EU 2040 Climate Target:

Contributions of the transport sector

Part 4 of 7 studies on sectoral contributions to the 2040 target

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Contents

Abbreviations

AFIR	Alternative Fuels Infrastructure Regulation
BEV	Battery-electric vehicle
CT	Combined Transport
EC	European Commission
ECL	European Climate Law
EEA	European Environment Agency
ESABCC	European Scientific Advisory Board on Climate Change
ESR	Effort Sharing Regulation
ETD	Energy Taxation Directive
ETS	Emissions Trading Scheme
EU	European Union
EV	Electric vehicle
FCEV	Fuel-cell electric vehicle
FEUM	FuelEU Maritime Regulation
GDP	Gross Domestic Product
GHG	Greenhouse gas
HDV	Heavy-duty vehicle
ICAO	International Civil Aviation Organization
ICEV	Internal combustion engine vehicle
IMO	International Maritime Organization
LNG	Liquefied natural gas
LRF	Linear reduction factor
LULUCF	Land use, land use change and forestry
MSR	Market Stability Reserve
OBFCM	On-board fuel and energy consumption monitoring
OEM	Original equipment manufacturer
RED	Renewable Energies Directive
RFNBO	Renewable Fuels from Non-Biological Origin
SAF	Sustainable aviation fuels
SCF	Social Climate Fund
TEN-T	Trans-European transport network
WAM	With additional measures (projection)
WEM	With existing measures (projection)
ZEV	Zero-emission vehicle

Executive summary

The 2040 climate target

The EU is legally obliged to achieve climate neutrality by 2050 and has an interim target for 2030 of reducing net GHG emissions by 55% compared to 1990. The European Climate Law also requires the EU to adopt a climate target for 2040. In its communication of 6 February 2024, the European Commission recommends a net emission reduction of 90% by 2040 when compared to 1990. The ESABCC (2023) recommends 90–95% net reductions. The indicated target range means that all sectors will have to contribute significantly. This paper explores the past contribution of the transport sector to already achieved emission reductions as well as its contribution to the upcoming 2040 climate target and what it takes for this sector to achieve the related emission reductions.

Emission trends in transport

The transport sector's greenhouse gas (GHG) emissions have substantially increased since 1990. Energy savings through efficiency gains in engines have been overcompensated by more traffic and more powerful engines (ESABCC 2024). According to Member States' national projections from 2023, current polices and measures will reduce GHG emissions from domestic transport to a level 4% above 1990 levels by 2030 (EEA 2023). Until 2040, projections estimate an 11% reduction with existing measures and a 32% reduction with additional measures compared to 1990 levels.

National projections expect GHG emissions from international transport to continue to increase until 2040. In international aviation, emissions are projected to be 143% above 1990 levels with existing measures almost reaching pre-pandemic levels. With additional measures, emissions are expected to be 112% above 1990 levels. In international maritime transport, the increase of emissions until 2040 is projected to be less pronounced with 41% above 1990 levels with existing measures and 38% above 1990 levels with additional measures.

What does the 2040 target mean for transport?

Several works present target scenarios of transport GHG emissions for 2040. With reductions of domestic transport emissions between -53% and -83% compared to 1990 the target scenarios differ considerably from Member States' national projections. In all scenarios, quick electrification of road transport is the cornerstone for reducing domestic transport emissions. GHG emissions from international transport differ considerably among the target scenarios ranging from a 13% increase to a -41% reduction compared to 1990 levels.

All scenarios indicate a modal shift towards rail in both passenger and freight transport. In passenger transport, the modal share of public transport and active modes increase while the share of individual transport decreases. In all scenarios, remaining liquid fuel demand is largely met by advanced biofuels and e-fuels. Target scenarios differ regarding their assumptions about overall transport activity. They range from a sustained growth in transport activity to an emphasis on sufficiency resulting in a decrease of passenger transport activity in general and passenger car traffic in particular (CLEVER network 2023).

Key challenges

Challenges in transport are manifold. In domestic transport, many decisions affecting energy consumption are made by private households and are, therefore, often characterized by routines and other non-economic factors that hinder quick transformations. This applies to the mode choice as well as to technology decisions when purchasing vehicles. A large difference in average lifespans of passenger cars between Member States goes along with an uneven uptake of zero-emission vehicles (ZEVs). Therefore, the planned pricing of CO_2 emissions can pose particular challenges in Member States where zero-emission vehicles are scarce. This can result in a growing number of vulnerable groups, such as households in transport poverty.

Coverage and ambition in international transport have been improved. Still, extra-EU aviation and 50% of extra-EU shipping is not covered by the ETS 1 and not covered by effective other international or national measures. The same applies to non-CO_2 effects. Efforts to produce climate-neutral fuels to meet the quotas defined in the newly regulation need to be intensified. The challenge is even bigger when considering that these quotas will still result in relevant GHG emissions in international transport in 2050.

What is already in current EU legislation?

Domestic transport is comprehensively regulated by EU climate policy framework. Still, several policy measures do not yet reflect the emission reduction ambition for 2040 and need to be strengthened. Among other instruments, EU policies regulate CO_2 emissions of new road vehicles, prescribe the share of renewable energies in the transport fuel mix, and set minimum requirements for alternative fuel infrastructure. To promote a modal shift from road to energy-efficient rail transport the EU has adopted several instruments, e.g., the TEN-T regulation or the Combined Transport Directive. From 2027, road transport will be covered by the ETS2. Overarching framework for domestic transport is the ESR with transport being its biggest sector. In international transport, coverage and ambition have been improved through the tightening of the ETS 1 and the adoption of the FuelEU Martime Regulation and ReFuelEU Aviation Regulation.

While improving the transport system has been regulated through several policy instruments, shifting transport to lower-emission and active transport modes is less addressed by EU policies. In international transport, there are very few policies focusing on demand reduction; so far, all improvements in energy efficiency in aviation and maritime transport have not been able to compensate the demand increase.

Policies, measures, and options to further reduce transport emissions

Policies, measures, and options should address all three dimensions of cutting transport GHG emissions: First, improve the transport system by electrifying road and rail transport, by reducing the GHG intensity of the fuel mix, and by increasing energy efficiency. Second, shift transport activity from motorised individual to public transport and from road to rail both in passenger and freight transport. And third, avoid transport activity by enabling short distance travel through regional planning and exploiting digitalisation potential.

Being the cornerstone for decarbonizing domestic transport electrification of road transport must be secured and accelerated. Political achievements have been made about the tightening of CO_2 emission standards for passenger cars, vans, and HDVs. Future reviews should focus on a moderation of vehicle electricity demand and a further tightening of HDV emission standards for the post-2030 period. Considering a shift in political forces after the European elections 2024 it is crucial for electrification of road transport that these regulatory achievements are not called upon question.

1 Introduction

The EU will adopt a climate target for 2040 in the coming years. This is a legal obligation set out in the European Climate Law (ECL). Article 4.4 of the ECL stipulates that "a Union-wide climate target for 2040 shall be set" – with a view to achieving the ECL's climate neutrality objective. Once the target is adopted, the EU is also set to adopt a legislative package to implement this target. This package will reform relevant EU laws and policies.

This paper is part of a group of sectoral papers, published in the context of a project funded by the German Federal Ministry for Economic Affairs and Climate Action. In this project, Ecologic and Oeko-Institut analyse the ambition level of the 2040 target and examine the impacts of a new 2040 target on Member States, sectors, and instruments. For more information about this project see: EU 2040 Climate Target. Level of ambition and implications. Besides other outputs of this project, these sectoral papers explore contributions of respective sectors to the upcoming 2040 climate target and what it takes for these sectors to achieve the related emission reductions. Relying on various emission reduction scenarios, the papers discuss different measures and policies that could help achieve the necessary contributions.

In this paper, the transport sector comprises the Member States' domestic transport greenhouse gas (GHG) emissions and the GHG emissions from international transport. While domestic transport emissions are entirely covered by EU regulation through the Effort Sharing Regulation (ESR) emissions from international transport are only partially covered by the EU Emissions Trading Scheme (ETS1). The ETS1 covers intra-EU aviation, intra-EU navigation, and 50% of extra-EU maritime. Climate effects due to non-CO_2 effects are not covered.

Domestic transport is comprehensively regulated by EU climate policy framework. Still, several instruments do not reflect the emission reduction ambition and need to be tightened. Among other instruments, EU policy regulates CO_2 emissions of new road vehicles, prescribes the share of renewable energies in the transport fuel mix, and sets minimum requirements for alternative fuel infrastructure, e.g., charging infrastructure or hydrogen fuelling station. Further, the sector is addressed by the Energy Taxation Directive (ETD). To promote a modal shift from road to energy-efficient rail transport the EU has adopted several instruments, e.g., the TEN-T regulation or the Combined Transport Directive. From 2027, road transport will be covered by the ETS2. The sector's overarching framework is the ESR that sets binding reduction targets for the sum of all sectors and activities not addressed by the ETS1. Domestic transport is the biggest sector of all ESR sectors.

Decarbonizing the sector, both domestic and international, is associated with several challenges. The sector's GHG emissions have risen significantly since 1990 and the majority of Member States is having difficulties bringing down emissions. As an end-use sector, many decisions affecting energy consumption of domestic transport are made by private households and are, therefore, often characterized by routines and other non-economic factors that hinder quick transformations. The sectors biggest emitter, passenger car transport, is characterized by a longevity of vehicles making it sluggish in reducing emissions. Vehicle fleets differ largely between Member States and high dependence on internal combustion engine vehicles (ICEVs) can lead to a growing number of vulnerable groups.

This paper explores the past contribution of the transport sector to already achieved emission reductions as well as the contribution of the transport sector to the upcoming 2040 climate target and what it takes for this sector to achieve the related emission reductions.

2 Sectoral trends

2.1 Historic and projected emission trends

The transport sector's GHG emissions have substantially increased since 1990. Emissions have increased steadily until 2007 and have not decreased significantly until before the COVID-19 pandemic. With its outbreak in 2020, transport GHG emissions dropped sharply due to reduced transport activity. With the easing of pandemic mitigation measures, transport activity and, consequently, the sector's GHG emissions increased again. However, transport emissions have not entirely bounced back to pre-pandemic levels.

According to Member States' national projections from 2023, current polices and measures will reduce GHG emissions from domestic transport to a level 4% above 1990 levels by 2030 (EEA 2023). With additional measures, GHG emissions are projected to reach a level 5% below 1990 levels. Compared to 2005 levels, national projections state a 17% reduction with existing measures and a 25% reduction with additional measures. Given these national projections and the national targets established in the ESR, the transport sector puts additional pressure on the other ESR sectors in most Member States. Until 2040, national projections estimate an 11% reduction with existing measures and a 32% reduction with additional measures compared to 1990 levels. Figure 1 depicts historic and projection domestic transport GHG emissions based on with additional measures projections as submitted by the Member States in 2023.

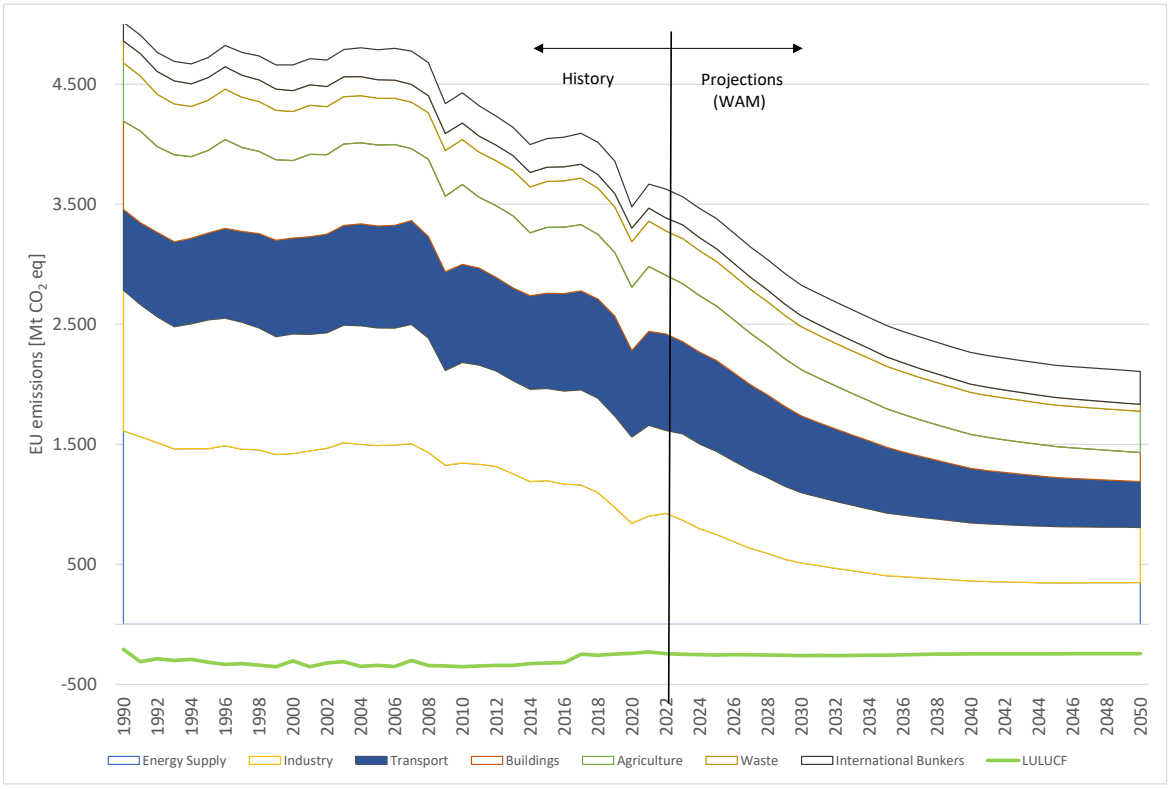

Figure 1: Historic and projected EU domestic transport GHG emissions (with additional measures projection, WAM)

GHG emission reductions are particularly challenging in international transport. After a steady increase until 2019 GHG emissions dropped significantly during the COVID-19 pandemic. This applies particularly to international aviation whose GHG emissions in 2020 almost fell to 1990 levels but increased significantly again in 2021 and 2022. In international maritime transport,

emission reductions due to the pandemic were less pronounced and have exceeded pre-pandemic levels already in 2022.

National projections expect emissions from international transport to continue to increase until 2040. In international aviation, emissions are projected to be 143% above 1990 levels with existing measures almost reaching pre-pandemic levels. With additional measures, emissions are expected to be 112% above 1990 levels. In international maritime transport, the increase of emissions until 2040 is projected to be less pronounced with 41% above 1990 levels with existing measures and 38% above 1990 levels with additional measures.

Until 2030, domestic transport is covered by the ESR being its largest sector. Compared to 2005 levels, the ESR sectors are set to reduce their GHG emissions collectively by -40%. Hence, the contribution of the ESR sectors to the EU 2030 climate target is lower than of the ETS1 sectors recognizing that emission reductions are harder to achieve in transport, heating, agriculture, and the remaining ESR sectors (see chapter 3.1.2). Member States' targets are differentiated according to Gross Domestic Product (GDP) per capita and reach from -10% in Bulgaria to -50% for Czechia, Denmark, Finland, Germany, Luxembourg, and Sweden.

National projections show a large variation of the Member States' reductions of domestic transport GHG emissions between 2005 and 2030. With additional measures projections indicate that emissions are likely to increase in eight Member States, likely due to strong catch-up economic growth and, consequently, transport activity. Most striking increase in emissions is projected in Romania (+87%) and Poland (+83%). On the other hand, Sweden (-70%) and Luxembourg (-68%) are likely to reduce domestic transport emissions considerably. In seven Member States, domestic transport emissions are projected to decrease more than the respective ESR target. In the 20 remaining Member States, the transport sector puts additional pressure on the other ESR sectors to meet the respective Member State ESR target. Figure 2 shows the projected change of domestic transport GHG emissions between 2005 and 2030 according to the with additional measures projections by Member States.

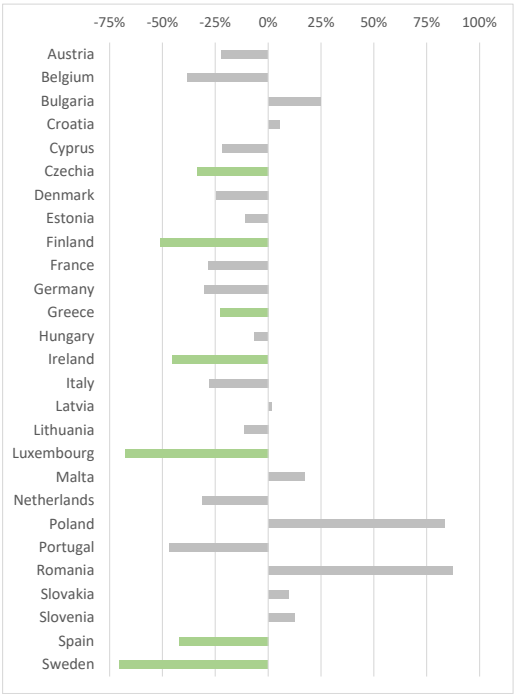

Figure 2: Projected change of domestic transport GHG emissions between 2005 and 2030 (with additional measures projection, WAM)

Remark: Green bars indicate that the projected domestic transport GHG emission reduction exceeds the Member State's ESR target in 2030, grey bars indicate that the projected emission reduction is smaller than the ESR target in 2030.

2.2 Relations to other sectors

Electrification of road transport will reduce GHG emissions from domestic transport significantly. As electric vehicles (EVs) are much more efficient than internal combustion engine vehicles (ICEVs) overall energy demand of the sector will decrease. Still, the switch from liquid fuels to electricity will increase demand for electricity considerably. This puts additional pressure on the energy sector in a way that the share of renewable electricity must increase while total electricity demand is also increasing.

With higher electricity demand of the transport sector comes a stronger integration with the energy sector. This is not only true for the supply of electricity but also for its distribution. The ramp-up of charging infrastructure for EVs both in passenger and freight transport will pose challenges for distribution grids as this is likely to increase power consumption in the low voltage as well as simultaneous grid usage. Timely and forward-looking upgrading of distribution grids is therefore essential to meet the challenges. In addition to upgrading the distribution grids, the control of electricity consumption is a part of the solution, for example via dynamic electricity prices or the possibility of control interventions by grid operators. In the longer term, there is great potential for the efficient integration of renewable energies into the electricity system by storing and feeding renewable electricity from EVs back into the grid (vehicle-to-grid).

In addition to the growing integration with the energy sector, the transport sector exhibits sectoral overlaps as its demand for renewable fuels competes with the ones of the other sectors. In the transport sector, biofuels are blended with fossil fuels today and will continue to be in the future. The Renewable Energies Directive (RED) prescribes a continuously increasing level of ambition for the use of renewable energy in transport (see chapter 3.1.3). The demand for advanced biofuels and Renewable Fuels from Non-Biological Origin (RFNBO) particularly from international transport will compete with domestic transport and the industry sector. It is difficult to predict today whether the transport sector will be dependent on hydrogen. Scenarios foresee its possible use in road freight transport (EC 2024; Kalcher et al. 2023; CLEVER network 2023; Climate Analytics 2022).

2.3 Key challenges in this sector

In contrast to other sectors, transport GHG emissions have risen significantly since 1990. Energy savings through efficiency gains in engines have been overcompensated by more traffic and more powerful engines (ESABCC 2024). The challenges of transport are manifold. A distinction can be made between typical challenges of end-use sectors and sector-specific challenges.

As an end-use sector, many decisions affecting the energy consumption of the domestic transport sector are made by private households and are, therefore, often characterized by routines and other non-economic factors, e.g., availability of energy infrastructure and perceived cost structures that hinder quick transformations. This applies to the mode choice as well as to technology decisions when purchasing vehicles. Regulation, like emission standards, is, therefore, necessary to ensure that manufacturers offer vehicles that protect households from the rising fossil energy costs.

Another challenge is the longevity of vehicles, especially passenger cars. Even if fewer new combustion engine cars are gradually registered in the future, these vehicles will remain in the fleet for many years. The challenge becomes particularly clear when the lifespans of passenger cars are compared between the Member States. While the average lifespan of passenger cars in Western European Member States is around 18 years, it is around 28 years in Eastern

European Member States (Held et al. 2021). These figures reveal that emission standards for new passenger cars will not ensure the elimination of combustion engine cars from the European fleet by 2050 without a significant reduction in their lifespan. Today, it is unclear to what extend the increase of fossil energy costs, e.g., through the ETS2, will contribute to a lifespan reduction of combustion engine cars. This challenge displays the importance of securing the political achievements that have been made about the tightening of emission standards for passenger cars. Further, an awareness about this challenge opens the discussion about potential policy instruments (see chapter 4).

The large difference in average lifespans of passenger cars goes along with an uneven uptake of zero-emission vehicles[1] (ZEVs) among Member States. For example, the ZEV-share in the passenger car stock at the end of 2022 was 4.0% in Denmark but only 0.1% in Poland (Eurostat 2024). Moreover, the number of new vehicles that are registered every year relative to the vehicle stock is much larger in Denmark than in Poland. In Poland, the passenger cars stock is influenced more by first registrations of imported used cars than by new registrations. Due to the age distribution of those imported used vehicles less than 1% are ZEVs today (PZPM 2024). Therefore, the planned pricing of CO_2 emissions can pose particular challenges in Member States where ZEVs are scarce. This can result in a growing number of vulnerable groups, such as households in transport poverty. The Social Climate Fund (SCF) provides Member States with dedicated funding to support the most vulnerable groups. However, financial resources to address the uneven uptake of ZEVs among Member States need to be strengthened.

With the imminent large-scale electrification comes the risk that traditional import dependency on a few suppliers of fossil energy is replaced by new dependency on a few supplies of materials and intermediate products needed for the technology transformation. The increase in demand for EVs is driving demand for batteries and related critical minerals (IEA 2023). Although the supply chain regarding EV production is expanding, manufacturing is still highly concentrated in certain regions with China being dominant in battery and EV component trade (Prognos et al. 2023). Building resilience through diversification is crucial for the decarbonization of the sector. With the Net Zero Industry Act, the EU has set targets to considerably increase European battery manufacturing capacity.

Emission reductions in international transport are particularly challenging. Coverage and ambition have been improved through the tightening of the ETS 1 and the adoption of the FuelEU Martime Regulation and ReFuelEU Aviation Regulation. Still, extra-EU aviation and 50% of extra-EU shipping is not covered by the ETS 1 and not covered by effective other international or national measures. The same applies to non-CO_2 effects. Efforts to produce climate-neutral fuels to meet the quotas defined in the newly regulation need to be intensified. The challenge is even bigger when considering that these quotas will still result in relevant GHG emissions in international transport.

[1] Zero-emission vehicles (ZEVs) do not emit exhaust gases and comprise battery electric vehicles (BEVs) and fuel-cell electric vehicles (FCEV).

3 Sector contributions to the 2040 climate target:

3.1 What is already in current legislation?

3.1.1 Emissions Trading System (ETS)

EU ETS 1

The EU Emissions Trading Scheme 1 (ETS 1) encompasses emissions from major sources such as power plants and industrial facilities, including flights within the European Economic Area and those to the United Kingdom and Switzerland. Additionally, starting in 2024, it extends to emissions from maritime transport. All EU Member States, as well as Norway, Iceland, and Liechtenstein, are part of the ETS 1. The United Kingdom ceased participation in 2021 upon exiting the European Union.

In 2012, aviation was incorporated into ETS 1, initially encompassing international flights. However, due to international political opposition, the scope was limited to cover flights within participating countries exclusively. From 2013 onwards, aviation contributed an average of 3% to ETS 1 emissions.

The EU ETS directive has undergone updates with the implementation of the Fit for 55 package. This includes setting a more ambitious cap and reinforcing the market stability reserve (MSR). Additionally, the European Funds for Modernisation and Innovation have been expanded, and the introduction of the SCF, which will receive partial contributions from ETS 1, has been made. Modifications relating directly to the transport sector include extending the coverage of aviation under EU ETS 1 and the incorporation of maritime emissions.

The ETS 1 covers 100% of CO_2 emissions from ships performing voyages between two EU ports, and 50% of emissions from ships performing voyages departing from an EU port to a non-EU port or vice versa. Methane (CH_4) and nitrous oxide (N_2O) emissions will be additionally phased in from 2026 onwards. In 2025, shipping companies must surrender allowances for 40% of their 2024 emissions. In 2026, this increases to 70% of 2025 emissions. From 2027 onwards, 100% of reported emissions must be covered. The maritime sector will not receive any free allowance allocations.

EU ETS 2

The forthcoming ETS 2, focusing on road transport, buildings, and other sectors, is scheduled to launch alongside the existing ETS 1 in 2027. Its cap, set at 1,040 million allowances, will be slightly lower than the ETS 1 cap of 1,125 million allowances, inclusive of aviation and shipping, for the same year. The initial cap will hinge on the ratio of ETS 2 emissions to total ESR emissions from 2016-2018, the ESR target for 2024, and the annual reduction rate for the cap given by the linear reduction factor (LRF). By 2028, the cap will be recalculated based on monitoring data from the sectors covered by ETS 2. Subsequently, the cap will diminish by 5.35% annually, eventually reaching zero by 2044.

In 2019, road transport accounted for 56% of the sectors included in ETS 2, making it significantly the largest sector. Emissions stemming from fuel consumption for heating and cooking in buildings constituted one-third of the overall total. The remaining 12% of emissions stem from the combustion of fossil fuels in small installations across both the energy and industry sectors. Germany accounts for nearly a quarter of all emissions, followed by France at 16% and Italy at 13%. These three nations, along with Poland and Spain, each contributing 8%, collectively represent 70% of the total ETS 2 emissions.

The development of the cap necessitates significant emission reductions in the sectors covered by ETS 2 compared to past reductions. Between 2009 and 2019, the EU 27 experienced an annual reduction rate of 8.4 Mt CO_2/year. Over the period from 2010 to 2020, which includes the notable emission decline in 2020 due to the COVID-19 pandemic, the annual reduction rate surged to 24.5 Mt CO_2/year, almost three times as high. Despite this, the required reductions to meet the cap of 62.8 Mt CO_2/year are still more than twice as high.

3.1.2 Effort Sharing Regulation (ESR)

The Effort Sharing Regulation (ESR) encompasses all greenhouse gas emissions beyond the ETS 1 framework, excluding the LULUCF sector, aviation, and international shipping. It establishes binding annual country-specific emission reduction targets until 2030 that reflect their financial capacity. Bulgaria, being the EU's lowest GDP per capita country, is mandated to reduce emissions by -10% compared to 2005 levels by the year 2030. Conversely, the wealthiest Member States are required to achieve a -50% reduction. Transport and heating constitute the largest sectors covered by the ESR, accounting for 35% and 25% respectively (EEA 2023). Agriculture ranks third with an 18% share. Energy installations, industrial processes, manufacturing, construction, and waste contribute the remaining ESR emissions.

The ESR provides Member States with a set of flexibilities. They can bank surpluses in years with lower emissions than emission allocations. They can also borrow a limited number of allocations from the following year if emissions are higher than emission targets. Moreover, Member States can buy and sell allocations from and to other Member States. Member States facing challenges in meeting their national targets may access a limited number of additional allocations through a safety reserve to offset their emissions.

3.1.3 Other relevant Directives or regulations

Renewable Energy Directive

The Renewable Energy Directive (RED) and its implementing regulations have two functions for the use of renewable energy in the transport sector. A continuously increasing level of ambition for the use of renewable energy in transport incentivises the fuel suppliers to deploy renewable energy fuels in the transport sector. Secondly, the RED defines under which production conditions and with which use of feedstock renewable fuels are eligible for compliance with the RED targets and which GHG emissions are attributed to these fuels.

Regulation (EU) 2023/2413, which was adopted with the Fit for 55 package, raises the level of ambition for the use of renewable energy in the transport sector for 2030 and extends the scope of the directive to all transport modes including international air transport and maritime shipping. With the RED, the Member States are required to set binding targets for the fuel suppliers in the transport sector. The ambition level of the RED is a 29 % share of renewable energy in the transport sector in 2030. Alternatively, a reduction in the GHG emissions intensity of the energy supply for transport of 14.5 % compared to a fossil comparator can be set as a 2030 target.

The RED defines various renewable fuels for some of which maximum eligible quantities or minimum shares to be achieved in the fuel mix. Biofuels from food and feed crops are limited for compliance to their 2020 energy share in transport plus one percentage point (maximum 7 %). Biofuels from used cooking oil and animal fats (see Annex IX Part B for eligible feedstocks) are also subject to an eligibility level for RED compliance. Their maximum energy share for compliance is 1.7 %. Advanced biofuels (see Annex IX Part A for eligible feedstocks) and Renewable Fuels from Non-Biological Origin (RFNBO) are subject to joint minimum share requirements regarding the final energy demand in transport. It increases from 1 % in 2025 to 5.5 % in 2030. However, all biofuels with feedstock from Annex IX and RFNBO shall be counted

twice their energy content in the compliance calculation. As a result, the actual mandatory blending rate for RFNBO and advanced biofuels is 0.5 % in 2025 and 2.75 % in 2030.

Another option for complying with the RED transport target is to take renewable electricity or GHG emission reductions from electricity use in transport into account. For this, a mechanism must be established to integrate the use of electricity in electric vehicles into the national quota system to support the roll-out of the electric vehicles charging infrastructure.

CO_2 emissions standards for newly registered cars and vans (fleet standards)

The EU recently adopted[2] its Regulation on CO_2 emission standards for newly registered cars (M1 vehicles) and vans[3] (N1 vehicles). The Regulation sets targets to reduce the average specific CO_2 emissions (in g CO_2/km) of the car manufacturers' new vehicle fleets. In 2030, each manufacturer's newly registered car fleet must reach 55 % lower specific CO_2 emissions than in 2021. For vans, the emission reduction target for the new vehicle fleet for 2030 is set to 50%. From 2035 onwards, all car and van manufacturers have to comply with a 100 % CO_2 emission reduction target. An exemption will be rewarded for manufacturers with less than 1,000 newly registered cars or vans. Flexibility is provided by the pooling option of manufacturers' vehicle fleets. Separate manufacturers can decide to merge their vehicle fleets in order to comply with the Regulation's targets.

CO_2 emissions standards for newly registered heavy-duty vehicles (fleet standards)

CO_2 emission standards for heavy-duty vehicles (HDV) have only existed in the EU since 2019 with Regulation (EU) 2019/1242. It covers the majority of newly registered trucks in the EU and aims to reduce the manufacturers' average fleet emissions for new vehicles by 15% (2025) and 30% (2030) compared to a baseline from 2019 and 2020. This means that around 70% of emissions from new HDVs in the EU are subject to the existing Regulation. A banking and borrowing system offers flexibility to the manufacturers for target compliance. For an early, ambitious reduction in CO_2 emissions, emission credits that can be used at a later date are granted; however, if the target is exceeded, the missed emission reduction can also be offset at a later date and within certain limits using emission credits.

In January 2024, the EU reached a provisional agreement for an update of the CO_2 emission fleet targets for HDV[4], which is expected to be legally confirmed by the EU. In future, the Regulation will also include emission reduction targets for small trucks, urban buses, coaches and trailers. With a few exceptions, all HDV are thus integrated into the CO_2 fleet targets. In future, CO_2 emission reduction requirements of 45 % (2030), 65 % (2035) and 90 % (2040) will apply to the average, specific CO2 emission values of the manufacturers' new trucks and coaches. The manufacturers must reduce the CO_2 emissions of new trailers by 7.5% from 2030; the reduction requirement for new semi-trailers is 10% from 2030. Urban buses are subject to a minimum quota of zero-emission vehicles (ZEV). From 2030, 90% of a manufacturer's new urban buses must be ZEV, rising to 100% ZEVs in 2035.

FuelEU Maritime Regulation

The EU recently adopted the FuelEU Maritime Regulation (FEUM) (EU 2023a). It aims to accelerate the use of renewable and low-carbon alternative fuels in the maritime sector by setting a greenhouse gas (GHG) emission intensity standard from 2025 until 2050. It has been agreed that the average GHG intensity of the energy used by ships (gCO_2eq/MJ) must decrease every 5 years: by 2% in 2025, 6% in 2030, 14.5% in 2035, 31% in 2040, 62% in 2045 and 80% in

[2] (EU) 2023/851
[3] Vans are also referred to as light commercial vehicles (LCV).
[4] https://www.consilium.europa.eu/en/press/press-releases/2024/01/18/heavy-duty-vehicles-council-and-parliament-reach-a-deal-to-lower-co2-emissions-from-trucks-buses-and-trailers/

2050 compared to a reference value of 91.16 g CO_2eq/MJ. Between 2025 and 2033, the use of RFNBO is rewarded with a multiplier of two for counting towards the GHG intensity limit. Vessels can be grouped in groups of two or more vessels to comply with the FEUM. In addition, there is a banking and borrowing mechanism that allows over-compliance to be carried forward to the next reporting period and a current shortfall to be made up with advance compliance from the next reporting period. In addition, container and passenger ships (with exceptions) will be required to use shore-side power or zero-emission technology in port from 2030.

FEUM is a fuel neutral standard using a well-to-wake approach. Emission factors (well-to-tank and tank-to-wake) are defined in the FEUM and are partly derived from the RED. In general, biofuels, RFNBOs and recycled carbon fuels that do not meet the sustainability and GHG savings criteria of the RED are assumed to have the same emission factors as the least favourable fossil fuel pathway for that type of fuel. The same applies to biofuels produced from food and feed crops as defined in RED. Unlike meeting RED targets or ReFuelEU Aviation targets, FEUM does not exclude, discriminate against or cap other high-risk or high-emission biofuels such as waste oils and fats and palm fatty acid distillates (Baldino and Mukhopadhaya 2022). Fossil fuels or conventional biofuels are also not completely excluded but remain compliant as long as their emission factor does not exceed the set limit. In fact, liquefied natural gas (LNG) and other fossil fuels will be compliant with the GHG intensity limit well beyond 2030 and even 2040.

ReFuelEU Aviation Regulation

An important new policy at EU level is the Regulation on ensuring a level playing field for sustainable aviation (ReFuelEU Aviation) (EU 2023b). The regulation also applies to international flights, as it obliges not only fuel suppliers but also outgoing flights. It provides for an increasing blending rate of sustainable aviation fuels (SAF) by distributors at EU airports. The quotas are given as minimum percentages required at each EU airport: 2% by 2025, 6% by 2030, 20% by 2035, 34% by 2040, 42% by 2045, 70% by 2050. The regulation also sets a sub-quota for RFNBOs, like e-kerosene: average shares of 1.2% in 2030/2031 and 2% in 2032 to 2034, and minimum shares of 0.7% in 2030/2031, 1.2% in 2032/2033 and 2% in 2034.

The regulation provides a flexibility mechanism: a transition period until 2034 allows fuel suppliers to meet the SAF blending mandate as a weighted average of the volumes they have supplied at EU airports.

SAF are defined as in the RED and comprise synthetic aviation fuels (RFNBOs incl. e-kerosene and renewable hydrogen), biofuels, and recycled carbon fuels (from liquid/solid waste streams of fossil origin of unavoidable or unintentional industrial sources). Biofuels eligible as SAF include advanced biofuels and biofuels from used cooking oil and animal fats (Part A and B of Annex IX of the RED) and other biofuels (not listed in Annex IX), excluding food and feed crops, intermediate crops, palm fatty acid distillate and palm and soya-based materials, and soapstock and its derivatives. These "other biofuels" are all biofuels that meet the RED sustainability criteria for fuels but are not listed in Annex IX of the RED and are not food and feed crops. They include, for example, edible animal fats (category 3) and other random feedstocks as identified by Baldino and Mukhopadhaya (2022). These other non-Annex IX biofuels are limited to a maximum of 3% of the SAF targets. Further, airlines can receive (a limited amount of) free allowances under the EU ETS for their uptake of SAF.

To prevent policy evasion through strategic refuelling outside the EU, airlines are required to refuel at least 90% of the fuel required for outbound flights at EU airports on an annual average. The regulation applies to commercial air transport (requiring aircraft operators to operate a minimum number of passenger or freight flights per year departing from EU airports). The regulation defines a traffic threshold below which small airports are exempted. This threshold should cover at least 95% of the total traffic departing from EU airports. ReFuelEU Aviation will be

reviewed by 2027 and every four years thereafter, including the possible inclusion of further mechanisms to support the production and collection of SAF and a review of the ambition (e.g., scope and quotas).

Energy Taxation Directive

The Energy Taxation Directive (ETD) sets the legal framework within which the Member States set energy taxes. Since the last revision in 2003, it has defined the minimum taxation of fuels for various sectors and specifies, among other things, which fuels and applications may be given preferential tax rates. An initiative by the EU Commission in 2011 to align the ETD more closely with climate protection concerns failed in 2015. With the Fit for 55 package, the EU Commission renewed this initiative and proposed to amend the ETD. Unlike climate protection instruments, an amendment to the ETD must be unanimously agreed in the EU Council because it is a tax directive. An agreement on an amendment to the ETD is currently pending. Nevertheless, the EU Commission's proposal for the adaptation of the ETD is briefly presented here. The EU Commission's proposal has two fundamental principles that should be considered in energy taxation within the EU.

Energy tax rates are normally set in absolute figures (e.g., in euro per litre). Therefore, the purchase power adjusted tax rates fall continuously in case of the rather usual case of increasing purchasing power. In response, the mitigation impact on energy consumption decreases over time. Accordingly, the EU Commission proposes the continuous offset of increasing purchasing power in the energy tax rates.

The second principle is to form different tiers for fuels, between which taxation is differentiated, but within the tiers the same tax is to be paid per energy used (e.g., euro per GJ). This would mean that it would no longer be possible to give preferential tax rates to diesel fuel over petrol, for example. Fossil fuels would be assigned to the highest tax rate, while several other tiers with lower tax rates would be introduced for different types of climate and environmentally friendly fuels. There would be transitional periods for changing the tax rates. The EU Commission is also proposing to impose an energy tax on air transport and shipping for intra-EU transport.

Alternative Fuels Infrastructure Regulation

In September 2023, the European Union adopted the alternative fuels infrastructure regulation (AFIR, Regulation (EU) 2023/1804), which sets binding targets for Member States for the deployment of charging infrastructure and – to a significantly lower extend – hydrogen refuelling infrastructure on the trans-European transport network (TEN-T, Regulation (EU) 1315/2013). The new regulation repeals the less binding directive 2014/94/EU, that resulted in an unharmonized and uneven distribution of alternative refuelling infrastructure in the EU.

For road transport, the AFIR sets distance-based minimum targets for charging pool locations along the TEN-T road network starting from 2025. For light-duty vehicles, additional fleet-based targets for the total charging power apply, whereas specific targets for heavy-duty vehicles are focused on distance-based targets for the charging power per location only. Furthermore, the AFIR aims at harmonizing technical standards of charging and refuelling infrastructure as well as payment requirements (e.g., on an ad hoc basis) in order to enhance user operability.

For inland waterway ports and certain frequented maritime ports, the new regulation demands a minimum shore-side electricity supply of the vessels by the end of 2024 or 2029, respectively. In addition, supply of electricity to stationary aircrafts is mandatory with exemptions for low-frequented airports from 2024 onwards.

Member States are obliged to report their national policy frameworks by 2025 and thereafter, monitor their progress of implementation on a yearly basis. For the next review of the regulation in 2026 an extension of the targets to post-2030 time frames is expected.

Eurovignette Directive

The Eurovignette Directive[5] was issued by the European Parliament and the Council in February 2022 and amends existing directives[6]. The focus of the Eurovignette Directive is on the charging of vehicles for the use of certain infrastructures. It aims to address inconsistencies in road infrastructure charging across the European Union and move towards the full internalization of external costs related to road and rail transport. The directive emphasizes the principles of 'polluter pays' and 'user pays' to generate revenue for future transport investments.

The directive sets the legal framework for transitioning from yearly taxation to a pay-per-kilometre system. Under the new rules, road charges for trucks travelling on the core trans-European transport network (TEN-T) will mostly move from time-based to actual kilometres driven-based charging by 2030.This shift aims to promote a fairer and more efficient method of charging for the use of road infrastructures. To address climate change mitigation, the directive mandates that rates be differentiated based on vehicles' CO_2 emission class by March 25, 2024. This differentiation applies Europe-wide, regardless of whether Member States opt for a distance- or time-related charging system. The revised directive introduces the option to charge for congestion and allows for higher charges in sensitive areas. Revenues generated from these additional charges will be utilized to benefit sustainable transport initiatives.

Trans-European transport network

The trans-European transport network (TEN-T) policy is based on Regulation (EU) 1315/2013 which is currently being revised. The revised TEN-T Regulation addresses the need to improve connectivity across Europe, promote the resilience of the transport system, shift more passengers and freight to sustainable modes of transport and strengthen the focus on sustainable urban mobility.

To address the gaps in connectivity and modernize the entire network, it is essential to elevate quality standards. By 2040, significant TEN-T passenger rail lines should support speeds of 160 km/h or higher. Canals and rivers need to maintain optimal navigation conditions for a minimum number of days each year. Improvements to trans-shipment terminals are imperative, as well as enabling piggy-back services on the TEN-T rail network. Additionally, all major cities should formulate sustainable urban action plans to foster zero-emission mobility. Furthermore, alongside the core and comprehensive networks, there will be an introduction of an extended core network, slated for completion by 2040. The core network corridors will merge with rail freight corridors, thereby establishing European Transport Corridors.

An assessment of the current TENT-T regulation revealed that the TEN-T contributes a European dimension to national infrastructure planning and delivers advantages beyond individual national strategies. It further determined that adjustments are necessary to align with new political objectives, such as those outlined in the European Green Deal and the Sustainable and Smart Mobility Strategy, which were formulated after the enactment of the TEN-T Regulation in 2013.

[5] (EU) 2022/362
[6] 1999/62/EG, 1999/37/EG, (EU) 2019/520

Combined Transport Directive/ Weights and Dimensions Directive

The European Union promotes Combined Transport through the Combined Transport (CT) Directive[7], which aims to enhance Combined Transport operations by eliminating authorization procedures and quantitative restrictions. It clarifies that road cabotage restrictions do not apply to road legs and offers fiscal incentives to certain CT operations. To qualify for the provisions of the CT Directive, the transportation of goods must meet specific criteria regarding the type of load units and distances involved. The directive's effectiveness has considerable room for improvement (ECA 2023). The third attempt to revise the directive in ongoing.

Among others, the CT Directive is supported by the Weights and Dimensions Directive[8], which allows Member States to authorize the transportation of heavier intermodal load units by road for CT operations. In 2023, the Commission tabled a proposal on the revision of the Weights and Dimensions Directive. The proposal seeks to further promote use of zero-emission trucks by allowing these to exceed the standard weight limits. It also seeks to clarify the rules on use of heavier and longer vehicles in cross-border transport operations between countries where such vehicles are allowed, promote intermodal transport, and simplify administrative procedures, while also improving enforcement of the rules. The revision is ongoing.

3.2 Possible range of emissions 2040 – with a glimpse on 2050

Several target scenarios present ambitious transport emission reductions until 2040. According to these scenarios, domestic transport emissions are expected to fall between -53% (EU Gas Exit Pathway) and -83% (CLEVER scenario) by 2040 compared to 1990. Domestic transport emission range between 313 Mt CO_2eq (EU Gas Exit Pathway) and 112 Mt CO_2eq (CLEVER scenario). International transport emissions under the target scope are not reported consistently among the target scenarios. In its communication on the EU 2040 climate target, the European Commission indicates a range between 42 and 52 Mt CO_2eq, that is a -51% to -61% reduction compared to 2015 levels. International transport emissions under the target scope are not reported for the base year 1990.

Most scenarios report international transport emissions separately, that is intra-EU and extra-EU aviation and shipping. They range considerably between 176 Mt CO_2eq (-85% net scenario) and 92 Mt CO_2eq (CLEVER scenario) which equals a 13% increase to a -41% reduction compared to 1990 levels. Table 1 provides an overview over the existing domestic transport scenarios including their assumptions on measures and drivers.

Table 1: List of target scenarios estimating domestic transport emissions in 2040.

	Estimated emissions in 2040 (Mt CO_2eq)	Estimated emissions compared to 1990	Assumptions on measures and drivers	Data source
EU Commission, **EU 2040 climate target, S3 scenario (2024)**	120	-82%	• Large-scale electrification (notably in road transport) • Measures to improve energy efficiency (notably in maritime and air transport)	EC (2024)
EU Commission, **EU 2040 climate target, S2 scenario (2024)**	143	-79%		

[7] Council Directive 92/106/EEC
[8] Directive (EU) 2015/719 amending Council Directive 96/53/EC

EU Commission, **EU 2040 climate target, S1 scenario (2024)**	190	-72%	• Deep transformation of fuel mix (from fossil to zero- and low-emission energy carriers) • Sustained growth in transport activity, modal shift to rail	
EU Commission, **EU 2040 climate target, LIFE scenario (2024)**	134	-80%	• As in S1-S3 plus stronger shift towards multimodal travel • Lower use of e-fuels as in S1-S3	EC (2024)
Strategic Perspectives, **-95% net scenario (2023)**	145	-78%	• By 2040, at least 84% of the total car fleet and 46% of the truck fleet will be electric • Shift to public transport and mobility as a service • Alternative fuels used for the remaining international transport emissions	Kalcher et al. (2023)
Strategic Perspectives, **-90% net scenario (2023)**	195	-71%		
Strategic Perspectives, **-85% net scenario (2023)**	271	-60%		
CLEVER network, **CLEVER scenario (2023)**	112	-83%	• Sufficiency as a no-regret option combined with other levers, especially electrification • Modal shift away from air travel, increase in rail travel • Smaller, lighter and increasingly shared and pooled fleets of electric vehicles	CLEVER network (2023)
Agora Energiewende, **EU Gas Exit Pathway (2023)**	313	-53%	• Direct electrification of road transport • Indirect electrification of shipping and aviation	Graf et al. (2023)
Climate Analytics, **1.5°C compatible range (2022)**	219	-67%	• Electrification • Increase of energy efficiency in transport	Climate Analytics (2022)

In all scenarios, electrification of road transport is the cornerstone for reducing GHG emission of domestic transport. Large proportions of the passenger car fleet in the EU will be zero-emission by 2040 with battery-electric vehicles (BEVs) being the dominating drivetrain. Electrification will also transform the heavy-duty vehicle (HDV) fleet, however later and with a bigger role of hydrogen among energy carriers. All scenarios indicate a modal shift towards rail in both passenger and freight transport. In passenger transport, the modal shares of public transport and active modes increase while the share of individual transport decreases. In all scenarios, remaining liquid fuel demand is largely met by advanced biofuels and e-fuels. These alternative fuels are primarily used to decarbonize shipping and aviation, partly also for remaining fuel demand in road freight transport.

Scenarios differ regarding their assumptions about overall transport activity. In its communication on the EU 2040 climate target, the European Commission foresees a sustained growth in transport activity in all assessed scenarios, both in passenger and freight transport (EC 2024). This holds also for passenger car traffic that dominates passenger transport activity as well as the sector's energy consumption and GHG emissions. This contrasts with the CLEVER scenario, for example, which emphasizes sufficiency and in which the passenger transport activity in general and passenger car traffic in particular decreases accordingly (CLEVER network 2023). While the Commission states energy efficiency primarily through electrification as well as in shipping and aviation, the CLEVER scenario explicitly considers efficiency gains due to more efficient and more efficiently used road vehicles.

The presented target scenarios differ considerably from Member States' national projections. While target scenarios estimate a range of 2040 domestic transport GHG emissions between -53% and -83% below 1990 levels, national projections only state a reduction of -11% (WEM) to -32% (WAM).

3.3 EU 2040 climate target scenarios

As they offer the most detailed scenario description, the EU 2040 climate target scenarios as part of EU Commission's impact assessment report accompanying its communication on Europe's 2040 climate target and path to climate neutrality by 2050 are taken to compare the target scenarios with the national projections. Also, the scenarios S1, S2, S3, and LIFE are compared regarding key transport indicators and the contributions of the respective decarbonization elements, i.e., electrification, transport activity, and fuel mix.

In the EU 2040 climate target scenarios, the decarbonization of the sector is largely achieved through the implementation of policy measures that have already been adopted or are under discussion. In addition, the scenarios do not assume a linear reduction of the ETS2 cap to zero by 2044. Still, the need for additional policy instruments is not seen for the presented fast reduction of GHG emissions until 2030, a significant drop in GHG emissions by 2040, and their near avoidance by 2050. Against this background, the large difference between the scenarios and the national projections appears at least questionable.

All assessed EU 2040 climate target scenarios show a sustained growth in transport activity together with a modal shift from road to rail. Rail capacity and attractiveness are assumed to increase due to the already implemented or foreseeable policies, e.g., TEN-T Regulation. However, the large-scale electrification of road transport will lower costs of the respective modes both in passenger and freight transport. Without additional pricing policies that address zero-emission road transport, e.g., through road toll systems, rail's competitiveness will likely decline and, consequently, its modal shares.

In this regard, the rather limited growth of passenger car transport in the EU 2040 climate target scenarios between 2030 and 2040, i.e., the period of rapid electrification, and the stagnation from there on can be questioned. Scenarios S1 to S3 are very similar in 2040 with respect to passenger transport activity. LIFE is characterized by lower passenger car transport and intra-EU aviation but higher rail transport due to assumed stronger substitution of business trips with video conferences, reduction in distance travelled for specific travel purposes, and a modal shift towards high-speed rail. Part of the reduction in passenger car transport is replaced by an assumed increase of active modes mobility. It is noteworthy to stress that there are no specific transport policy instruments modelled that can cause this assumed modal shift.

The rather limited growth in road freight transport between 2040 and 2050 despite rapid HDV electrification can also be questioned. With lower rail modal shares energy consumption of the sector would be higher than estimated by the scenarios. With given supply of biofuels, hydrogen, and RFNBOs to the sector, this would increase its GHG emissions in the medium-term and would increase the demand of these climate-neutral energy sources until 2050. The development of road freight transport is very similar in the scenarios S1 and S2. Scenario S3, however, shows a smaller growth of road freight transport demand in 2040. In 2050, road and total freight transport demand is the lowest among all four scenarios. This lowest road freight transport demand in S3 is noteworthy given that CO_2 standards for HDVs are the most ambitious (-100% in 2040) and, consequently, electrification of the HDV fleet is the highest. All other mentioned freight transport policies, e.g., the TEN-T Regulation, the proposed revision of the Combined Transport Directive, and the proposed revision of the Weights and Dimensions Directive, are reflected in the same way in all scenarios. Differences between the scenarios are likely due to different energy prices of the energy carriers.

Passenger car, van, and HDV fleets experience large-scale electrification in the EU 2040 climate target scenarios. Electrification of passenger car and van fleets is dominated by BEVs. However, fuel-cell electric vehicles (FCEVs) gain stock shares in 2040 that increase to 10% to 15% by 2050. Given that competitiveness of FCEVs in the passenger car and van segment is low and, therefore, only very few original equipment manufacturers (OEMs) offer FCEVs today or will in the future these FCEV stock shares seem optimistic. BEVs will likely by far be the dominating zero-emission powertrain in the passenger car segment. The passenger car fleet in 2040 is very similar in the scenarios S1, S2, and S3 with a ZEV-share of more than 60%. In the LIFE scenario this share is slightly lower which, however, cannot be attributed to a specific instrument. In 2050, the ZEV-share of well over 90% is identical among all scenarios.

In HDV transport, it is currently difficult to estimate whether and to which extent hydrogen will be used. BEVs will likely dominate electrification of the segment and hydrogen might play a role. However, the share of FCEV and H_2-ICEVs in the HDV segment with 26-31% seems to be the upper end of plausible scenarios. A smaller role of FCEVs would reduce hydrogen demand, increase electricity demand, but decrease overall energy demand of road transport. Among the four scenarios, the CO_2 standards for HDVs, i.e., the key instrument for HDV electrification, differs between scenarios with S1 being the least ambitious and S3 and LIFE being the most ambitious. Consequently, ZEV-shares differ slightly between scenarios already in 2040 but especially in 2050 when fleet turnover has progressed further.

Besides fleet composition the speed of fleet turnover is noticeable in the EU 2040 climate scenarios. While the share of ZEVs in the passenger car fleet is below 20% in 2030 it jumps to over 60% in 2040 in all scenarios. This sharp increase appears to be very optimistic given fleet turnover dynamics of passenger cars in Europe. According to Held et al. (2021), the average lifespan of passenger cars is around 18 years in Western European and around 28 years in Eastern European Member States. Held et al. (2021) criticize that PRIMES-TREMOVE does neither apply country-specific survival rates nor does it consider the import and export flows of used cars between countries. Hence, the sharp increase of ZEV stock shares is likely due to assumed optimistic vehicle survival rates. Given that imported used passenger cars play a much bigger role than new registrations in fleet turnover in large Member States, e.g., Poland, passenger car electrification will likely happen slower than estimated in the EU 2040 climate scenarios. Slower electrification will increase fossil energy demand and, consequently, GHG emissions. In the long term, slower electrification will increase demand for climate-neutral fuels. To avoid this, additional policies that shorten lifespans of

ICEVs, e.g., scrapping schemes, export restrictions, or incentives for retrofitting are possible policy interventions.

As describes above, electrification of road transport is the cornerstone of GHG emission reduction in domestic transport. In all EU 2040 climate target scenarios, energy demand for liquid fuels in road transport drops drastically until 2040. In passenger car transport, liquid fuel demand in 2040 is only about one quarter the 2015 liquid fuel demand. In HDV transport, the liquid fuel demand in 2040 is less than half the 2015 liquid fuel demand. This decrease is dominated by vehicle electrification especially due to CO_2 emission standards for passenger cars, vans, and HDVs. In 2040, the difference in CO_2 emissions between the scenarios is mainly due to the different use of renewable fuels (especially e-liquids). The scenarios differ between a very limited uptake of e-fuels in S1, a larger uptake in S2, and a high share of e-fuels in S3. In 2050, however, the use of renewable fuels is highest in S1 and lowest in S3 especially in HDV transport. This is due to the different sizes of the remaining ICEV stock (because of different CO_2 emission standard ambitions) that need to be fully supplied by renewable fuels. The differences in renewable fuel supply between the scenarios is part of the scenario definitions. In international transport, the use of renewable fuels differs between scenarios due to different levels of ambition in the design of the ReFuelEU Aviation and the IMO GHG emissions reduction target for international shipping. Further, the FuelEU Maritime defines GHG intensity limits more stringent over time until 2050 equally in all scenarios.

The contribution of shifting and avoiding transport activity is difficult to isolate without detailed modelling insights. Differences in transport activity between scenarios come along with different ZEV-shares or different use of renewable fuels. The assumed shift towards shared and collaborative mobility services and multimodal travel, more efficient operation of freight vehicles and delivery of goods, and higher use of intermodal freight transport is smallest in S1 and largest in LIFE. In passenger transport, the lowest transport activity of passenger cars in LIFE is counteracted by the lowest ZEV-share. Still, total energy demand of passenger car transport is lowest in LIFE indicating that shifting and avoiding transport activity can overcompensate the slightly lower rate of passenger car electrification. However, CO_2 emissions from passenger cars is not the lowest in LIFE because of its lower share of renewable fuels. Hence, a moderation of transport activity in the scenarios affects energy demand primarily. Until 2050, moderating transport activity in LIFE lowers total energy demand for electricity and RFNBOs in the transport sector noticeably.

The EU 2040 climate scenarios appear to be optimistic regarding domestic transport GHG emission reductions. The sole implementation of agreed or planned policy measures suggests that no additional action is needed to transform the sector quickly. Given the scenario assumptions, e.g., the high speed of passenger car electrification, this conclusion should not be drawn. Instead, the sector's transformation requires policy action that is likely to provoke heated debates. This includes, among others, the moderation of transport activity, lowering the attractiveness of individual ICEV transport, shortening ICEV lifespans, and financing infrastructure expansion for rail as well as for public transport and active modes.

4 How to achieve the necessary contribution: Discussion of possible policies and measures and options

To achieve the necessary contribution of the transport sector to an ambitious 2040 climate target the political achievements of the past legislative period must be secured and need to be followed by strengthening existing policy instruments and designing new ones. This applies to all three dimensions of cutting transport GHG emissions: First, improve the transport system by electrifying road and rail transport, by reducing the GHG intensity of the fuel mix, and by increasing energy efficiency. Second, shift transport activity from motorised individual to public transport and from road to rail both in passenger and freight transport. And third, avoid transport activity by enabling short distance travel through regional planning and exploiting digitalisation potential.

As GHG emissions from domestic transport come almost exclusively from road transport improving the transport system through electrification of passenger cars, vans, and heavy-duty vehicles (HDVs) is the crucial element of the sector's decarbonization. Emission standards for cars and vans have primarily caused the sharp uptake of zero-emission vehicles in Europe since 2020. Political achievements have been made about the tightening of these standards and the phase-out of fossil internal combustion engines from 2035. For HDVs, ambitious emission standards were provisionally agreed in 2024, signalling that electrification of the segment is imminent. Considering a possible shift in political forces after the European elections 2024 it is crucial for electrification of road transport that these regulatory achievements are not called upon question. Increasing ambition levels for the HDV standards beyond 2030 – especially for 2040 – could increase the speed of electrifying the vehicle stock and reduce the emissions quicker than with the pending amendment.

Further improvement of the sector should be pursued through regulating real-world emissions. As shown by Dornoff et al. (2024), the gap between real-world and laboratory CO_2 emission data for internal combustion engine cars and hybrid cars has grown considerably since the introduction of the Worldwide harmonized Light vehicles Test Procedure (WLTP) in 2017. Consequently, the reduction of real-world CO_2 emissions is lower than intended. The European Commission is already asked to develop a mechanism that prevents this gap from growing. This mechanism should apply as soon as the availability of on-board fuel and energy consumption monitoring (OBFCM) data allows. Moreover, real-world consumption should be used for consumer information through its display on vehicle efficiency labels or public availability of anonymized OBFCM data. Real-world consumption monitoring should also be developed and applied for HDVs.

A shortcoming of regulating CO_2 emissions is that it does not address energy consumption of zero-emission vehicles (ZEVs). There are today no requirements for the energy consumption of ZEVs. The ecodesign regulation currently awaiting adoption even explicitly excludes motor vehicles from its scope. This exclusion does not reflect that ZEVs will foreseeably be among the largest consumers of electricity in Europe. Consequently, a new, separate regulation should set energy efficiency targets of ZEVs. These energy efficiency targets should refer as much as possible to real-world consumption as monitored by OBFCM data. Even though improving energy efficiency of ZEVs has no direct effect on GHG emissions of the transport sector, the inefficient use of electricity by vehicles will continue to lead to considerable additional

challenges in the decarbonization of the electricity supply and distribution and indirectly to higher GHG emissions and costs.

To further stimulate demand for ZEVs in public procurement tenders the Clean Vehicles Directive should be reviewed to include more ambitious national targets. The directive foresees a review in 2027. However, the European Commission should examine whether more ambitious national targets can be implemented earlier to make the directive consistent with the already strengthened emission standards to cars, vans, and HDVs. Moreover, the European Commission should examine measures to stimulate private demand for ZEVs, for example by ZEV purchase targets for corporate fleets. Higher shares of ZEVs for corporate fleets would make sure that affordable ZEVs will become available on the used vehicle market quicker. The proposal of the Greening Corporate Fleets Initiative should, therefore, be set out as soon as possible. In freight transport, with OEMs and infrastructure being regulated the European Commission should also consider regulating the user groups, e.g., through CO_2 reporting obligations for logistics companies.

Other policy instruments that improve the transport system and should be strengthened relate to the sectors' energy sources and their provision. To further reduce the GHG intensity of the fuel mix the Renewable Energy Directive (RED) should be reviewed timely to implement targets for the period post 2030. The post 2030 targets should preferably cover the period up to 2050. This would ensure bankability of investments into the production of advanced biofuels and RFNBOs that go beyond quotas regulated by ReFuelEU Aviation Regulation and FuelEU Maritime Regulation. Considering recent allegations of fraud against producers of advanced biofuels weaknesses in certification must be remedied. Concerning the provision of the sector's energy sources, the Alternative Fuels Infrastructure Regulation (AFIR) should also be reviewed timely to implement targets for HDVs for the period post 2030. The commission should in this course evaluate competition concerns as well as price transparency and payment methods.

As described in chapters 2 and 3, the longevity of vehicles, especially passenger cars, constitutes a major hurdle for the envisioned quick electrification of road transport. A discussion of this hurdle and the development of adequate policy instruments should be initiated quickly. Policy instruments that shorten vehicle lifespans, e.g., scrapping schemes or export restrictions, are likely to be heavily debated and should be assessed by the Commission. With an accelerated ramp-up of electric vehicles comes the need for funding mechanisms to tackle the upfront cost barrier especially for low-income households and small and medium enterprises. In this regard, new targeted financial tools should be examined. Less controversial instruments to tackle the foreseeable high number of internal combustion engine vehicles (ICEVs) comprise incentives for retrofitting. In this regard, technical requirements for new ICEVs that facilitate a future retrofit should also be considered.

While improving of the transport system has been regulated through several policy instruments, shifting transport to lower-emission and active transport modes is less addressed by EU policies. As pointed out by ESABCC (2024), EU policies aimed at promoting a modal shift have so far had little success owing to lack of ambition and incomplete and heterogeneous implementation at the Member State level. The European Commission should enhance support for a modal shift by tackling operational and regulatory hurdles both at EU and Member State level (e.g., different electricity and train control systems or operating regulations hamper a modal shift to cross-border rail traffic), infrastructure bottlenecks, and the lack of available and integrated data.

These challenges relate particularly to rail transport, which can play a central role in modal shift both in passenger and freight transport. Long-distance European transport could be increasingly provided by rail freight transport if the infrastructure were upgraded. This upgrading

requires political commitment and corresponding financial resources. These financial resources could be channelled by supporting the member states in implementing the European Train Control System (ETCS), just as there is support today for the implementation of the TEN-T corridors. The support should be targeted and consider the different economic capacities of the Member States but also their transit traffic loads. The TEN-T quality standard that major TEN-T passenger rail lines should allow trains to travel at 160 km/h or faster by 2040 should be scrutinized regarding energy efficiency, wear and tear and reliability. The aim in rail passenger transport should be to develop from a high-speed system to a reliability system. A separate TEN-T Rail could take account of the special role of rail transport in the modal shift. Opening booking platforms is key to facilitating cross-border passenger rail transport. The objectives of the Sustainable and Smart Mobility Strategy (SSMS) should be pursued more vigorously and the development of Multimodal Digital Mobility Services (MDMS) should be intensified.

Modal shift in passenger and rail transport should be facilitated through a further alignment of pricing policies (ESABCC 2024). Electrification of road transport will reduce costs and will strengthen road transport modes in passenger and rail transport. The Commission should, therefore, examine the mandatory introduction of toll systems that can also guarantee the financing of the transport system in the long term. Possible social impacts of toll systems resulting from the uneven uptake of ZEVs should be considered. The uneven electrification will lead to an uneven burden for households in the Member States also through the EU ETS 2. The Social Climate Fund (SCF) is set up to address this burden. However, the European Commission should examine further instruments to address this burden, e.g., through increasing the supply of used ZEVs through an uptake of corporate fleets or the close monitoring and evaluation of national social leasing schemes. To initiate a discussion on the regulation of modal shift, the Commission could introduce national modal shift targets that consider preconditions of the Member States.

Avoiding transport activity as the third dimension of reducing transport GHG emissions remains unconsidered by existing EU policy. Moderation of overall transport demand is not part of the EU's SSMS but has been explicitly excluded in past EU strategies (ESABCC 2024). Avoiding transport is often associated with the risk of reduced economic output and income losses. However, there are policies that could decouple this correlation (IPCC 2022). Spatial planning policies that promote denser urban development and decrease commuting distances to workplaces or educational institutions can yield favourable economic and social advantages as well. Advancing digitalisation will continue the trend towards working from home. However, this trend should be closely monitored regarding changing settlement structures and transport.

With the EU ETS 1, ReFuelEU Aviation Regulation, and FuelEU Maritime Regulation GHG emissions from international transport are today partly covered by EU policies. However, extra-EU aviation and half of extra-EU maritime transport remains exempt from the EU ETS 1 (ESABCC 2024). In addition, there are very few policies focusing on demand reduction; so far, all improvements in energy efficiency in both sectors have not been able to compensate the demand increase. International transport should be included in the scope of the EU 2040 climate target to sustain the recently acquired policy momentum (Wissner and Graichen 2024a). Scheduled reviews of the EU ETS 1, ReFuelEU Aviation Regulation, and FuelEU Maritime Regulation are crucial for expanding coverage, enhancing ambition, providing additional incentives for climate-neutral fuels, and addressing potential policy implementations at the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO). The decision regarding the incorporation of non-CO_2 aviation emissions in the EU ETS 1 as of 2027 requires ambitious implementation. Still additional and complementary regulatory action should be taken to minimize non-CO_2 effects, i.e., regulating aviation fuel quality and promoting contrail avoiding flight paths. Expanding coverage of the EU ETS 1 should also comprise ships

below 5,000 gross tonnage which the Commission shall present a feasibility report on by the end of 2026 (Wissner and Cames 2023).

Expected future CO_2 prices will likely lead to efficiency gains but will not ensure the uptake of climate-neutral fuels and the needed investments (Wissner and Graichen 2024b). Therefore, spending ETS revenues are important to facilitate the uptake. Prevailing exemptions for aviation and shipping in the Energy Taxation Directive (ETD) are an unresolved problem. As negotiations for the revision of the ETD continue and the outcome remains uncertain, countries with similar objectives could and should proceed independently by implementing bilateral tax agreements. Moderating international transport demand by creating attractive alternatives to air travel, changing air travel narratives, and reducing demand for fossil fuels and primary materials must accompany fuel switch efforts.

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