Production of renewable hydrogen is still limited. The scale-up of renewable hydrogen is being encouraged through policies that promote the use of renewable

hydrogen in refining for road transport fuels (and the production of 'green' steel for cars).

In the future, more renewable hydrogen will be needed for the production of e-fuels, for example for aviation. There is competition with other sectors, such as industry, where there is no alternative to hydrogen. Establishing import chains for hydrogen and e-fuels will be important, as it is not certain that, in the long term, we will have sufficient renewable electricity capacity in the Netherlands to meet the demand for hydrogen.

Scaling up the production and use of renewable fuels – alongside electricity – requires a cross-sectoral, long-term perspective, for both synthetic fuels and biofuels (see Boxes 3 and 4). Scaling up production as demand rises will remain a challenge, which could lead to shortages, and the future trends in both costs and prices are uncertain. As discussed earlier, these fuels compete with each other to a certain extent: if the price of biofuels remains structurally lower than that of e-fuels, the role of the latter will be much smaller than if the price of hydrogen (and thus e-fuels) falls sharply. In that case, e-fuels may become attractive for sectors such as shipping.



Photo: Alamy

5 Synthesis



Photo: Rijksbeeldbank

The energy transition is essential for achieving climate targets, but also offers opportunities for energy security in an increasingly unstable geopolitical world. This geopolitical uncertainty also increases the 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

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. Part of this will be achieved through the implementation of existing policy, yet additional measures will also be required.

Electric transport is often a preferred option due to its higher efficiency and lower total operating costs. 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 supply of biofuels and e-fuels will be required as well.

Potential tension between policy objectives

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



Considering energy security, we see opportunities for improvement through the diversification of energy carriers towards electricity and biomass, particularly if these sources are sourced within the EU. When importing raw materials from outside the EU, ensuring a broad base of suppliers is a key focus for governments, 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 objective of industrial competitiveness, the picture is mixed. The transition presents threats but also offers opportunities. The European automotive industry has been much slower than China to embrace electric vehicles. Given that China is now further ahead and the transition to EVs has clearly begun, in line with European policy, the EU automotive industry will need to accelerate the shift towards EV production. Crucial needs in this regard include restructuring 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 renewable fuel production.



From the perspective of affordability for the public, 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 a private parking space or solar panels, for whom charging is more expensive, and also for those who rely on the second-hand market. Equity – that is, the distribution of costs and benefits across different groups and over time – therefore remains a key consideration in order to maintain public support.

Uncertainties and opportunities: adjusting policy

This potential trade-off between objectives, combined with inherent uncertainty in technological and administrative developments (PBL/TNO, 2024a) and geopolitics, presents policymakers with a complex task. 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 acknowledging 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 necessary to have a clear picture of the various objectives. In this regard, it is important to prioritise the objectives in relation to one another, possibly as the subject of a public discussion. Which goals take precedence, and is there, for example, a minimum requirement for other goals? What might a potential shift in priorities lead to?

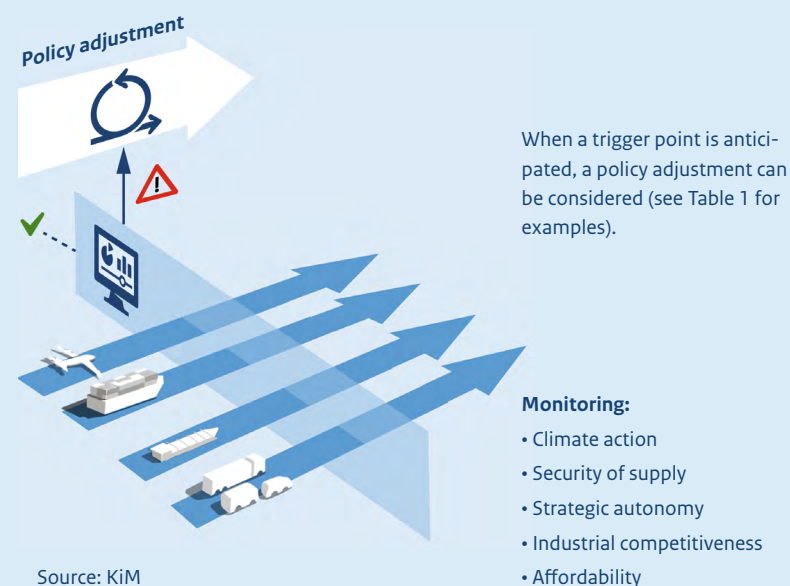
It is then important to sufficiently define objectives. Climate objectives are clear for the long term and provide a long-term target. For energy supply security, the necessary emergency reserves for crisis situations are well established, but this does not apply to limiting risky dependencies. Aiming 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. Furthermore, objectives and priorities can shift – these are a matter of political considerations. However, policymakers can monitor potential ‘trigger points’ and developments in order to adjust course more proactively. To illustrate this, we provide a few examples in Table 1. We note that not all issues 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 within the current system. And sometimes, less policy rather than introducing new measures may be desirable.

Figure 9

Principle of adaptive policy in the energy transition for transport



Source: KiM

Table 1

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

	Scaling up biofuels	Electrification of passenger cars and vans	Zero-emission trucks	Making internal combustion engine (ICE) vehicles more sustainable
Target for energy mix / CO₂ emissions in the EU	<ul style="list-style-type: none"> • 20% SAF in aviation (2035) • 14,5% CO₂ reduction in maritime transport (2035) 	<ul style="list-style-type: none"> • 90% reduction for new vehicles (European Commission proposal) (2035) 	<ul style="list-style-type: none"> • 90% reduction in emissions from new trucks (2040) 	<ul style="list-style-type: none"> • No CO₂ allowances for road fuel suppliers: high blends of renewable fuels (2044)
Potential trigger points	<ul style="list-style-type: none"> • Scarcity of bio-feedstocks • High-risk dependence on non-EU sources • Limited production capacity • Loss of competitive position of the Dutch petrochemical cluster 	<ul style="list-style-type: none"> • Grid congestion hinders electrification • Affordability 	<ul style="list-style-type: none"> • Grid congestion hinders the uptake of BEV trucks 	<ul style="list-style-type: none"> • HVO scarcity • Other drop-in fuels are expensive • Limited options for petrol engines • Limited refuelling options (especially in rural areas)
What is needed at these trigger points?	<ul style="list-style-type: none"> • Expansion of bio-feedstock production in Europe and import options • Policy consideration: should SAF production capacity be stimulated? 	<ul style="list-style-type: none"> • Address 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 fallback 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 that a problem? Does it make sense to take action on this by promoting engine modifications?
Possible indicators	<ul style="list-style-type: none"> • Are there (sufficient) policies in place to increase the availability of bio-feedstock within and outside Europe? • 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"> • Availability of vehicles suitable for non-drop-in fuels • Interest among vehicle manufacturers in bringing these to market • Road fuel prices • Proportion of ICE vehicles in the freight and passenger vehicle fleet • Availability of refuelling points

Examples are based on the challenges in Chapter 4 and the objectives of the policy measures shown in Figure 2.

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KiM Netherlands Institute for Transport Policy Analysis conducts mobility analyses that may inform policy. As an independent institute within the Ministry of Infrastructure and Water Management (IenW), KiM carries out strategic studies and policy analyses.

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Background report

For a more detailed analysis and overview of the literature, please refer to the background report written by KiM in collaboration with the Netherlands Enterprise Agency (RVO) and the European Transport and Energy Research Centre (ETERC / ITS-Davis), which can be downloaded from the website www.kimnet.nl:

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