

DIRECTORATE-GENERAL FOR INTERNAL POLICIES

POLICY DEPARTMENT
STRUCTURAL AND COHESION POLICIES **B**

Agriculture and Rural Development

Culture and Education

Fisheries

Regional Development

Transport and Tourism

**Research for TRAN
Committee -
Decarbonisation of EU
transport**

STUDY



DIRECTORATE-GENERAL FOR INTERNAL POLICIES
Policy department for structural and cohesion policies

TRANSPORT AND TOURISM

Research for TRAN Committee - Decarbonisation of EU transport

STUDY

This document was requested by the European Parliament's Committee on Transport and Tourism.

AUTHORS

CE Delft: Anco Hoen, Anouk van Grinsven, Bettina Kampman, Jasper Faber, Huib van Essen
TEPR: Ian Skinner

Research manager: Marc Thomas
Project and publication assistance: Lyna Pärt
Policy Department for Structural and Cohesion Policies, European Parliament

LINGUISTIC VERSIONS

Original: EN

ABOUT THE PUBLISHER

To contact the Policy Department or to subscribe to updates on our work for the TRAN Committee please write to: Poldep-cohesion@ep.europa.eu

Manuscript completed in September 2017
© European Union, 2017

Print	ISBN 978-92-846-1276-5	doi:10.2861/97712	QA-04-17-668-EN-C
PDF	ISBN 978-92-846-1277-2	doi:10.2861/840058	QA-04-17-668-EN-N

This document is available on the internet at:
[http://www.europarl.europa.eu/RegData/etudes/STUD/2017/601989/IPOL_STU\(2017\)601989_EN.pdf](http://www.europarl.europa.eu/RegData/etudes/STUD/2017/601989/IPOL_STU(2017)601989_EN.pdf)

Please use the following reference to cite this study:

Hoen, A, van Grinsven, A, Kampman, B, Faber, J, van Essen, H & Skinner, I, 2017, Research for TRAN Committee – Decarbonisation of EU transport, European Parliament, Policy Department for Structural and Cohesion Policies, Brussels

Please use the following reference for in-text citations:

Hoen, van Grinsven, Kampman, Faber, van Essen & Skinner (2017)

DISCLAIMER

The opinions expressed in this document are the sole responsibility of the author and do not necessarily represent the official position of the European Parliament.

Reproduction and translation for non-commercial purposes are authorized, provided the source is acknowledged and the publisher is given prior notice and sent a copy.

DIRECTORATE-GENERAL FOR INTERNAL POLICIES
Policy department for structural and cohesion policies

TRANSPORT AND TOURISM

Research for TRAN Committee - Decarbonisation of EU transport

STUDY

Abstract

This study shows that very significant GHG reductions are still necessary in the transport sector to meet EU medium and long-term climate targets. The urgency of swift policy action has increased with the Paris Agreement.

CONTENTS

LIST OF ABBREVIATIONS	5
LIST OF TABLES	7
LIST OF FIGURES	7
EXECUTIVE SUMMARY	9
1. INTRODUCTION	13
1.1. Need for GHG reduction	13
1.2. Importance of timing of GHG emission reductions often overlooked	13
1.3. Reducing transport CO ₂ emissions - No silver bullet	14
1.4. Approach followed in this study	14
1.5. Aims and objective of this study	15
1.6. Report structure	15
2. CURRENT AND FUTURE GHG EMISSIONS FROM THE TRANSPORT SECTOR	17
2.1. GHG emission trends in the EU and within EU transport	17
2.2. Required GHG emission reductions to 2050	22
2.3. Are we on course for 2050?	25
3. EU Policy And Industry Strategies To Decarbonise Transport	27
3.1. EU policy strategies to meet targets	27
3.2. Industry strategies to meet targets	35
3.3. Conclusions	36
4. POLICY ANALYSIS - CURRENT SITUATION AND FUTURE POTENTIAL	37
4.1. Vehicle efficiency	37
4.2. Decarbonisation of transport fuels and energy sources	53
4.3. Efficiency of the transport sector	61
5. SYNTHESIS OF PREVIOUS SECTIONS	73
5.1. Effectiveness of existing policy efforts	73
5.2. Overall potential for decarbonisation	76
5.3. Discussion	78
6. MAIN CONCLUSIONS AND RECOMMENDATIONS	81
6.1. Main conclusions	81
6.2. Recommendations for future EU policy	82
REFERENCES	87

LIST OF ABBREVIATIONS

ATAG	Air Transport Action Group
BEV	Battery Electric vehicle
C-ITS	Cooperative Information Technology Systems
CIVITAS	CItY-VITAlity-Sustainability
CNG	Compressed Natural Gas
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CVD	Clean Vehicle Directive
EEA	European Environmental Agency
EEDI	Energy Efficiency Design Index
ESD	Effort-Sharing Decision
EU ETS	European Union Emission Trading Scheme
FCEV	Fuel-Cell Electric Vehicle
FQD	Fuel Quality Directive
GHG	Greenhouse Gases
GMBM	Global Market-based Measure
GPP	Green Public Procurement
HDV	Heavy-Duty Vehicle
HGV	Heavy Goods Vehicle
ICAO	International Civil Aviation Organisation
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
IEA	International Energy Agency
ILUC	Indirect Land Use Change
IMF	International Monetary Fund
IMO	International Maritime Organisation
INDC	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
ISA	Intelligent Speed Adaptation
ITF	International Transport Forum
ITS	Intelligent Transport Systems
LCV	Light Commercial Vehicle

LDV	Light-Duty Vehicle
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LULUCF	Land Use, Land-Use Change and Forestry
MRV	Monitoring, Reporting and Verifying
NEDC	New European Driving Cycle
NGO	Non-governmental organisation
OECD	Organisation for Economic Co-operation and Development
PBL	Netherlands Environmental Assessment Agency
PEMS	Portable Emissions Measurement Systems
PHEV	Plug-in Hybrid Electric Vehicle
PtL/PtG	Power-to-Liquid, Power-to-Gas
PV	photovoltaic
RED	Renewable Energy Directive
RES-T	Renewable energy sources in transport
SUMP	Sustainable Urban Mobility Plan
TCO	Total Cost of Ownership
TEN-T	Trans-European Transport Network
TTW	Tank-to-Wheel
UCO	Used Cooking Oil
UIC	International Union of Railways
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value Added Tax
WLTP	Worldwide harmonized Light vehicles Test Procedure
WTW	Well-to-Wheel
ZEV	Zero-Emission Vehicle

LIST OF TABLES

Table 1	
Overview of global carbon budgets for the two climate targets	14
Table 2	
GHG reductions by sector compared to 1990, actual (2005) and required to deliver 80% reduction economy-wide	24
Table 3	
Difference between the 2020 Package and 2030 Framework	30

LIST OF FIGURES

Figure 1	
Historic and projected economy-wide GHG emission trends and targets, EU-28 (million tCO ₂ -eq)	18
Figure 2	
Changes in emissions of all GHGs by the main sectors between 1990 and 2014, EU-28 (percentages and absolute values in million tCO ₂ -eq)	19
Figure 3	
GHG emissions from transport (excluding aviation and shipping) under the scope of the Effort Sharing Decision, 1990 to 2030 (million tCO ₂ -eq)	20
Figure 4	
GHG emissions by transport mode, EU-28 (million tCO ₂ -eq)	21
Figure 5	
Transport volumes for main passenger and freight modes (indexed to 2007)	22
Figure 6	
Illustrative sensitivities in the context of meeting the 60% reduction target for transport in 2050	25
Figure 7	
GHG emissions from transport for the EU-28	25
Figure 8	
Overview of EU transport-related strategies and their scope	28
Figure 9	
CO ₂ emissions for new cars and LCVs, actual, targets and 2050 assumptions	39
Figure 10	
Development of the average type-approval test value of new cars sold in the EU and their real-world CO ₂ emission factors	40
Figure 11	
Car labels in place in France, Austria and Italy	44
Figure 12	
Direct and indirect GHG emissions from biofuels produced from different feedstocks	57
Figure 13	
RES-T share in individual Member States (2015)	58
Figure 14	
Illustration of the contribution of three pathways to reach long-term climate targets of -60 and -90%	78

EXECUTIVE SUMMARY

Background

To meet medium and long-term climate targets requires robust decarbonisation of the transport system. The overarching long-term EU target for the transport sector is set out in the 2011 Transport White Paper (EC, 2011b). It was set at 60% carbon dioxide (CO₂) emissions reduction in 2050 compared to 1990 levels.

This target has its origin in the long-term worldwide goal to limit global warming in this century to no more than 2°C above pre-industrial levels. Recently, a more ambitious target was adopted through the Paris Agreement in response to the latest report of the Intergovernmental Panel on Climate Change (IPCC). The Paris Agreement aims to strengthen the global response to climate change by “holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change”. Clearly, a 1.5°C target is substantially more ambitious than a 2°C target, which will have implications for all sectors, including transport.

Considering the existing medium and long-term GHG reduction targets and the recently stepped up ambition, the question arises how these targets are to be met and what implications they have for EU transport policies. This paper describes the effectiveness of current and future climate policies for transport and discusses the policy action needed at EU level for meeting the commitments made in Paris.

Aim of this study

The aim of the present study is twofold:

- To assess the impacts of the different (existing or developing) strategies currently implemented in the EU to reduce GHG emissions and those of the European Commission’s 2016 Low Emission Mobility Strategy.
- To describe how decarbonisation of transport in the EU can be achieved.

This study is designed to serve as a background report providing input for the follow-up policy debate on the aforementioned Commission’s Low Emission Mobility Strategy and related initiatives. The focus is on the design of the EU’s policy strategy towards 2030. However, since the period after 2030 is also crucial for meeting long-term climate goals, considerations for the period until the year 2050 are also included.

Main findings

While the EU’s GHG emissions have been declining since 1990, GHG emissions from transport have increased. In the immediate aftermath of the economic crisis, transport GHG emissions and demand for transport in the EU declined, but both have now begun to increase again. GHG emissions from international shipping increased even more between 1990 and 2014, while those from international aviation nearly doubled over the same period.

This increase occurred despite EU policy efforts to limit transport GHG emission. The EU policies that had the largest impact on decarbonisation were CO₂ standards for passenger cars and policies aimed at increasing the share of renewable energy sources in transport (RES-T). However, in both cases, real-world emission reductions have been far smaller than the intended reduction. The growing discrepancy between real-world CO₂ emissions and those measured in the ‘New European Driving Cycle’ (NEDC) test cycle has had an important

impact on the effectiveness of CO₂ standards for cars and vans. The use of biofuels might even have led to a net increase in CO₂ emissions if indirect emissions are taken into account. The effectiveness of EU modal shift policies has not been properly assessed to date, but may very well have been limited. The policy impact on GHG emissions from aviation and maritime shipping has so far been limited.

Very significant GHG reductions are still necessary in the transport sector to meet the longer-term climate agreements. The urgency of swift policy action has increased with the Paris Agreement.

Although the GHG reduction target for 2020 of 20% compared to 1990 levels looks likely to be met, further policy action is needed to meet the proposed 2030 target of 40% compared to 1990 levels. Limiting warming to the proposed 1.5°C requires net zero emissions globally at some point between 2040 and 2060.

A step change in GHG emissions reductions will be needed to meet the 60% GHG reduction target for transport in 2050. This becomes especially clear when it is realised that without further policy action, transport GHG emissions are expected to be 15% above 1990 levels by 2050. Moreover, the 2050 target is based on a maximum temperature increase of 2°C, not 1.5°C. In 2014 transport GHG emissions were 20.1% above 1990 levels, implying they will need to fall by 67 % by 2050 in order to meet the Transport White Paper target (EEA, 2016d) and even significantly more to meet the commitments made in the Paris Agreement.

A wide range of measures are available to reduce the future CO₂ emissions of the transport sector. The largest potential comes from technological options to improve the energy efficiency of vehicles, ships and planes. The second largest potential comes from renewable fuels and energy carriers for the different transport modes. A more limited impact may be expected from measures that improve the efficiency of the transport system itself (i.e. measures that impact on transport demand).

Current technologies are either insufficient or need further development to meet the future GHG reduction targets. Of particular importance are:

- Cost reductions for battery electric vehicles and fuel-cell vehicles.
- Realisation of charging and/or fuelling infrastructure for electric and fuel-cell vehicles, including development of (smart) integration of these vehicles in terms of grid capacity and stability, flexible demand and energy storage.
- Technologies for the production of large-scale, affordable, low-carbon and renewable fuels from biomass, wind and solar power, in particular for transport modes or applications for which electrification is unlikely to be a viable option (e.g. aviation, shipping and possibly heavy-duty vehicles). In particular, the development of power-to-gas and power-to-liquid should be developed.

Main recommendations

To decarbonise the transport sector further, it is recommended to continue and strengthen the existing range of policies, targeting the efficiency of vehicles, the decarbonisation of fuels and the efficiency of the transport system as a whole. The challenges ahead are very substantial, and an effective and stable policy package that provides certainty to the market about an ambitious reduction path is essential to ensure adequate investments by the industry, to trigger the innovations needed and to create support by NGOs and citizens. This policy package should cover all transport modes, including aviation and maritime shipping.

In designing a strategy and policies for the decarbonisation of transport, it is important not to focus solely on the 2050 emission target, but also on the cumulative GHG emissions over time, since the timing of emission reductions influences the global temperature increase.

Since the costs for companies and citizens are likely to increase, it is important to adequately communicate the reasoning behind the policies and have a transparent decision process in place in order to ensure broad support for the actions taken throughout the EU.

Recommendations regarding energy efficiency

Further improvement of the energy efficiency of all transport modes is key for decarbonisation. It is recommended to continue and strengthen vehicle CO₂ regulations over time, to introduce regulations for heavy-duty vehicles (HDVs), and to ensure that the effectiveness of the regulations are improved by reducing the gap between real-world and test-cycle emissions. Swift policy action on vehicle regulations is recommended, since new legislation takes time to adopt and applies only to new vehicles, which means it takes roughly ten to fifteen years (depending on vehicle lifetime) for the full effects to kick in.

In the long-term, climate targets can only be met if light-duty vehicles become nearly zero-emission. A mandate for ultra-low or zero-emission vehicles has the potential to ensure a sufficiently fast uptake of electric and fuel-cell vehicles.

Efficiency policies will induce rebound effects: they will result in lower costs per kilometre in both passenger and freight transport, which will induce additional travel demand and result in additional GHG emissions. Moreover, climate policies will result in reduced demand for fossil fuels, which will in turn decrease oil prices. To meet long-term targets, climate policies should give due consideration to these rebound effects.

Recommendations regarding renewable fuels and energy carriers

To speed up the use of renewable energy sources in transport (RES-T), implementing stable and effective sustainability criteria for the period after 2020 is key, combined with equally stable targets thereafter, such as blending obligations, RES-T or CO₂ targets. To set these targets at an optimum level, a longer-term outlook is needed on the future transport energy mix with which the climate targets can be met.

Policies and strategies for RES-T should not be assessed and developed in isolation, but be considered together with the other sectors working on decarbonisation of their energy supply, notably the power sector, industry and the built environment. To meet their decarbonisation targets and challenges, these sectors will also have a growing need for sustainable biomass as a renewable energy source (and chemical feedstock), for renewable electricity output and for renewable fuels from solar or wind power. Since the availability of sustainable biomass feedstocks is limited, competition for these feedstocks and other sources of renewable energy is likely to increase costs. At the same time, though, this might also create opportunities for cooperation and synergies, in bio-refinery processes, for example, resulting in output of multiple biomass products making fully use of the available biomass.

Power-to-gas and power-to-liquid should be developed in order to ensure the transport sector can also benefit from the full potential of decarbonisation from renewable fuels produced from wind and solar power.

Recommendations regarding efficiency of the transport sector

Climate policies for transport need to anticipate the possibility that vehicle efficiency measures in tandem with sustainable fuels may be insufficient to meet long-term climate targets. Currently, cost-effective measures to improve the efficiency of the transport system are largely overlooked in EU policy. Measures such as improving logistics efficiency through

Cooperative Information Technology Systems (C-ITS), congestion charges and optimising spatial planning and infrastructure planning might be more cost-effective than certain vehicle-efficiency and low-carbon fuel measures. It should be noted, however, that as climate targets become increasingly stringent, measures impacting on travel demand may also be necessary.

This begs the question whether the notion “curbing mobility is not an option” from the Transport White Paper can be maintained indefinitely.

The EU should look for ways to further encourage Member States to embrace measures directed at improving the efficiency of the transport sector, recognizing that such measures are often the responsibility of regional and local authorities. There is a wide variety of tools that can potentially achieve this, including speed limits, environmental zones, energy taxation based on CO₂ emissions, road charging and spatial planning policy. Each of these can contribute to meeting long-term climate goals.

Urbanisation is an ongoing process in many Member States and will lead to further pressure on air quality, noise, safety and general liveability, in addition to the increasingly stringent climate goals which will alter (urban) transport (e.g. car and ride-sharing and a resurgence of cycling and walking). As a result, cities will play an important role in the transition towards sustainable transport. Considering that decisions on infrastructure and spatial (urban) planning will have an impact for many decades, the EU could promote these being tied more closely to GHG emission policy. Sustainable Urban Mobility Plans (SUMPs) can function as an important tool in this respect.

Recommendations regarding aviation and maritime

Aviation and maritime transport are preferably regulated at a global level in ICAO and IMO, respectively, as these are global sectors. Still, in the case of aviation, the EU policy framework needs to recognise the weaknesses of both the current global market-based measures for aviation and the CO₂ standards for aircraft. It is recommended to ensure that aviation makes a fair and appropriate contribution to long-term GHG reduction efforts. Keeping a share of aviation emissions in the EU ETS in the short-term could be considered.

The Parliament’s proposal to include maritime shipping in the EU ETS (EP, 2017) could be a way to address the GHG emissions of this sector if the IMO does not succeed in developing a comprehensive GHG emissions strategy.

Promoting the use of renewable fuels in both aviation and maritime transport is required to ensure that both modes decarbonise. One of the main barriers that needs to be addressed is the price difference between sustainable low-carbon fuels and fossil fuels, which will also require innovation in advanced biofuels.

1. INTRODUCTION

1.1. Need for GHG reduction

To meet medium and long-term climate targets requires robust decarbonisation of the transport system. The overarching long-term EU target for the transport sector is set out in the 2011 Transport White Paper (EC, 2011b). This took as its starting point the need to reduce carbon dioxide (CO₂) emissions from transport by 60% in 2050 compared to 1990 levels.

This target has its origin in the long-term worldwide goal to limit global warming in this century to no more than 2°C above pre-industrial levels. To achieve this goal, the Intergovernmental Panel on Climate Change (IPCC) has stated that GHG emissions reductions of between 80% and 95% are needed by 2050 compared to 1990 levels in developed countries.

The EU embraced this long-term target and engaged in the preparation of several policy documents to elaborate the necessary steps to meet the 2°C target. An important milestone in this respect was the Commission's publication of the Low Carbon Economy Roadmap in 2011, which explored scenarios for delivering reductions in GHG emissions of around 80% in 2050 compared to 1990 levels, for all sectors combined (but excluding international shipping). In addition to the long-term target, there are medium-term targets. The EU communicated its medium-term plans to the United Nations Framework Convention on Climate Change (UNFCCC) in the run-up to the meeting in Paris. Its intended nationally determined contribution stated that the EU and its Member States were committed to a binding target of at least a 40% domestic reduction in GHG emissions by 2030 compared with 1990.

Through the Paris Agreement, a more ambitious target was adopted in response to the IPCC's latest report on climate change. This Agreement aims to strengthen the global response to climate change by "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change". Clearly, a 1.5°C target is substantially more ambitious than a 2°C target, which will have implications for all sectors, including transport.

1.2. Importance of timing of GHG emission reductions often overlooked

The objectives set out in the 2011 Low Carbon Economy Roadmap and Transport White Paper are based on setting reduction percentages in a specified target year compared to a base year, e.g. a reduction in GHG transport emissions of (at least) 60% in 2050 compared to 1990 levels. This approach neglects the fact that the *timing* of emission reductions, not just the long-term annual levels, affects the rise in global temperature. This is because long-term global temperature is mainly determined by *cumulative* GHG emissions (PBL, 2016). Based on the relationship between global temperature and cumulative GHG emissions, it is possible to derive so-called carbon budgets: the maximum amount of GHGs that can be emitted globally so as not to exceed the targets set out in the Paris Agreement.

Table 1 shows the carbon budgets that PBL (the Netherlands Environmental Assessment Agency) derived from the 5th Assessment IPCC report for both the 1.5 and 2°C targets. To put these values into perspective: global annual GHG emissions in 2015 amounted to 36 GtCO₂. This means that if annual global CO₂ emissions stayed at current levels, the carbon budget to limit temperature increase to a maximum of 2°C would run out in roughly 31 years.

However, the budget associated with limiting the temperature rise to 1.5°C would be depleted within 10 to 12 years, i.e. by 2028 at the latest.

Climate policies that reduce GHG emissions will lengthen the time available before the budgets in Table 1 are depleted. The time available will increase faster if swift policy action results in a prompt reduction of GHG emissions. This stresses the importance of an effective policy framework for GHG mitigation in the period until 2030.

Table 1: Overview of global carbon budgets for the two climate targets

	Chance of reaching 1.5°C		Chance of reaching 2°C	
	At least 50%	At least 66%	At least 50%	At least 66%
Carbon budget from 2015 onwards (GtCO ₂)	375-425	225	1,125 (975-1,225)	825 (575-1,225)
Number of years until depletion at current level of global emissions	10 to 12	6	31	23

Source: (PBL, 2016).

1.3. Reducing transport CO₂ emissions - No silver bullet

Over the past ten years numerous reports have focused on the policy actions that are needed to meet the transport climate targets (PBL, 2009); (AEA, CE Delft, TNO, 2010); (EC, 2011c); (EEA, 2016d); (ITF, 2017). A constant in the conclusions of these reports is that there is no 'silver bullet' that tackles all problems simultaneously. Each and every transport mode will have to make a substantial contribution to CO₂ reductions. Moreover, a combination of measures aimed at (1) vehicle efficiency, (2) decarbonisation of transport fuels and (3) efficiency of the transport system (aimed at controlling modal split, promoting efficient vehicle use and curbing transport demand) is needed for each of the various modes.

1.4. Approach followed in this study

The method employed in the present study is twofold. The core of the research is based on an extensive literature study and is mostly qualitative in nature. In addition, we also add a quantitative element, for which we use a method based largely on a review and analysis of existing sources, complemented by high-level calculations. All transport modes are covered, including aviation and shipping. For each of these modes we examine the potential of CO₂ reduction policies aimed at:

- vehicle efficiency;
- decarbonisation of transport fuels;
- efficiency of the transport system.

It is important to note that most GHG reduction policies for transport, while directly targeting vehicles, energy sources or vehicle use, often also indirectly affect one or both of the other elements. For example, measures to improve vehicle efficiency also affect the choice of fuels and, possibly, also how vehicles are used. In this paper, policies are discussed with reference to their principal means of reducing transport CO₂ emissions, but where relevant indirect impacts on GHG emissions are mentioned too.

1.5. Aims and objective of this study

This report seeks to answer the following research questions:

- What are the impacts of the various (existing or developing) strategies currently implemented in the EU to reduce GHG emissions, and what is the role of the 2016 Commission Communication on Low Emission Mobility in this respect?
- How can transport decarbonisation in line with the Paris Agreement be achieved in Europe?

This study is designed to serve as a background report providing input for the European Parliament's follow-up policy debate on the Commission's 2016 Low Emission Mobility Strategy and related initiatives. The focus is on the design of the EU's policy strategy towards 2030. However, since the period after 2030 is also crucial for meeting long-term climate goals we also discuss the 2050 context where relevant.

Working towards decarbonisation will definitely impact the economies of Member States and the EU as a whole. On the one hand, major investments will be required to ensure innovation and the production of low-carbon fuels and vehicles that use them. On the other hand, new markets may form, creating job opportunities and adding to the green growth strategy of the EU. The costs and benefits associated with transport decarbonisation and the impact on economic (green) growth would require a separate study, however, and are beyond the scope of this report.

1.6. Report structure

The remainder of this report is structured as follows. In Section 2 we start with a review of current and future transport GHG emissions in the EU. The gap between emission trends based on current policies and the medium and long-term GHG targets set out in the EU climate strategies is indicated. Section 3 continues with an overview of the EU policy strategies and industry strategies to decarbonise transport that have been implemented since 2011. Section 4 reviews current policies and the future GHG reduction potential of these strategies as well as of new options that have been studied but have not yet been implemented in the EU. This overview is divided into three pathways for decarbonising transport: (1) vehicle efficiency, (2) transport fuel decarbonisation and (3) transport sector efficiency. The GHG reduction effectiveness of policies in each of the three pathways is discussed. In Section 5, findings from the previous sections are put into context and a synthesis is provided, focusing on the effectiveness of existing policies and the maximum future potential for transport decarbonisation. Section 6 concludes with the main conclusions and policy recommendations.

2. CURRENT AND FUTURE GHG EMISSIONS FROM THE TRANSPORT SECTOR

KEY FINDINGS

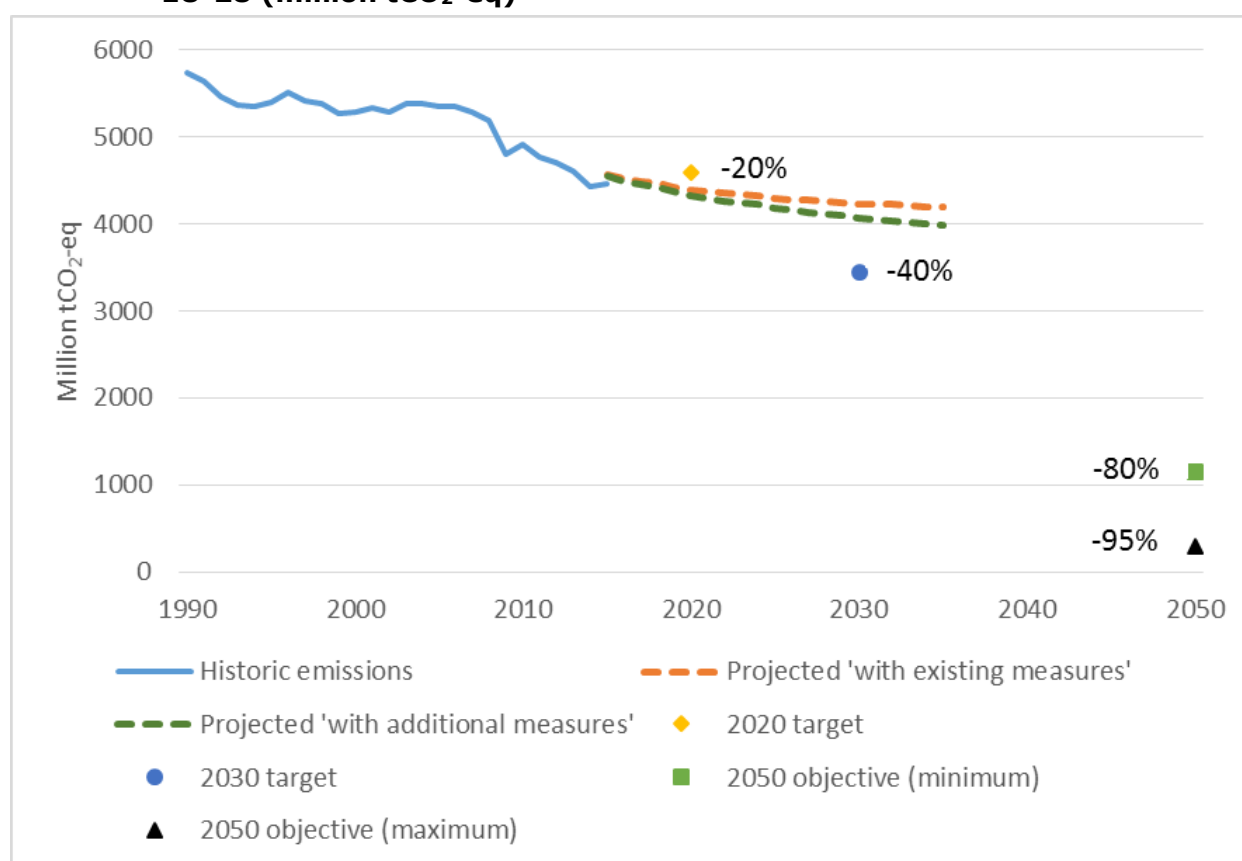
- Limiting global warming to 1.5°C pursuant to the Paris Agreement **requires net zero emissions** globally at some point between 2040 and 2060. The Intended Nationally Determined Contributions delivered by countries before Paris **are not sufficient** to limit warming to 1.5°C, nor to 2°C.
- The EU is focusing on reducing its GHG emissions by around 80% by 2050, which is at the **lower end of the 80 to 95% range needed** from developed countries to limit warming to 2°C.
- The EU's economy-wide GHG emissions have been decreasing and its **GHG reduction target for 2020 looks likely to be met**. **Further policy action** is needed to meet the 2030 target, while a **step change in GHG emissions reductions** will be needed to meet long-term targets.
- As part of its overall GHG emissions reduction effort, the EU is focusing on reducing GHG emissions from transport by **60% by 2050 compared to 1990 levels**, which will require significant improvements in vehicle and fuel technology. An interim target aims to **reduce transport GHG emissions by 20% below their 2008 levels by 2030**, which would still leave them 8% higher than in 1990.
- While the EU's GHG emissions have been declining **since 1990, GHG emissions from transport have increased**. In the immediate aftermath of the economic crisis emissions declined, but both have now begun to increase again. Without further policy action, the EU's current reference scenario projects that transport GHG emissions will be **15% above 1990 levels by 2050**, which means that emissions in 2050 would be almost three times higher than the EU target for transport.
- For the first time since the financial crisis, **transport GHG emissions increased in 2014** compared to the previous year. **More policies are needed** to put transport back on course to delivering its medium and long-term targets.

Action to reduce GHG emissions has been underway for a number of years now. Section 2.1 summarizes the progress achieved to date within the EU in terms of GHG emissions reductions, both for the economy as a whole and for the transport sector in particular. The implications of the EU's longer-term goals for GHG emissions reduction related to limiting global warming to 2°C are discussed in Section 2.2 along with the high-level EU policy response. Section 2.3 assesses whether the EU's progress is sufficient to meet its short-term and long-term ambitions, including the Paris Agreement.

2.1. GHG emission trends in the EU and within EU transport

Since 1990 the EU has made progress in reducing its GHG emissions and economy-wide GHG emission reduction targets have been set for 2020 and 2030. Recent emission projections show that the target for 2020 is likely to be met. Additional measures are needed to meet the 2030 target, though, which requires GHG emissions cuts of 40% compared to 1990 levels (see Figure 1).

Figure 1 also makes it clear that a step change in the rate of GHG emissions cuts is required to meet long-term 2050 targets to limit global warming to 2°C.

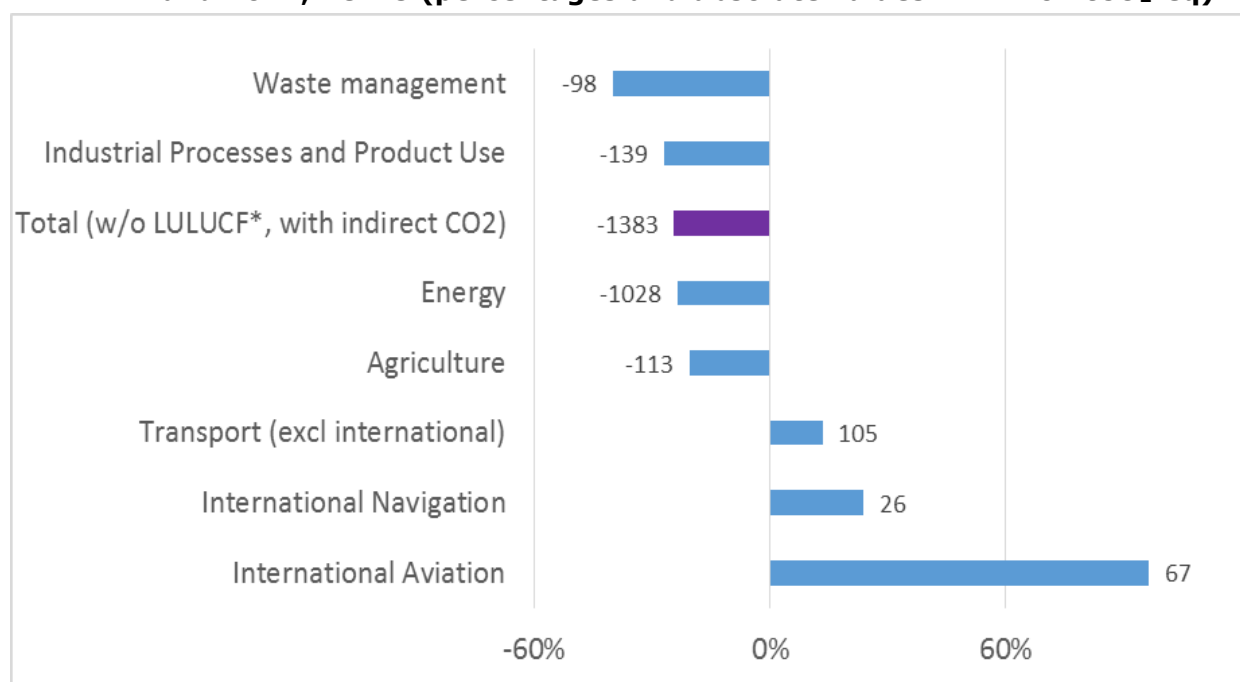
Figure 1: Historic and projected economy-wide GHG emission trends and targets, EU-28 (million tCO₂-eq)

Source: (EEA, 2016e), redrawn Figure 2.1 based on EEA data.

All the values in Figure 1 include emissions from international aviation, but exclude those from international maritime transport and those resulting from land use change. The figure is based on data reported by Member States. The projection of GHG emissions 'with existing measures' includes measures in place at the time of the projections. The projection 'with additional measures' is based on data from 18 Member States and includes measures that were planned, considered or prepared when the projections were drawn up, but not yet formally decided. The projections do not reflect the GHG reductions that would be delivered from measures that are being proposed at the EU level for the post-2020 period, e.g. the post-2021 targets for passenger car CO₂ emissions.

Performance in reducing GHG emissions varies significantly by sector, with most sectors having reduced their GHG emissions by at least 20% since 1990. Transport is the exception. In 2014 GHG emissions from transport were 13% higher than in 1990. GHG emissions from international navigation have increased even more and those from international aviation nearly doubled over this period (see Figure 2).

Figure 2: Changes in emissions of all GHGs by the main sectors between 1990 and 2014, EU-28 (percentages and absolute values in million tCO₂-eq)

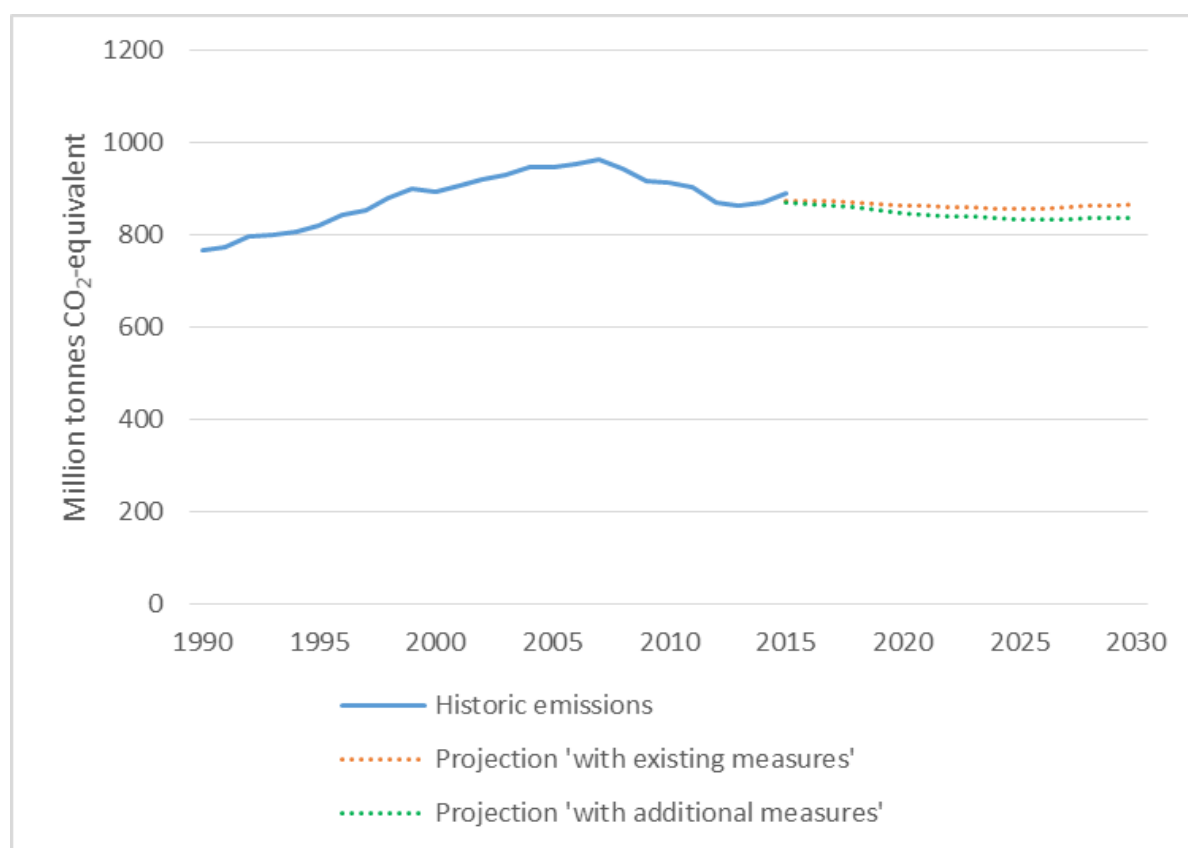


Source: (EEA, 2017a)

Notes: *LULUCF stands for 'Land use, land use change and forestry'; the figures next to the bars are the absolute changes in GHG emissions for each sector between 1990 and 2014, in million tCO₂-eq; the figures for international aviation and international navigation are based on the change in the sales of bunker fuel in EU countries. For aviation, this is closely related to emissions from flights leaving EU airports. For shipping, the relationship between emissions and shipping leaving EU ports is weaker because ships can bunker fuels for several weeks and the choice of port where the ship refuels may be determined by the local fuel price rather than by where cargo is loaded or delivered. International navigation and aviation are presented separately from the total figures for transport, as these are international modes and so are governed by international bodies that have been given the responsibility for taking action to reduce their emissions.

From GHG projections by the European Environment Agency (EEA) we see that measures currently planned for transport would reduce transport emissions by 5.7% by 2030 compared to the situation with existing measures (see Figure 3).

Figure 3: GHG emissions from transport (excluding aviation and shipping) under the scope of the Effort Sharing Decision¹, 1990 to 2030 (million tCO₂-eq)

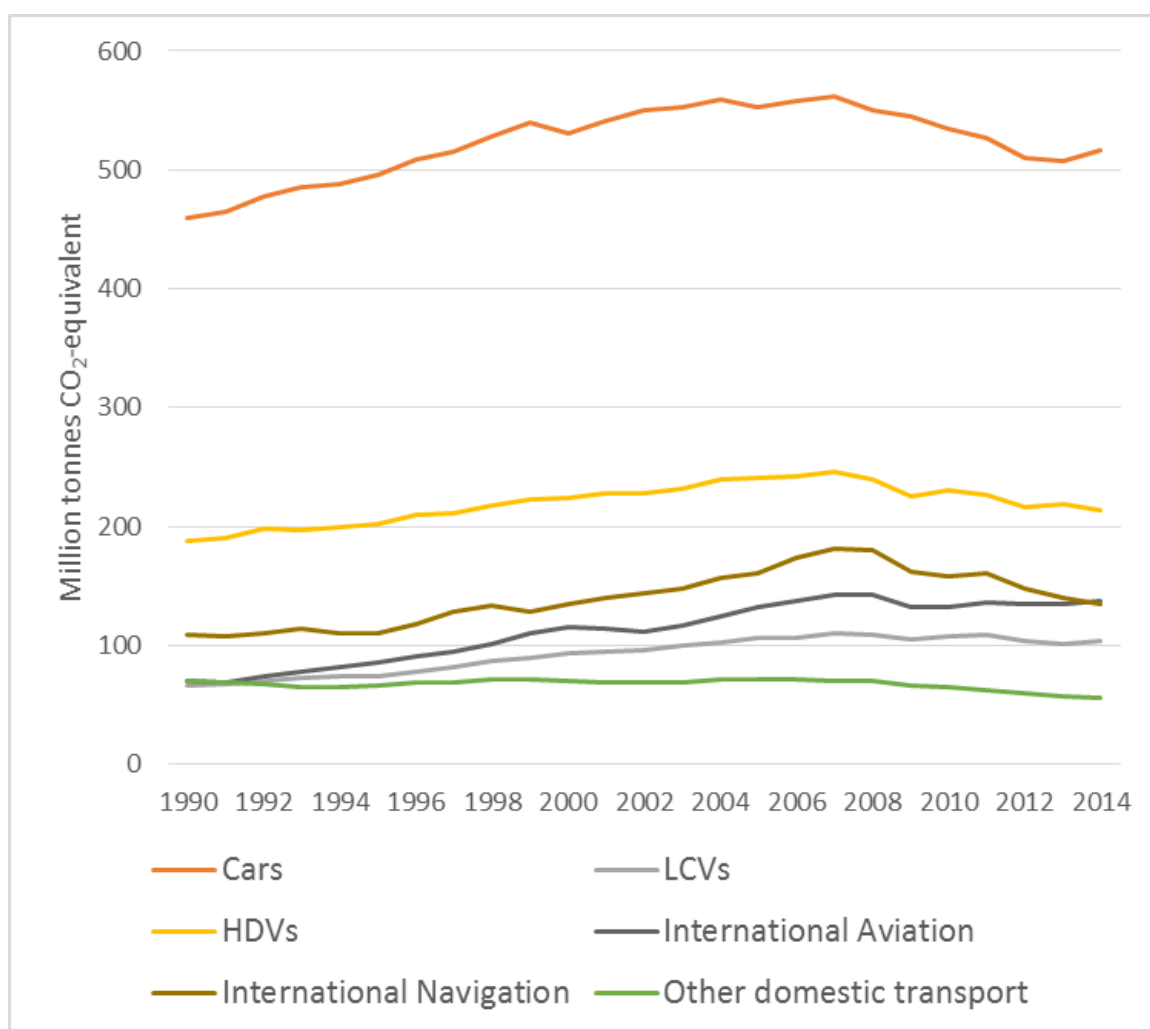


Source: (EEA, 2016e) redrawn Figure 2.4 based on EEA data (removing information relating to other sectors). Analysis based on national data reported by Member States. The projection 'with additional measures' is based on data from 18 Member States and includes measures that were being planned when the projections were prepared. These projections do not reflect the GHG reductions that would be delivered by measures that are being proposed at EU level for the post-2020 period, e.g. the post-2021 targets for passenger car CO₂ emissions.

Passenger cars have contributed most to transport GHG emissions since 1990 (see Figure 4). The second largest source, heavy-duty vehicles (HDVs), which includes heavy goods vehicles (HGVs) and buses, emitted less than half the GHG emissions of cars. International aviation and navigation also contribute significantly. GHG emissions from international aviation overtook those from international navigation for the first time in 2014. GHG emissions from these four modes peaked around the time of the financial crisis in 2007. In 2014, emissions from both cars and light commercial vehicles (LCVs or vans) increased for the first time since their peak, while those from HDVs continued to decline. Together, cars, HDVs, LCVs and international transport make up 95% of the GHG emissions from the EU's transport sector.

GHG emissions from 'other domestic transport' (i.e. railways, domestic shipping and aviation) have been in decline since long before 2007 (see Figure 4). GHG emissions from domestic aviation are also currently declining, after peaking in 2007. Together, GHG emissions from domestic aviation and domestic shipping contribute about 3% to the EU's total transport emissions, with railways contributing a further 1%.

¹ Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020.

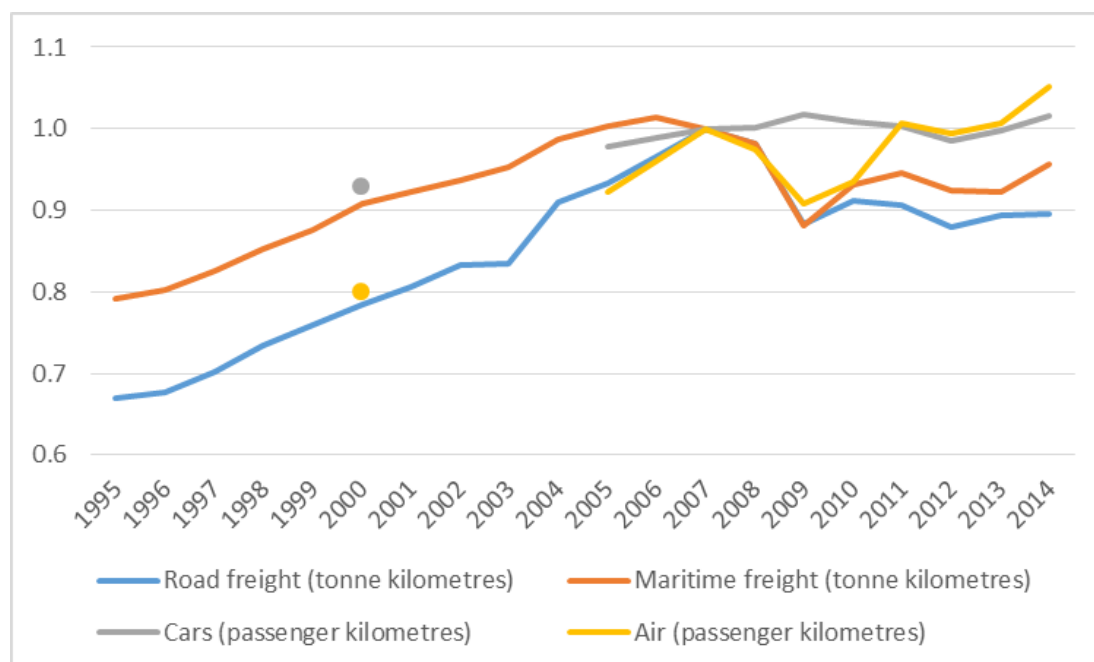
Figure 4: GHG emissions by transport mode, EU-28 (million tCO₂-eq)

Source: (EEA, 2017a); see notes to Figure 2 regarding international aviation and navigation.

A key driver for past and future trends in CO₂ emissions is the change in transport volume. Figure 5 demonstrates that passenger travel by car peaked in the late 2000s. It declined slightly between 2009 and 2012, after which it recovered. Air travel shows a similar pattern but is now already exceeding its 2007 peak. Road and maritime freight transport are still below their pre-crisis peaks and have remained reasonably static in recent years, although maritime freight also appears to be recovering. These changes in volumes affect GHG emissions trends.

In summary, while the EU's GHG emissions have been declining since 1990, GHG emissions from transport have increased. In the immediate aftermath of the economic crisis, transport GHG emissions and demand for transport in the EU declined, but both have now begun to increase again. This underlines that transport demand plays an important role in determining the level of transport GHG emissions. To what degree these emissions decrease in the future will depend on the extent to which improvements in vehicle efficiency and decarbonisation of transport fuels can significantly outpace any increase in the demand for transport resulting from the EU's economic recovery.

Figure 5: Transport volumes for main passenger and freight modes (indexed to 2007)



Source: (EEA, 2016d), Figures 2.7 and 2.8 combined and redrawn based on the data on the EEA's website.

Note: Since it overtook bus and coach travel in 2006, air travel has been the second most popular transport mode in terms of passenger-km every year apart from 2009.

2.2. Required GHG emission reductions to 2050

As noted in Section 1, prior to the Paris Agreement the Intergovernmental Panel on Climate Change (IPCC) had stated that, in order to limit global warming to 2°C, GHG emissions reductions of between 80 and 95% by 2050 were needed from developed countries (IPCC, 2007). The Paris Agreement went further and agreed that the aim should be to "pursu[e] efforts to limit" the increase in temperature to 1.5°C in order to reduce the risks associated with climate change. This makes even more ambitious what was already a challenging target. The International Energy Agency (IEA) has concluded that limiting warming to 2°C will be "very tough", while limiting it to 1.5°C would require net zero emissions at some point between 2040 and 2060, which requires the deployment of "every known technological, societal and regulatory decarbonisation option" (IEA, 2016).

In the run-up to the Paris Agreement, countries submitted their Intended Nationally Determined Contributions (INDCs), which identify actions that they intend to take to contribute to delivery of the Agreement. (UNEP, 2016) has estimated that the INDCs submitted are, at best, only consistent with staying below a temperature rise of 3°C.

As discussed in Section 1, limiting the temperature rise to any level implies a maximum level of cumulative GHG emissions, which effectively gives a CO₂ emissions budget until 2050. The existing INDCs, aimed at limiting global warming to 2°C by 2050, will result in depletion of the budget by 2030. The budget corresponding to 1.5°C **will already have been exceeded by 2030**. Consequently, 'negative emissions technologies', e.g. carbon capture and storage, carbon sequestration in plants and soils, will be needed to limit warming to less than 1.5°C (UNEP, 2016).

The International Transport Forum has demonstrated the scale of the challenge facing transport globally (ITF, 2017). In its baseline scenario for 2050, CO₂ emissions from transport increase by 60% globally compared to 2015, even though emissions from the OECD (Organisation for Economic Co-operation and Development) countries remain relatively stable. This increase is despite a 40% improvement in the efficiency of passenger and freight transport. In a 'low-carbon' scenario, the ITF demonstrates that transport CO₂ emissions **could be maintained at 2015 levels globally**. However, this would require greater efficiency improvements for all vehicles of around 50% more than assumed in the baseline, higher fuel taxes equivalent to oil prices of \$ 120 a barrel, full optimisation of vehicles for road freight, as well as land use and transport planning in urban areas.

The need for radical changes to meet the long-term targets has been recognised by the European Council, at least in the context of limiting warming to 2°C. In 2011, prior to the publication of the Commission's low-carbon strategy for 2050² (EC, 2016b), the European Council underlined that securing the IPCC's objective for developed countries of reducing GHG emissions by between 80 and 95% by 2050 would require a revolution in energy systems, which needed to begin immediately (EUCO, 2011). In response, the Commission's Low Carbon Economy Roadmap³ (EC, 2011a) focused on identifying cost-effective scenarios for reducing the EU's domestic GHG emissions (i.e. real reductions within the EU, not involving offsetting or trading) to around 80% by 2050, which is at the lower end of the range called for by the IPCC. Overall, the Commission concluded that, compared to 1990 levels, emissions reductions of around 40% by 2030 and 60% by 2040 would be on the cost-effective pathway for the EU to deliver an 80% reduction in GHG emissions economy-wide by 2050 (EC, 2011a).

The Commission proposals that have followed have assumed a similar target for 2050. In support of the climate change and energy package, an impact analysis established a target of 40% for the year 2030 (EC, 2014b). In the run-up to the Paris Agreement, the EU's INDC committed the Union and its Member States to a binding target of at least a 40% reduction in domestic GHG emissions by 2030 compared to 1990 to be met jointly. This was explicitly in the context of limiting warming to below the 2°C objective (EU, 2015b).

The Low Carbon Economy Roadmap also identified cost-effective GHG emissions for each sector. For transport, it concluded that overall GHG emission reductions of between 54 and 67% (between 1990 and 2050) could be delivered, arising largely from improved vehicle efficiency, increased electrification and increased use of biofuels for heavy-duty vehicles and in aviation (EC, 2011c). The contribution of transport was notably less than those from most other sectors (see Table 2).

² COM(2016) 501 final.

³ COM(2011) 112 final.

Table 2: GHG reductions by sector compared to 1990, actual (2005) and required to deliver 80% reduction economy-wide

Sector	2005	2030	2050
Power (CO₂ only)	-7%	-54 to -68%	-93 to -99%
Industry (CO₂ only)	-7%	-34 to -40%	-83 to -87%
Transport (inc aviation CO₂, excluding maritime)	+30%	+20 to -9%	-54 to -67%
Residential and services (CO₂ only)	-12%	-37 to -53%	-88 to -91%
Agriculture (non CO₂)	-20%	-36 to -37%	-42 to -49%
Other non-CO₂	-30%	-72 to -73%	-70 to -78%
TOTAL	-7%	-40 to -44%	-79 to -82%

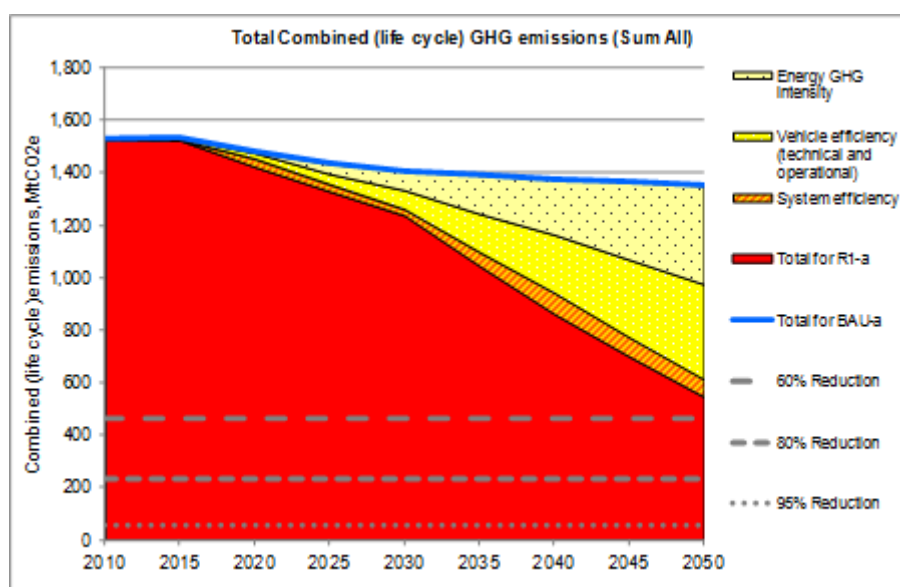
Source: (EC, 2011c).

The 2011 Transport White Paper provides the strategic framework for delivering the necessary GHG reductions from the EU transport sector, as well as for delivering other transport objectives (EC, 2011b). From the perspective of GHG emissions, the White Paper takes as its starting point the need to reduce the sector's emissions by at least 60% by 2050 compared to 1990. This long-term ambition was restated in the 2016 Commission's Low Emission Mobility Strategy (EC, 2016b).

The White Paper also includes a target for 2030, by which time transport GHG emissions should be 20% below their 2008 levels, which would still leave them 8% higher than in 1990 (see Figure 7). The White Paper includes one other target related directly to GHG emissions: EU CO₂ emissions from maritime bunker fuels should be reduced by 40% – or 50% if feasible – by 2050 compared to 2005 levels. The Commission's Low Emissions Mobility Strategy sets out the actions to be implemented in the 2030 timeframe. These should contribute to reducing transport GHG emissions in the context of the EU's 2030 economy-wide GHG reduction target of 40% by 2030 compared to 1990 (EC, 2016b). More information on these actions is provided in Section 3.

To secure the target of 60% by 2050, the White Paper opts for a balanced approach involving improving the internal market and infrastructure, taking action on pricing and taxation and development and deployment of technological solutions. More on the policy options can be found in Section 4. Consistent with findings on the global scale, a study undertaken for the European Commission underlined the need for action to improve vehicle efficiency, to decarbonise transport fuels and to improve overall transport efficiency (see Figure 6) (AEA, TNO, CE Delft, TEPR, 2012). If transport GHG emissions need to be reduced further, e.g. to deliver the aims of the Paris Agreement, it is likely that more attention will need to be paid to the sector efficiency.

Figure 6: Illustrative sensitivities in the context of meeting the 60% reduction target for transport in 2050

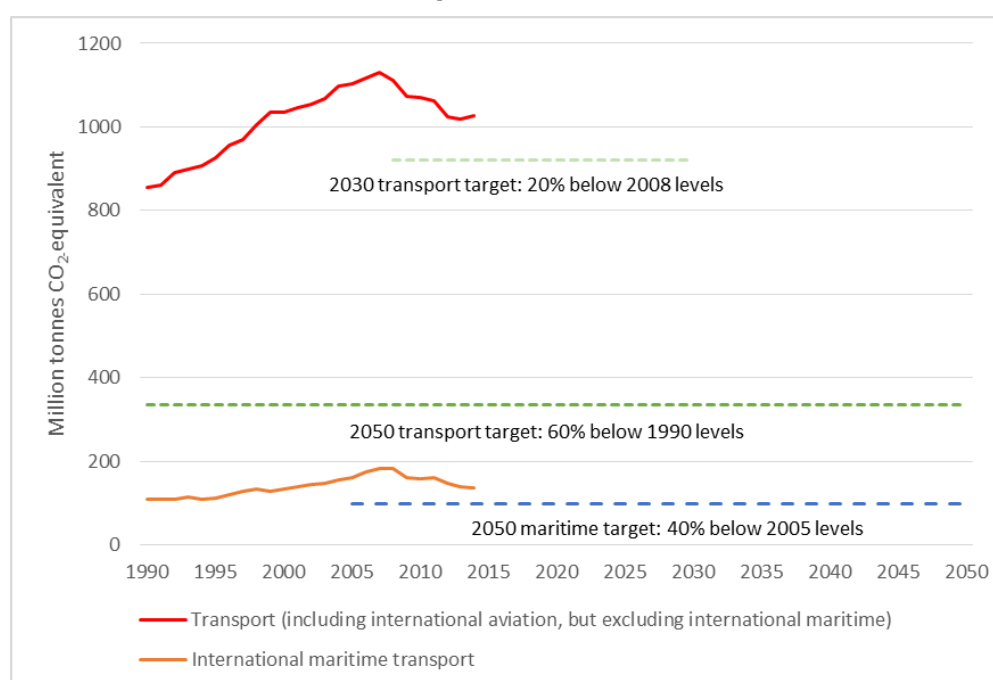


Source: (AEA, TNO, CE Delft, TEPR, 2012).

2.3. Are we on course for 2050?

Until the upturn in 2014, transport GHG emissions had been declining towards the respective targets set in the Transport White Paper (see Figure 7). Transport GHG emissions (excluding those from international maritime transport) now need to decline by 10% to reach the 2030 target and by 67% to reach the 2050 target (see Figure 7). For international maritime shipping, the situation is not as clear (see also the note to Figure 2). This is in part because there is no clear definition as to which GHG emissions are included in the target.

Figure 7: GHG emissions from transport for the EU-28



Source: (EEA, 2016d) redrawn, based on data from EEA's website; note that the overall targets for transport include international aviation, but do not include international maritime transport.

The Commission's 'reference scenario' for transport assumes that demand will continue to increase by 1% a year up to 2030, before slowing to 0.7% annually until 2050 (EC, 2016c). At the same time, the price of oil imports will increase significantly to over \$ 120 a barrel. Under the reference scenario, transport CO₂ emissions decline until around 2035, driven by the CO₂ targets for cars and LCVs. After that, they start to increase, mainly as a result of growth in road freight and aviation. By 2050, transport emissions under this scenario are more than 15% above 1990 levels (EEA, 2016d).

While progress has been made in reducing GHG emissions from transport, it is clear that more policy action is necessary to deliver medium and long-term targets, particularly as the EU's economy continues to recover. This will require the development and implementation of the necessary policies to improve vehicle efficiency, decarbonise transport fuels and ensure that taxation and pricing policy support the long-term decarbonisation objectives. Moreover, the aspiration of the Paris Agreement means that the range of 80 to 95% in GHG emissions reduction to be delivered by developed countries will need to be made more stringent in order to limit warming to 1.5°C. For the EU's transport sector, the Paris Agreement suggests that the 60% target will also not be sufficient. This potentially has implications for the EU policy framework, which is focused on the delivery of an 80% economy-wide reduction. An assessment of the broader implications of limiting warming to 1.5°C is beyond the scope of this report.

3. EU POLICY AND INDUSTRY STRATEGIES TO DECARBONISE TRANSPORT

KEY FINDINGS

- The **EC continually recognizes that decarbonisation of the transport sector requires major policy action on all levels** for each of the three pathways: vehicle efficiency, low-carbon fuels and transport system efficiency.
- **There has been no major shift in the basic elements of the policy strategies:** vehicle efficiency, low-carbon fuels and transport system efficiency remain the key challenges. These were already mentioned in the 2011 White Paper. This might imply that the European Commission is consistent at this policy level; it could also mean that many actions require long-term systemic changes.
- EU policy documents have continually stressed that **aviation and maritime shipping merit special attention**.
- A clear change in policy strategies is the emphasis on the role of ITS/ICT to improve the overall efficiency of the transport system rather than actively pursuing modal shift. Also apparent is the increasing urgency of a faster rate of decarbonisation and a stronger push for zero-emission vehicles in addition to the low-emission vehicles already being promoted.
- EU **policy strategies** that focus on the transport sector are not strictly about **decarbonisation**. They also include objectives related to accessibility, social cost, air quality, noise or competitiveness of the European economy. Although these other policy objectives should not be discarded, it is important to realise the potential risk of trade-offs when applying multi-objective strategies.
- Regarding the implementation of targets set at the national level, the 2015 Energy Union package has introduced a **shift from national targets to the EU-wide target**. This **generates uncertainty** about the realisation of the latter target and may therefore be an issue for discussion.
- Private actors have also formulated strategies based on the long-term decarbonisation targets. It is difficult to say whether these initiatives will contribute substantially to decarbonisation.

This Section provides an overview of the EU policy framework and industry strategies to decarbonise transport. The EU policy documents are described in Section 3.1, the industry strategies in Section 3.2.

3.1. EU policy strategies to meet targets

In the previous Section the main EU policy strategies were briefly cited. In this Section, we provide a more comprehensive overview. We also look more closely at the GHG targets that have been set and the role of the various transport modes in securing them. In doing so, we distinguish between high-level policy strategies focused on economy-wide decarbonisation and strategies aimed specifically at the transport sector. The main economy-wide documents of relevance that have been published since 2011 are:

- the Low Carbon Economy Roadmap (2011);
- the Climate and Energy Framework (2014);
- the Energy Union Package (2015);
- the EU Winter Package (2016).

The main transport-specific documents published since 2011 are:

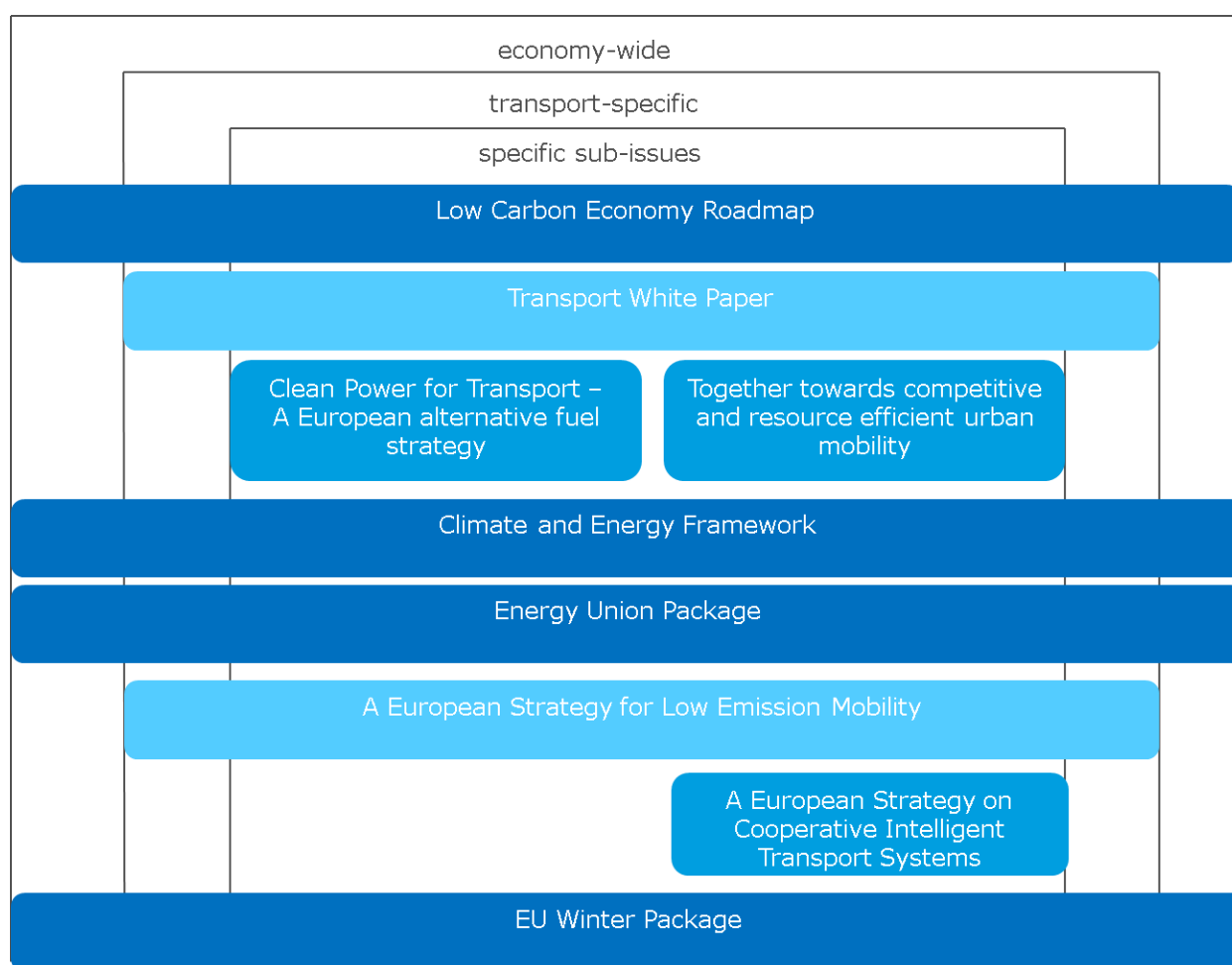
- The Transport White Paper (2011);
- A European Strategy for Low-Emission Mobility (2016).

In addition to the economy-wide and the transport-specific strategies, several documents have been published that deal with a specific aspect of the decarbonisation strategy for transport, such as the development of alternative fuel infrastructure or ITS (Intelligent Transport Systems). The main documents in this category are:

- Clean Power for Transport - A European alternative fuel strategy (2013);
- Together towards competitive and resource efficient urban mobility (2013);
- A European Strategy on Cooperative Intelligent Transport Systems (2016).

The three categories and the associated strategies are shown schematically in Figure 8.

Figure 8: Overview of EU transport-related strategies and their scope



Economy-wide strategies

- The 2011 **Low Carbon Economy Roadmap**⁴ includes the decarbonisation strategy for all sectors. This Roadmap aims at a GHG reduction of around 80% compared to 1990 levels by 2050. This would require a 20% reduction by 2020, a 40% reduction by 2030 and a 60%

⁴ COM(2011) 112 final. A Roadmap for moving to a competitive low carbon economy in 2050.

reduction by 2040. The Roadmap warns that a less ambitious pathway could result in 'locking in' carbon-intensive investments, resulting in increasing abatement costs.

For transport, this means GHG emission cuts of between 54% and 67% by 2050. This includes a higher contribution from passenger cars (69-75%) compared with freight vehicles (54-65%). The Roadmap also acknowledges the need for action in the three areas: vehicle efficiency, fuel decarbonisation and transport system efficiency.

The Roadmap stresses the benefits of electrification for other policy areas, such as air quality, public health and reduced oil dependency. Sustainable biofuels should be reserved for aviation and heavy-duty trucks. It argues that biofuels will need to play a greater role if large-scale electrification of transport proves difficult. In that case, there is a pressing need for more advanced biofuels owing to their reduced environmental impact. In addition, the Roadmap calls for the completion of work on indirect land use change (ILUC) and sustainability criteria for biofuels.

The need to unlock the investment potential of the private sector is presented as a major challenge on the grounds that markets tend to discount future benefits and disregard long-term costs. To resolve this issue requires a policy framework providing appropriate conditions and financing models for investment. The importance of the EU Emissions Trading System (ETS) is also stressed.

- In October 2014, the European Council adopted the **2030 Climate and Energy Framework**⁵ which builds on the 2020 Climate and Energy Package⁶, the 2011 Low Carbon Economy Roadmap, the 2011 Energy Roadmap for 2050 (COM (2011) 885) and the 2011 Transport White Paper (EC, 2011d).

The 2030 Climate and Energy Framework was adopted in the run-up to the Paris climate conference. It sets targets for 2030 (see Table 3). In addition, it is intended to provide guidance to the industry on what to expect over the 2020-2030 period.

The GHG emissions reduction target of 40% in 2030 relative to 1990 applies to land-based emissions plus the emissions of fuels sold to international aviation; international maritime transport is excluded from the target (SWD, 2014).

According to the Framework, the Commission does not consider it appropriate to establish new targets for the share of renewable energy or the GHG intensity of fuels in transport post-2020. No binding national targets are therefore defined.

Instead of a binding target, a range of alternative renewable fuels (excluding food-based biofuels) and a mix of targeted policy measures, based on the Transport White Paper, are required to decarbonise further the transport sector towards 2030 and beyond. The focus is on improving the efficiency of the transport system and the development of (and further innovations in) electric vehicles and advanced biofuels. This calls for a more holistic and integrated approach compared with the 2020 Climate and Energy Package, in line with both the Transport White Paper and the Clean Power for Transport strategy. On the one hand, the lack of binding targets might increase uncertainty about the timely delivery of the 2030 goals but, on the other hand, it provides greater flexibility for Member States. Note that later on, binding national targets for the share of renewable energy have been tabled through the proposal for the Renewable Energy Directive II (RED II). This is detailed in Section 4.2.

⁵ EUCO 169/14 of 24 October 2014.

⁶ The 2020 Climate and Energy Package contains Directive 2009/29/EC, Directive 2009/28/EC, Directive 2009/31/EC and Decision No. 406/2009/EC of the Parliament and the Council. It sets a 20% GHG reduction target, a 20% energy efficiency target and a 20% target for the share of renewable energy.

The Framework furthermore states that the efficiency improvements in passenger cars are on the right track and need to continue. It also states that a significant acceleration of policy efforts is needed for the other transport modes in order to meet the 2030 objectives.

Table 3: Difference between the 2020 Package and the 2030 Framework

Target area	2020 Package	2030 Framework
GHG emission reduction	20% compared to 1990 Binding via ETS and Effort - Sharing Decision (ESD)	40% compared to 1990 Binding via ETS and ESD methodology
Increase of renewable energy use	20% of total energy consumption Binding via Renewable Energy Directive	27% of total energy consumption Only binding at EU level
Increase of energy efficiency	20% compared to baseline scenario Binding via Energy Efficiency Directive	27% compared to baseline scenario Only binding at EU level

The 40% economy-wide GHG emission reduction target between 1990 and 2030 requires a 30% reduction of GHG emissions by non-ETS sectors⁷ between 2005 and 2030. This is less than the 43% reduction required of companies covered by the EU ETS. The non-ETS target would be allocated amongst Member States based on relative wealth (GDP per capita). The drop in GHG emissions due to the economic crisis is expected to be temporary, which is why greater efforts will be needed to achieve the Transport White Paper objectives. According to the 2030 Framework, this will require:

- a gradual transformation of the entire transport system towards improved integration of modes;
- greater exploitation of non-road alternatives;
- improved management of traffic flows through intelligent transport systems;
- extensive innovation in/deployment of new propulsion and navigation technologies and alternative fuels.

Improvements in infrastructure design and smarter pricing should be in place in order to support these aims. In addition to infrastructure charging, this should also involve vehicle and fuel taxation - which can be challenging at the EU level, as evidenced by the withdrawal of the most recent EC proposal on the taxation of energy products (EC, 2014; see Section 4.3).

Regarding aviation, the 2030 Framework refers to the EU's participation in the ongoing work of the International Civil Aviation Organisation and the aim to create a global market-based mechanism operating from 2020 onwards. For maritime emissions, the Commission will continue the work on integrating this sector in EU GHG policies, while at the same time working together with the International Maritime Organisation.

⁷ The non-ETS sectors are those not included in the EU Emission Trading Scheme, such as transport, building, agriculture and waste.

- The 2015 **Energy Union Package**⁸ stressed again the need for a single EU-wide Energy Union rather than 28 national regulatory frameworks. An integrated energy market is thought to result in increased competition, greater market efficiency and affordable prices for consumers. This may contribute to the production of affordable and climate-friendly energy. With a simultaneous focus on energy saving and the combatting of climate change, economic benefits such as increased employment are considered possible.

Regarding the energy efficiency of vehicles and the transport system, the following points were highlighted:

- tightening of CO₂ emissions standards for passenger cars and LCVs post-2020;
- increasing fuel efficiency and reducing CO₂ emissions of HGVs and buses;
- transport management to increase overall system efficiency;
- internalisation of external costs;
- modal shift towards less GHG-intensive transport modes.

With respect to the decarbonisation of fuels, the following points are worth noting:

- The Commission once again stresses the need for a steady and simultaneous uptake of more efficient infrastructure and vehicles and alternative fuels: all three should be rolled out at a similar pace.
- Electrification of the transport system should focus on short and medium-distance road and rail transport. Greater integration of electric vehicles (EVs) in urban mobility policies is needed if the EU is to become a leader in electro-mobility. This also includes the integration of EVs into the electricity grid.
- There is a need to invest in advanced, sustainable alternative fuels, also within the broader context of the bio-economy, while at the same time taking into account potential impacts on the environment.

- In November 2016 the European Commission adopted the **“Clean Energy For All Europeans”** package⁹, more commonly referred to as the **“EU Winter Package”**. This package of measures is to serve as the new basis for the Energy Union. It contains proposals for a “consumer-centred clean energy transition”. It significantly revises the 2009 package of electricity liberalisation and includes proposals for revised rules on renewable energy, energy efficiency and eco-design principles. As mentioned in the Low-Emission Mobility Strategy, an important issue is the revised design of the electricity market, which should lead to a single market and a level playing field at the EU level.

Regarding specific directives, the Winter Package includes proposals for revision of the Renewable Energy Directive (Directive 2009/28/EC - RED), the Energy Efficiency Directive (Directive 2012/27/EU), the Energy Performance in Buildings Directive and the Electricity Market Regulation (amongst others). New aspects of these directives relate to the inclusion of synthetic waste-based fuels in the RED and the requirement to equip a certain share of parking spaces in buildings with electric charging points (Energy Performance in Buildings Directive).

⁸ COM(2015) 80 final. A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy

⁹ COM(2016) 860 final.

Specifically, the new RED II proposes:

- A (binding) minimum 1.5% share of renewable energy in transport in 2021, rising to 6.8% in 2030, in each Member State.
- Abolition of the double-counting provision¹⁰ after 2020.
- A 3.8% cap on land-based biofuels in 2030. Note that the current market share of land-based biofuels is approximately 4.9% (in 2014).
- A sub-target for advanced biofuels of 3.6% in 2030 (currently 0.5% for 2021).
- An additional reward for biofuels used in aviation and maritime shipping (their energy content is counted as being 20% more than biofuels in other transport modes).
- All biomass energy should meet the sustainability criteria, not only biofuels and bioliquids, i.e. also biomass used in the heating and electricity sector.
- Renewable fuels from renewable electricity (also referred to as RES-E) can also count towards the target, provided they meet certain conditions.

An annex to the Winter Package also announces the setting up of the Cleaner Transport Facility in combination with the European Investment Bank, which will use financial instruments to deploy low-carbon technologies in order to accelerate the shift to low-emission mobility.

Specific details of the proposed revisions of the directives are discussed further in Section 4.

Transport-specific strategies

- The 2011 **Transport White Paper** focuses solely on the transport sector and the realisation of the EU's transport policy objectives, including GHG emissions. The White Paper calls for a 60% reduction in GHG emissions from transport by 2050 compared to 1990. It also includes an intermediate target for 2030 (20% below 2008 levels) which would result in an emission level 8% higher than in 1990. The White Paper also set a specific target for maritime shipping: GHG emissions from maritime bunker fuels are to be reduced by 40 to 50% by 2050 compared to 2005.

The White Paper focuses strongly on the efficiency of the transport system and the use of more energy-efficient vehicles since it is based on the assumption that 'curbing mobility is not an option': reducing transport emissions should come from new technologies for vehicles and traffic management. Establishing clarity in order to guarantee investment security and coherence at the EU level are marked as important priorities as well.

- The 2016 **European Strategy for Low Emission Mobility**¹¹ is the first transport-related strategy published after the Paris Agreement. It focuses entirely on transport and reiterates the White Paper 60% target for 2050. For 2030, however, it refers only to the economy-wide target of a 40% reduction in GHG emissions, not the related White Paper target. Yet, the strategy stresses the need to accelerate the pace of GHG emission reduction in the transport sector, while at the same time guaranteeing the mobility needs of people as well as global connectivity. This is to be achieved through improved efficiency of the transport system, low-emission alternative energy for transport and low and zero-emission vehicles.

As in earlier communications, the need for appropriate incentives and investments is underlined, in order to simulate innovation. In addition, the role of lower-level governmental

¹⁰ Biofuels from waste and residues count double towards Directive 2009/28/EC targets.

¹¹ COM(2016) 501 final. A European Strategy for Low-Emission Mobility.

authorities (regions and cities) to help deliver low-emission mobility solutions is mentioned on the grounds that behavioural choices are easier to influence at the local level.

More specifically, the Communication defines the following priority areas:

- Efficiency of the transport system. Key issues identified are (open) data, price incentives and multimodal transport aided by Intelligent Transport Systems (ITS).
- Alternative fuels. The strategy refers to an obligation on fuel suppliers as the most effective framework for renewable fuels, such as advanced fuels and synthetic fuels. It also refers to the roll-out of infrastructure for alternative fuels, as regulated by the Alternative Fuel Infrastructure Directive (Directive 2014/94/EU), and the relevance of standardisation and interoperability, especially in relation to electro-mobility.
- Zero-emission vehicles. The strategy states that zero and low-emission vehicles will need to have gained a significant market share by 2030, which will require incentives on both the supply and demand side. An important point made is that there are still tax incentives in place, such as fossil fuel subsidies, that discourage low-emission mobility.

Finally, the Strategy also mentions international actions to decarbonise aviation and maritime shipping and the need to take further action within the appropriate international organisations.

Strategies on specific sub-issues

- The 2013 **Clean Power for Transport - A European alternative fuels strategy**¹² acknowledges the need to support the development of a market for alternative fuels and to invest in the infrastructure required for these fuels in order to make the EU, and especially the transport sector, less oil-dependent. Although efficiency improvements are identified as the most cost-effective measure in the short and medium-term, alternative fuels are considered to be required to the long-term targets.

The alternative fuels strategy identifies market fragmentation as a key barrier for large-scale uptake of alternative fuels. It therefore aims to provide a strategic approach to meet the long-term needs of all transport modes. According to the strategy, there is no single fuel solution and all main alternative fuel options must be pursued, depending on the needs of each individual transport mode. The approach should thus be technology-neutral and contribute to achieving security of energy supply and diversification at the same time.

The following combinations of fuels and transport modes should become available EU-wide and should be provided with common technical specifications:

- **Road transport:** Road-passenger and road-freight transport travelling all distances should be able to run on Liquefied Petroleum Gas (LPG), Liquefied Natural Gas (LNG) and liquid biofuels. Compressed Natural Gas (CNG) and hydrogen are not seen as alternatives for long range road-freight transport. Electricity is identified as an option for shorter ranges only.
- **Aviation:** For aviation the Communication only sees liquid biofuels as an alternative for fossil fuels.
- **Rail:** Alternative fuels for rail transport are LNG, electricity, liquid biofuels and hydrogen.

¹² COM(2013) 17 final. Clean Power for Transport: A European alternative fuels strategy.

- **Shipping:** Both inland and short-sea shipping should be able to shift to LPG, LNG and liquid biofuels. LNG and liquid biofuels are identified as potential alternatives for maritime shipping. Hydrogen is only an option for inland shipping.

A more detailed description of which transport modes can run on which types of alternative fuel, including a discussion on how this should be taken into account in policy, can be found in Section 4.2.

According to the strategy, no public spending is required for the development of infrastructure because Member States already have various measures to mobilise private investment cost-efficiently. The TEN-T funds, Cohesion and Structural Funds together with European Investment Bank lending can provide EU support.

• The 2013 Communication **Together towards competitive and resource efficient urban mobility**¹³ underlines the roles of Member States and European cities in developing in a more sustainable manner. The key points of this Communication are:

- Sustainable urban mobility plans (SUMP); these entail an integrated approach to make urban areas more sustainable and should be developed in cooperation across different policy areas and sectors (not only transport). One of the main priorities of the Commission is to set up a European Platform on Sustainable Urban Mobility Plans to coordinate EU cooperation and develop the concept further.
- Coordinating public and private-sector intervention, focusing on:
 - more action on urban logistics;
 - smarter urban access regulations and road user charging;
 - coordinated Deployment of Urban Intelligent Transport Systems;
 - Urban Road Safety.
- Reinforcing EU support, focusing on:
 - sharing experience, showcasing best practices and fostering cooperation;
 - focusing research and innovation on delivering solutions for urban mobility challenges; CIVITAS, an initiative comprising a network of cities and focused on innovation, is identified as an important engine for further development and innovation in urban mobility.

The focus on urban mobility is in line with the White Paper's focus on urban logistics and on the potential of captive fleets. As in the Clean Power for Transport Communication, the role of the TEN-T network is emphasised since urban nodes are seen as key elements in the construction of this network.

• The 2016 **Strategy on Cooperative Intelligent Transport Systems**¹⁴ focuses on the role of ITS in improving the efficiency of the sector and therefore its decarbonisation. The strategy underlines the potential of digital technologies and the need to act in areas such as road safety and congestion. It describes the potential of Cooperative Intelligent Transport Systems (C-ITS) that allow road vehicles and road infrastructure to interact. It stresses that other regions and countries are ahead of the EU in terms of bringing these technologies to the market. Concerning the implementation of C-ITS, the strategy discusses data protection, cybersecurity and interoperability, which are all seen as critical issues.

¹³ COM(2013) 913 final. Together towards competitive and resource-efficient urban mobility.

¹⁴ COM(2016) 766 final. A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility.

3.2. Industry strategies to meet targets

Private actors have formulated their own strategies to decarbonise transport. Some are based on the strategies of the European Commission and the targets they contain. There are also several examples where industry has taken a leading role and where the EU has considered or even included some of these initiatives in the legislation. Cases in point are the voluntary certification schemes for biofuels, some of which can now be used to prove compliance with the sustainability criteria of the Renewable Energy Directive (RED).

Lima-Paris Action Agenda¹⁵

The Paris Agreement sets the long-term decarbonisation objective. The Lima-Paris Action Agenda aims to demonstrate the commitment of various actors to this objective. Involved in the Action Agenda are national governments, local authorities such as cities and regions, international organisations, businesses and academic institutions.

The Lima-Paris Action Agenda aims to enhance the implementation of climate action by providing practical guidelines not only to states, but also to non-state actors. Industries and businesses in general can engage in cooperative action, individual action or public-policy action. Some of the transport-related initiatives are briefly described below.

Low-Carbon Rail Transport Challenge

The UIC, the International Railway Association (with 240 members worldwide), has proposed to improve the energy efficiency of the rail sector, to reduce GHG emissions and to work towards a more sustainable balance between transport modes (modal shift). The so-called Low-Carbon Rail Transport Challenge has set the following ambitious targets for 2030 and 2050, with the year 1990 as the baseline:

- a 50% reduction of final energy consumption and GHG emissions from train operations by 2030 through technical measures, improved management, decarbonisation of energy consumption and better use of existing rail assets;
- a doubling of the share of railway passenger transport by 2050 by means of modal shift.

To secure these targets, UIC is seeking partnerships. For the first objective, this is most likely to include partnerships with the private sector, while the objective on modal shift will benefit more from partnerships with national governments and international organisations.

Global Fuel Economy Initiative

The Global Fuel Economy Initiative is a partnership of six organizations, including the International Energy Agency (IEA), the United Nations Environment Programme (UNEP), the International Transport Forum (ITF) and the International Council on Clean Transportation (ICCT). It aims at doubling vehicle fuel efficiency globally by 2050. This should not only reduce emissions, but also result in cost savings for consumers. The initiative is part of the Sustainable Energy for All Global Energy Efficiency Accelerator Platform. According to the initiative, the savings from improved efficiency can be used for development of a global market for electric vehicles.

The core activities consist of data analysis and research on the fuel economy potential by country and region, in-country capacity-building support for policy-making efforts and awareness-raising.

¹⁵ <http://newsroom.unfccc.int/lpaa/transport/>

Global Green Freight Action Plan

This action plan aims to foster the environment-friendly transport of goods within and between countries. This will be achieved by expanding and harmonizing green freight programmes and improving fuel efficiency. Fifty governments, together with civil society and numerous companies support this action plan. The most successful green freight programmes provide incentives for investments in fuel-saving, emission-reducing technologies and operational strategies.

Collaborative Climate Action Across the Air Transport World

ICAO (with 191 Member States) and the Air Transport Action Group (ATAG) representing the aviation industry aim to improve air transport fuel efficiency and stabilise the sector's net CO₂ emissions from 2020 onwards (i.e. achieve carbon-neutral growth). The aim for 2050 is to reduce net CO₂ emissions by 50% compared to 2005 levels.

ATAG and ICAO have committed to actions supporting the development of sustainable alternative fuels for aviation, continuation of the deployment of new technology in aircraft and operational improvements and development of a global CO₂ standard for new aircraft (see Section 4.1.3).

Industry strategies put into perspective

We conclude that industries are in certain cases pursuing relatively ambitious targets. There are various explanations for this. First, industries might consider taking early action in the field of decarbonisation as yielding an advantage over competitors, because of the first-mover principle. Decarbonisation options might still be expensive at the start of the transition, but the first movers might improve their market position because of the experience gained early on. Secondly, in the early stages less negotiation and compromise with policy-makers and other stakeholders is likely to be required, which means that actions can be implemented much faster.

3.3. Conclusions

EU policy strategies focusing on the transport sector are not strictly about decarbonisation. They also include policy objectives related to accessibility, social cost (resulting from accidents and negative health impacts, for example), air quality, noise impacts and competitiveness of the European economy. This means that these strategies are not optimised to secure the greatest possible GHG emission cuts. Although the other policy objectives should not be discarded, it is important to appreciate the risk of potential trade-offs when applying multi-objective strategies. On the other hand, synergies with these other policy objectives might also help achieve the GHG targets.

It is clear from the policy strategies that the EC recognizes that decarbonisation of transport requires major policy action at all levels of the sector and for the three pathways that are also at the heart of this study: vehicle efficiency, low-carbon fuels and transport system efficiency. These three elements have not changed over the past six years. Many of today's challenges were already mentioned in 2011. This implies, firstly, that the European Commission is consistent at this policy level (although this does not necessarily mean this is the case at the level of directive and regulation implementation). Secondly, it underlines that many policy actions require long-term systemic changes, which could not be resolved in the short period of time since publication of the policy strategies. Whether there is room for improvement will be discussed in Section 4.

A clearly new element in the policy strategies is the emphasis on the role of ITS/ICT to improve the overall efficiency of the transport system, instead of actively pursuing modal shift. Also apparent is the increasing urgency of a faster rate of decarbonisation and a stronger push for zero-emission vehicles, in addition to the low-emission vehicles already being promoted.

4. POLICY ANALYSIS - CURRENT SITUATION AND FUTURE POTENTIAL

This Section reviews current policies for reducing transport GHG emissions and their future GHG reduction potential, as well as other available options to this end. This review is structured under three headings: (1) vehicle efficiency, (2) transport fuel decarbonisation and (3) transport sector efficiency.

As noted above, this subdivision into three 'pathways' does not mean there is no interaction between the policies discussed in the respective sections. On the contrary, the various measures in the three pathways interact in a variety of ways and mutually affect their effectiveness in terms of GHG emission reduction. This Section nevertheless focuses on the individual pathways, as this makes it easier to discuss the various measures. The combination of policies in all three pathways is discussed In Section 5.

4.1. Vehicle efficiency

KEY FINDINGS

- Regulation of fleet-wide CO₂ emissions from cars and LCVs **has been successful** to date in reducing these emissions, at least those measured on the test cycle, with costs estimated *ex post* less than those estimated *ex-ante* and fuel savings being delivered for consumers. For the post-2020 policy framework, various reports have considered a 2025 target of around 70 gCO₂/km and have underlined the benefits of the **early introduction of electric vehicles** on compliance costs as well as for consumers. The targets chosen for the post-2020 period need to be those that deliver cost-effective CO₂ emission reductions in line with long-term CO₂ reduction targets. A mandate for low- or zero-emission vehicles has the potential to bring additional benefits, but it must ensure the overall target is not weakened.
- The discrepancy between real-world CO₂ emissions and those measured on the NEDC test cycle has **been increasing in recent years**. It is expected that the new WLTP test cycle will reduce but **not eliminate this gap**. To ensure the gap does not grow in the coming years, a **framework for monitoring real-world CO₂ emissions** should be put in place.
- The evaluation of the passenger car CO₂ labelling Directive concluded that it played an important role in the overall policy framework, but that its effectiveness could be improved. Consideration should be given to amending the Directive to at least require the use of a **hierarchical, colour-coded label** and the inclusion of **fuel costs and relevant taxes**, while requirements on the presentation of information on **alternatively-fuelled vehicles** need to be set out.
- The new CO₂ standards that are being developed for HDVs need to ensure that the **energy efficiency of the new EU HDV fleet improves** in a manner consistent with long-term targets, drawing on experience in the US to identify the level of improvements that might be feasible.
- It has been estimated that ICAO's global market-based measure (CORSIA) would **deliver less** in terms of GHG emissions than including all flights to and from EU airports in the EU ETS, while ICAO's CO₂ standards for aircraft **deliver less** than has historically been delivered without a standard. Once the impact of these initiatives has been fully understood, the manner in which aviation is covered by the EU ETS should

be reviewed, to ensure that there **continues to be a strong signal to reduce aviation's GHG emissions.**

- IMO has taken initial action to improve the energy efficiency of ships, which could **deliver benefits in the medium-term**, while the European Parliament has proposed that GHG emissions from international maritime transport **be included in the EU ETS** if the IMO has not put in place further measures, including targets, to reduce the sector's GHG emissions. Parliament's proposal is potentially an important step in ensuring that action is taken to reduce GHG emissions from the maritime sector post-2021.
- Consideration should be given to ensuring that information on the CO₂ emissions and fuel efficiency of new motorcycles and other small passenger vehicles and of new engines used in railway vehicles and inland waterway vessels **be communicated to potential buyers in a way that can inform purchasing decisions.**

As shown in Figure 4, above, passenger cars have been by far the largest source of transport GHG emissions in the EU since 1990. Consequently, EU policy on vehicle efficiency began with cars, before being extended to LCVs. Targets have been set on the basis of the CO₂ emissions measured in the course of vehicle testing and to date have been largely met. In recent years, on-road measurements and data from leasing companies have shown that there has been an increasing discrepancy between the CO₂ emissions (and fuel efficiency) measured in the type approval test cycle and emissions in the real world. This has been problematic for EU policy, as **the apparent reductions in tailpipe CO₂ emissions have not been delivered in practice**, while the information provided to consumers on the CO₂ emissions and fuel economy of new cars has not been accurate. These issues, and others relating to the efficiency of cars and LCVs, are discussed in more detail in Section 4.1.1.

The extension of EU legislation on vehicle efficiency to LCVs before action was taken on HDVs, the second-largest source of transport GHG emissions, was due partially to the fact that many of the smaller models of LCV are based on similar car models. The other main reason for tackling the CO₂ emissions of LCVs before those of HDVs is that it was relatively straightforward to use passenger car CO₂ policy as a model for the equivalent LCV legislation. Unlike LCVs, HDVs are often manufactured to cater directly to the demands of specific customers, e.g. a major haulage operator or bus company, making across-the-board vehicle regulation far more challenging. This is one of the reasons why Euro standards that regulate air pollutant emissions for HDVs apply to engines rather than whole vehicles. Measures addressing the efficiency of HDVs are discussed in Section 4.1.2.

International aviation and maritime transport are the next-largest source of transport GHG emissions (see Figure 4). EU action to reduce the GHG emissions of these two modes is more problematic, owing to the international nature of both the travel and the respective industries. **These two modes are regulated by international organisations:** the International Civil Aviation Organisation (ICAO) and the International Maritime Organisation (IMO), respectively. The UNFCCC's 1997 Kyoto Protocol called on Annex I Parties (i.e. developed countries) to take action to limit or reduce GHG emissions from aviation and shipping via these international bodies, which poses a challenge to EU action. Measures for these modes are discussed, respectively, in Sections 4.1.3 and 4.1.4, while Section 4.1.5 discusses the remaining transport modes that contribute a small and declining share of transport GHG emissions.

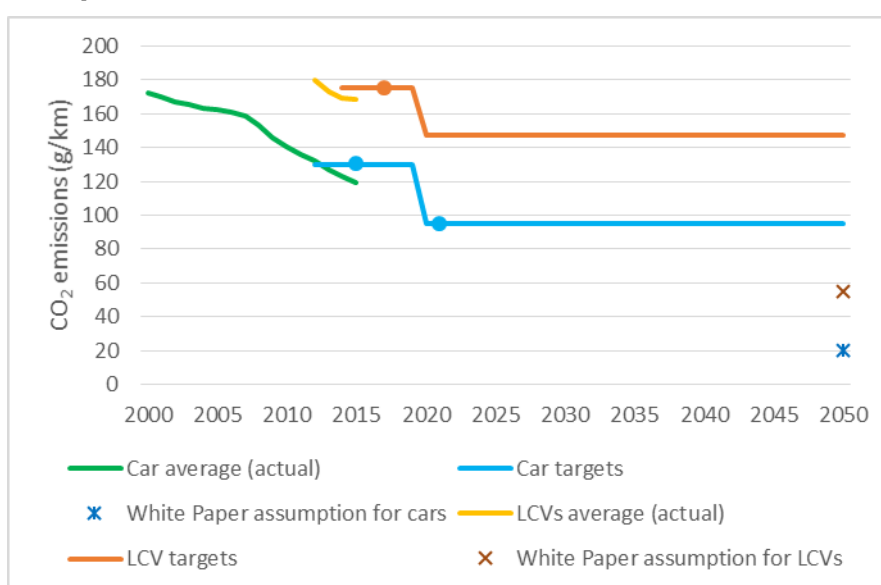
4.1.1. Light-duty road transport vehicles

Current emission standards and effectiveness

The CO₂ emissions of new light-duty vehicles (LDVs), i.e. cars and LCVs, are regulated by Regulations 443/2009 and 510/2011, respectively, which are generally referred to as the Passenger Car and LCV CO₂ Regulations. The Passenger Car CO₂ Regulation replaced voluntary agreements, which had been concluded with the respective manufacturers associations in 1998 and 1999, under which manufacturers had agreed to reduce the average CO₂ emissions of new cars to 140 gCO₂/km by 2008. In 2007 the Commission proposed that a regulation be introduced, concluding that progress had been insufficient to meet the agreed targets (EC, 2007). The Regulation came into force in 2009 and set a target of 130 gCO₂/km, to be achieved through improvements in vehicle technology by 2015, and set a provisional target of 95 gCO₂/km for 2020, which was to be confirmed by a review. This was followed two years later by the LCV CO₂ Regulation, which set a target of 175 gCO₂/km for new LCVs to be achieved in 2017, and proposed a target of 147 gCO₂/km for 2020. Both the 2020 targets were confirmed in 2014, although manufacturers of passenger cars were given an additional year to meet their target. All these targets relate to CO₂ emissions as measured on type approval tests using the New European Drive Cycle (NEDC), i.e. in a laboratory when the vehicle is being approved for the EU market.

The most recent data demonstrate that both the 2015 target for passenger car CO₂ and the 2017 target for LCV CO₂ were met early, in 2013, and that emissions have since continued to decline, although significant reductions are still needed to reach the 2020 (LCVs) and 2021 (cars) targets (see Figure 9). It is important to note, however, that the CO₂ emission reductions delivered in the real world are much less than the reductions implied by the test cycle figures, as will be discussed below.

Figure 9: CO₂ emissions for new cars and LCVs, actual, targets and 2050 assumptions



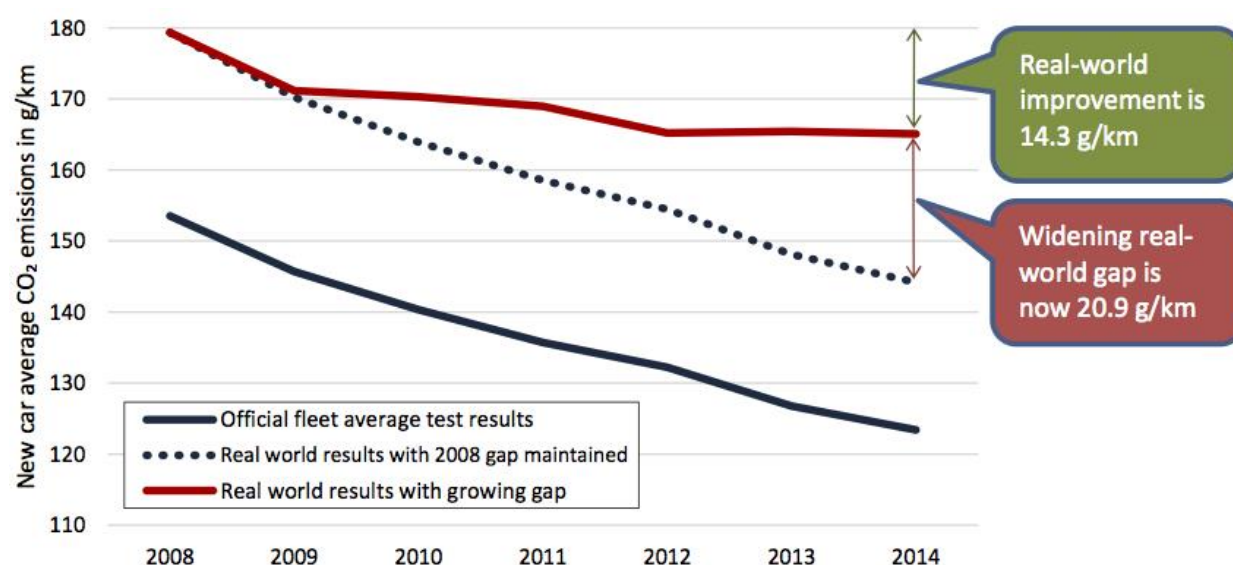
Sources: The actual numbers are taken from (EEA, 2016c), see Tables 3.1 and 4.1; the assumptions for 2050 are from (EC, 2011c).

Note: The first target for cars and LCVs, and the second for cars were phased in, as they only applied to a proportion of the new car fleet initially. The circles indicate when the targets applied to all the respective new vehicle fleets, which are the dates mentioned in the main text.

The evaluation of the LDV CO₂ Regulations concluded that the Passenger Car CO₂ Regulation had delivered annual CO₂ reductions from new cars of between 3.4 to 4.8 gCO₂/km per year, compared to the 1.1 to 1.9 gCO₂/km achieved by the voluntary agreements. It also estimated that the Regulations had generated net economic benefits for society and were more cost-effective than had been expected. The main reason is that the costs to manufacturers were only € 183 per car, which is much lower than the *ex-ante* cost estimates of between € 430 and € 984 per car. The evaluation also concluded that, for new cars registered in 2013, the lifetime discounted fuel savings resulting from the Regulations would be around € 1,300 for petrol cars and € 980 for diesel cars, with similar values estimated for LCVs. For cars, in particular, these savings would deliver social benefits, as the savings would benefit drivers of second-hand cars, who are more likely to have lower incomes (EC, 2015c).

The evaluation concluded that the effectiveness of the Regulations had been adversely affected by the discrepancy between test-cycle and real-world emissions. The increasing gap between the average type-approval CO₂ emission factor and the real-world emission factor, as depicted in Figure 10, has seriously reduced the effectiveness. Between 2008 and 2014, about 60% of the CO₂ reduction on paper has been absorbed by this widening gap.

Figure 10: Development of the average type-approval test value of new cars sold in the EU and their real-world CO₂ emission factors



Source: [Transport & Environment](#), derived from ICCT, 2014.

Future vehicle regulation

As noted in its Low Emission Mobility Strategy, the Commission is in the process of developing proposals for new targets for the post-2020 period for both the Passenger Car and LCV CO₂ Regulations, which it expects to publish in 2017 (EC, 2016b); (EC, 2016d). Studies for the Commission in support of the post-2020 policy framework are ongoing or have been completed but have not yet been published. These will be comprehensive and aim to support identification of the most appropriate post-2020 targets, taking account of market developments and updated estimates of the costs and CO₂ reduction potentials of various technologies.

Key choices for the post-2020 legislation are:

- The stringency of the target (the target level) in relation to the costs.
- The approach for determining vehicle performance (test cycle, or (also) some way to determine real-world emissions).
- Specific incentives for stimulating Ultra Low Emission Vehicles (such as super credits or a 'ZEV mandate', as implemented in California).
- Including well-to-tank emissions in the metric used.
- The choice of the utility parameter.

Below, each of these issues is briefly discussed.

The choice of the **target level** for the post-2020 regulations should strike a balance between the GHG reductions required to meet the overall GHG reduction targets and costs. In 2013 the European Parliament recommended an indicative target level of 68–78 g/km for 2025. The following considerations are important for the choice of target level:

- Targets should be in line with the overall GHG emission reductions needed for meeting the Paris Agreement. For this it is expected that the emissions of new LDVs need to be reduced to zero (well) before 2050. In some countries the national parliament has even called for a far quicker shift to 100% zero-emission vehicles in 2025 or even 2020 (Norway, Austria, the Netherlands, India). Member States, or bodies advising them, have also been making assumptions about the level of CO₂ emissions from cars and LCVs needed in 2025 and 2030. The latest progress report from the Committee on Climate Change, which advises the UK Government on the delivery of its long-term GHG reduction objective, recommended that new car and LCV standards reflect the need to increase the uptake of battery electric vehicles (BEVs), and so be moving towards 50 gCO₂/km for cars and 60 gCO₂/km for LCVs by 2030 (CCC, 2016). Modelling in support of the development of the Swedish climate strategy assumed similar targets, i.e. 70 gCO₂/km by 2025 and 50 gCO₂/km by 2030 (Environmental Advisory Council, 2016). The official position of the government of the Netherlands recommends a target level of no more than 70 g/km in 2025 and 35 g/km in 2030. (Ministry of Infrastructure and the Environment, 2016) In contrast, in the Impact Assessment in support of the Commission's Low Emission Mobility Strategy, three scenarios with different levels of ambition were modelled. These assumed that the average fleet-wide CO₂ emissions from new cars would be 85 gCO₂/km, 80 gCO₂/km or 74 gCO₂/km in 2025, with levels 10 gCO₂/km lower by 2030 (EC, 2016e).
- The net societal costs associated with a target level (taking into account the wider societal benefits as a result of lower fuel costs) should be reasonably in line with the reduction costs of other measures and in other sectors. In addition, there should be net economic benefits for drivers or at least any net costs should not be too high. The ongoing studies for the Commission will provide the latest data on the costs of meeting different target levels. Previous studies have shown that lowering the targets below the levels agreed for 2020 (LCVs) and 2021 (cars) can have limited costs or even bring benefits. (ICCT, 2016a) estimated that a target of 70 gCO₂/km in 2025, which is in the range recommended by the European Parliament, could be achieved with little contribution from electric vehicles and would cost an additional € 1,000 to € 2,150 per vehicle, which could be reduced by up to € 500 per vehicle if manufacturers began the transition to electric vehicles earlier (because of economies of scale). This underlines the economic benefits of an earlier transition to electric vehicles, which could be stimulated by specific incentives (see below). For LCVs, similar costs and cost reductions from an earlier transition to electric vehicles would be delivered by a

2025 target of 110 gCO₂/km. A report for the consumers association BEUC (Element Energy, 2016a) concluded that further reductions in the CO₂ emissions of new cars would benefit consumers, particularly those on lower incomes. They found a reduction in the total cost of ownership over the entire vehicle lifetime of 16% to 28% compared with a 2015 car (about € 11,000 to € 19,000), with a target level of 71 g/km in 2030.

- The stringency of the target depends not only on the actual numbers but equally on how the emissions are determined. For example, a 70 g/km target measured on the NEDC is much less stringent than a 70 g/km target determined by on-road fuel economy data gathered from the Engine Control Units of cars. Most assessments made so far have used NEDC values and all the 'gCO₂/km' figures presented in this report relate to measurements in the NEDC. However, when a different approach is used, the values need to be 'translated'. Even for the existing regulations such a translation will be needed when the current NEDC test is replaced by the 'Worldwide harmonized Light vehicles Test Procedures' (WLTP).

A second issue that deserves particular attention for the post-2020 CO₂ regulations is **the approach used for determining vehicle performance**. The currently used NEDC was developed in the 1970s, and although it has subsequently been updated, it does not adequately reflect the heavier and more powerful vehicles on the road today (EEA, 2016b). The new WLTP has been developed, which better reflects modern real-world driving conditions and behaviour. However, initial tests have suggested that the WLTP will not completely close the gap between test-cycle and real-world emissions (EEA, 2016b). As a result, the Commission's Scientific Advice Mechanism was asked to look at further ways of closing this gap. Their report, which was published in 2016, concluded that a framework for monitoring real-world CO₂ emissions was needed, using data from portable emissions measurement systems (PEMS), and that regulatory oversight of the process needed to be improved and made more transparent. The report also recommended a review and further development of the WLTP every five years in order to ensure that the gap between test-cycle and real-world emissions does not continue to grow (Scientific Advice Mechanism (SAM), 2016).

An alternative for PEMS could be the use of the fuel consumption data measured and registered on the road by the engine control unit (ECU) of all modern vehicles. The precise procedure for determining the CO₂ performance of vehicles using (a combination of) WLTP, PEMS and/or ECU data would need to be determined. It should be emphasised that the most important challenge is not closing the gap between type-approval and real-world values, but rather making the gap predictable and more or less the same for all car models. Once that has been achieved, the target level can be set at the appropriate level and enforced.

With the current type approval test, not all GHG reduction options have an impact on the CO₂ value of a car or LCV. Examples are LED headlights. The uptake of these measures is stimulated by granting so-called eco-innovations. Depending on how the CO₂ emissions are determined and whether or not such reduction options are reflected in the CO₂ value, it may or may not be useful to continue or even extend the eco-innovations provisions in the post-2020 regulations.

Two such measures, tyre-pressure monitoring systems (TPMS) and gear-shift indicators (GSIs), are required for all new cars by another Regulation, (EC) No 661/2009 (referred to as the General Safety Regulation because of some of its provisions) (JRC; TEPR; CE Delft, 2016). Other devices that could potentially help reduce real-world CO₂ emissions include fuel-consumption displays and speed-limiting devices. In its work on a 2014 Commission proposal relating to pollutant emissions (EC, 2014c), the European Parliament's Environment Committee (ENVI) called for the mandatory fitting of fuel-consumption meters to all new vehicles and for the Commission to consider extending the mandatory introduction of GSIs

to all vehicles, not only cars (EP, 2015)¹⁶. A recent report for the Commission recommended that the revision of the LCV CO₂ Regulations should take the opportunity to incentivise the use of intelligent speed adaptation (ISA) in new LCVs, as a result of their potential benefits for CO₂ reduction, which were higher than simple speed-limiting devices (CE Delft, 2016). Such measures could be made mandatory or be stimulated by eco-innovations.

A third issue for the post-2020 regulations concerns **specific incentives for stimulating Ultra Low Emission Vehicles**. The Commission's Low Emission Mobility Strategy noted that different ways of incentivising low- and zero-emission vehicles, including possibly setting specific targets for these vehicles, could be part of the post-2020 legislative framework (EC, 2016b). At this point, it is not clear what the Commission is intending in this respect, but it could be some type of mandate along the lines of California's zero-emission vehicle (ZEV) mandate.

The Californian ZEV mandate requires that, in 2020, at least 9.5% of the cars on sale in California are either a ZEV or a 'transitional' ZEV, e.g. a plug-in hybrid vehicle (PHEV), with a minimum of 6% being ZEVs. These rates will increase annually to reach 22% in 2025, with at least 16% ZEVs (State of California, 2016). The programme has recently been subject to a mid-term review, which recommended a continued strengthening of the requirements beyond 2025 (ARB, 2017).

In the EU context, a recent report concluded that there would be a potential benefit in including a mandate for ultra-low-carbon vehicles alongside post-2020 CO₂ targets for passenger cars. The focus of the system could be on ZEVs, although PHEVs could be included by counting each PHEV as a proportion of one ZEV. It was also suggested that a 'flexible mandate' could be adopted under which manufacturers are rewarded with a less stringent target if they over-deliver on the mandate, although this would risk weakening the overall target if it was not designed properly (Element Energy, 2016b).

In the current regulations, vehicles with emissions below 50 g/km are incentivised by so-called super-credits. However, these have been criticised as potentially weakening the overall stringency of the regulation.

The interaction between the overall, fleet-wide CO₂ reduction targets and any further incentivisation of low- and zero-emission vehicles will need to ensure that they are complementary and that their interaction does not weaken the overall target.

A fourth issue for the post-2020 regulations concerns the option of including **well-to-tank (WTT) emissions in the metric**. The LDV CO₂ Regulations explicitly focus on tailpipe CO₂ emissions, also referred to as 'tank to wheel' (TTW) CO₂ emissions. Together WTT and TTW GHG emissions are known as the lifecycle or 'well-to-wheel' (WTW) emissions. Consequently, the emissions from fuel production (extracting, transporting, refining and distributing fossil fuels) and electric power generation or hydrogen production are not covered by the metric. If those other emissions are not sufficiently covered by other policies, this may lead to carbon leakage and reduce the overall effectiveness of the policy. Furthermore, some vehicles (such as electric vehicles) might be over-incentivised relative to what would be justified according to their overall GHG emissions performance.

Including WTT emissions in the metric used for CO₂ targets in the LDV CO₂ Regulations would potentially lead to double regulation, as such emissions are already covered by other legislation, and would also complicate the legislation. If the actual WTT had to be known for each vehicle, this would require more complicated monitoring and assessment. Alternatively, typical 'factors' could be used instead of actual figures to simplify monitoring and assessment, but this would still not be straightforward and could potentially be controversial. Moreover,

¹⁶ Mid-June 2017, this proposal was still awaiting Parliament's first reading - [see procedure 2014/0012\(COD\)](#).

regulating the WTW emissions instead of TWW emissions would have an opposite effect to super-credits or a ZEV mandate, as it would be a disincentive for producing ZEVs. Combining these two elements in the same Regulation does not therefore seem useful.

A fifth key issue for the post-2020 regulations is the choice of the so-called **utility parameter**. In the current regulation, vehicle mass is used, but various studies such as (TNO et al. 2011) concluded that the vehicle's footprint (i.e. the area between the four tyres) should be the preferred option, as it is a better proxy for the true utility of the vehicle, and that it fully rewards the benefits of weight reduction as a CO₂ reducing option. The latter is relevant, as advanced levels of weight reduction will be an increasingly important option for meeting targets for 2020 and beyond.

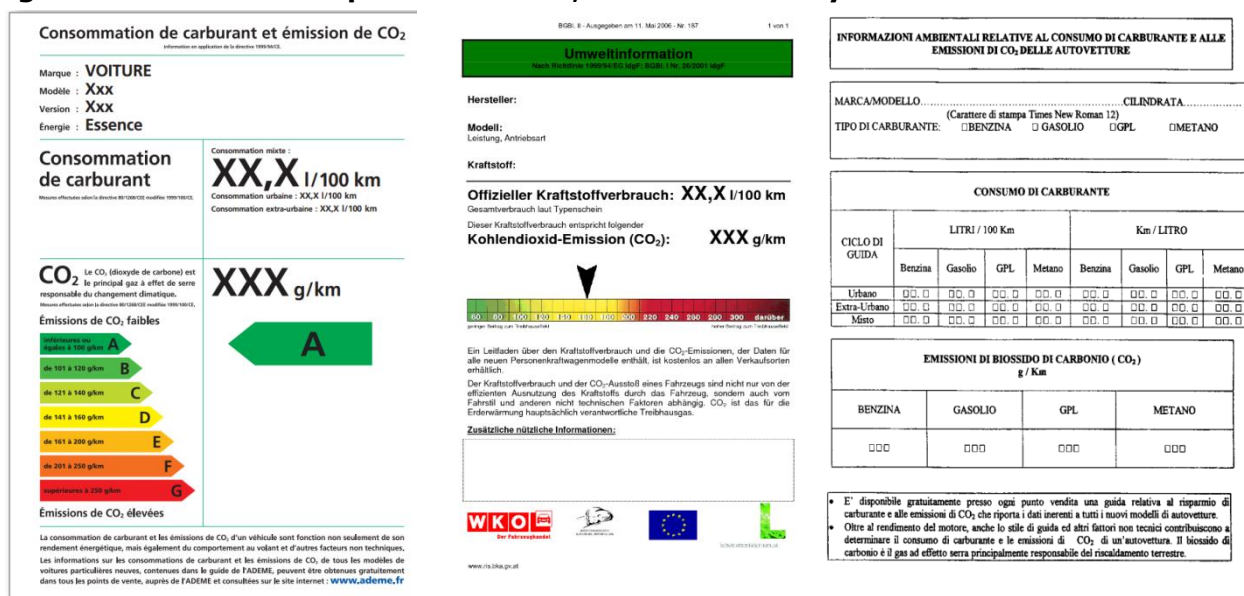
Labelling

The passenger car labelling Directive (Directive 1999/94/EC) dates from 1999 and has since remained largely unchanged. It requires that a label containing information on a new car's CO₂ emissions and fuel economy be displayed at the point of sale, and that this information is also presented on other relevant promotional material. The provision of this information to potential purchasers is complementary to the supply-side CO₂ reduction targets, as it ensures that consumers are aware of, and can compare, the difference in performance between different new cars.

The evaluation of the Directive concluded that its effectiveness could be improved if use of a colour-coded, hierarchical label (similar to the format used for the EU Energy Label) and information on a car's running costs and relevant taxes were both mandatory, this being important to drivers when deciding between different cars.

Around half the Member States currently use a colour-coded, hierarchical label to present information on the CO₂ emissions of new cars, and most of these follow the format of the EU Energy Label, while around a quarter also include information on running costs and relevant CO₂-based taxes (see Figure 11).

Figure 11: Car labels in place in France, Austria and Italy



Source: (Ricardo and TEPR, 2016).

The need for the Directive to be clear about what information should be presented for alternatively-fuelled cars, and how this should be done, has also been identified as one means of improving the effectiveness of the Directive (Ricardo and TEPR, 2016) (ANEC; BEUC, 2014) (ICCT, 2016d).

An open question is the extent to which the methodology for assigning labels to cars should be harmonised at the European level. As average CO₂ emissions in different EU markets vary considerably, e.g. ranging from 101 gCO₂/km in the Netherlands to 137 gCO₂/km in Estonia (EEA, 2016c), a label categorisation designed for one Member State market could be less relevant for another.

However, the general rules for allocating a car to a label category could be harmonised. The simplest way of allocating a car to a category is to compare a new car's CO₂ emissions to those of **all new cars**, referred to as an 'absolute' approach. This approach is taken in 11 of the 14 Member States that use a colour-coded label. The other three countries take a 'relative' approach, which relates a car's CO₂ emissions to another variable, such as a car's 'mass', thus effectively categorising a car relative to **'similar' vehicles** (Ricardo and TEPR, 2016). Studies have suggested that a relative label is more confusing to consumers than an absolute approach (e.g. (Hille et al., Forthcoming)).

Given the gap between real-world and test emissions, it may be appropriate in the context of the car labelling Directive to replace or complement the test-based CO₂ emissions by real-world emission factors, e.g. by applying a suitable factor, as has also been noted by (ANEC; BEUC, 2014). This is the approach taken in the US, where fuel-economy figures that are more representative of real-world driving are used on the fuel-economy label, while different unadjusted figures are used for the purpose of assessing manufacturer compliance with the fuel-economy standards (US EPA, 2016).

Other measures, including vehicle taxation

While the LDV CO₂ Regulations and the car labelling Directive are the two pieces of EU legislation that directly target the CO₂ emissions of LDVs, there are others that have the potential to contribute to developing the market for lower CO₂ emitting vehicles. There are two on the public procurement of cleaner vehicles, both of which apply to some HDVs in addition to cars and LCVs: the Clean Vehicle Directive (CVD) and the EU's green public procurement (GPP) criteria for transport¹⁷. The former requires public authorities to take account of energy and environmental considerations when buying vehicles, while the latter sets voluntary environmental criteria that can be used by public authorities when procuring clean vehicles. Hence, both cover more than a vehicle's CO₂ emissions, although these emissions are an important element of both. As noted in the Low Emission Mobility Strategy, public procurement has a potentially important role to play in developing a market for clean vehicles. Both these initiatives are currently under review, with a proposal to revise the CVD and a revised set of GPP criteria both expected later in 2017. An evaluation of the CVD concluded that it had not been effective to date, even though there was broad support for its retention (Ricardo Energy & Environment; TEPR, 2015). Hence, the challenge in its amendment will be to make it more effective in terms of stimulating the market for clean vehicles, while at the same time enabling public authorities to continue to make the procurement decisions that are most appropriate to local needs.

Another consumer-focused piece of legislation is the tyre labelling Regulation (EU, 2009), which requires that new tyres for road transport vehicles have a label attached that provides information on the rating of the tyre with respect to its fuel efficiency, external rolling noise

¹⁷ For the current criteria, see http://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm
For the review of the criteria, see <http://susproc.jrc.ec.europa.eu/Transport/index.html>

and wet grip. The label is based on the format used for the EU Energy Label, and so is colour-coded and hierarchical. A recent evaluation of the tyre labelling Regulation recommended that more should be done to increase consumer awareness of the label, including obliging suppliers and distributors to provide information on all tyres to consumers, and that market surveillance and enforcement be improved (Viegand Maagøe A/S, 2015).

An important means of influencing consumer behaviour towards purchasing and owning more efficient and low- or zero-emission vehicles is through taxation, incentives and rebates. (Taxes on the use of transport are covered in Section 4.3.2.) The purchase and ownership of cars are subject to many different taxes, including registration taxes, annual circulation taxes, value added tax (VAT) and company car taxes related to the corporate ownership of vehicles. In many Member States, registration and annual circulation taxes are based on a car's CO₂ emissions or on its fuel efficiency (ACEA, 2016).

Gerlagh et al. (2015) found that increased CO₂ sensitivity of registration taxes has reduced the CO₂ emissions of the average new car in the fifteen EU Member States that had linked their car taxes to CO₂ emissions. These findings are in line with a growing body of empirical literature on the effects of fiscal policies on the fuel efficiency of new cars. In general, these studies find that fiscal policies are effective in incentivising the purchase of energy-efficient cars. Various reports have highlighted that varying taxes on all vehicles by their CO₂ emissions can be a driver of fuel efficiency, although varying registration or purchase taxes is seen as a stronger driver than varying annual circulation taxes (Cambridge Econometrics, 2013); (T&E, 2014). The tax treatment of company cars is also an issue, as their purchase can be subsidised, which reduces the impact of other taxation policies (ICCT, 2011) and their tax treatment often provides incentives to drive further in these cars (Harding, 2014).

Clearly, BEVs will benefit from CO₂-based vehicle taxes, as they have zero tailpipe CO₂ emissions. Additionally, some Member States have one-off subsidies for the purchase of BEVs and sometimes PHEVs that can take various forms, e.g. exemption from (or reduced) registration taxes, grants that go towards the purchase of a new vehicle or grants to scrap an old car and replace it with a BEV (EEA, 2016a). The fact that some Member States include information on relevant CO₂-based vehicle taxes on the car labels, as noted above, underlines the potential synergies between CO₂ standards, taxation and labelling, and also between EU and Member State policies.

The promotion of fuel economy through vehicle taxation was the third element, alongside the voluntary agreements with manufacturers and car labelling, of the Commission's 1995 strategy on passenger car CO₂ (EC, 1995). The challenge for EU policy in the area of vehicle taxation is that it is a Member State competence. A previous legislative proposal to require circulation taxes to be based on a car's CO₂ emissions (EC, 2005) had to be withdrawn as a result of resistance from Member States (Skinner, 2015). The 2016 Low Emission Mobility Strategy recognised the benefit of using taxation to promote the purchase and ownership of clean vehicles, and underlined the potential benefits of a "well-designed framework" for company car taxation.

Given the potential benefit of CO₂-based vehicle taxation, and the different approaches and experiences of various Member States, it could be useful for the Commission to develop a 'good practice' framework for vehicle taxation, including the tax treatment of company cars, more generally, which would draw on good examples and Member States' experience of what has worked and what has not. This could assist Member States in introducing and developing their own CO₂-based vehicle taxation systems.

4.1.2. Heavy-duty road transport vehicles

Efficiency standards

Regulating the GHG emissions of HDVs is more challenging than for LDVs. Whereas air pollutant emissions from HDVs are regulated by focusing on their engines, this approach is less appropriate for CO₂ emissions as there are many factors associated with HDV design and use that influence their real-world CO₂ emissions. Prior to development of the passenger car CO₂ Regulation, a means of measuring a car's CO₂ emissions in the LDV type-approval legislation and a CO₂ emissions monitoring scheme had both already been put in place to enable and support the previous voluntary agreements with manufacturers. Currently, neither of these systems are in place for HDVs.

To address these gaps the Commission has overseen development of the Vehicle Energy Consumption Calculation Tool (VECTO) in collaboration with the industry. The aim of VECTO is to enable simulation of CO₂ emissions from different types of HDVs, including buses, coaches and HGVs with trailers (EC, 2014d). VECTO has reached the point where it can be used for the purpose of legislation: in May 2017, (1) Member States reached agreement on a Commission proposal on the certification of CO₂ emissions from HDVs under Regulation (EC) No 595/2009 and (2) the Commission published a proposal to monitor and report these certified data¹⁸. The Commission is also developing CO₂ emission standards for HDVs, which are already in force in the US, Japan and China. The legislation would first apply to certain types of HGV and then be extended.

Real-world testing of tractor-trailer combinations in the EU suggests that the fuel consumption of such vehicles has remained relatively stable in the last decade, at around 35 litres/100 km. US regulation of such vehicles began in 2010 with a baseline fuel consumption of over 45 litres/100 km, thus significantly worse than the performance of such vehicles in the EU. However, by 2021 the average fuel consumption of tractor-trailer combinations in the US should be 35 litres/100 km, declining to just over 30 litres/100 km by 2027 as a result of US legislation. While the EU and US HDV fleets are not identical, the stringent American standards suggest that there is potential for the EU market to improve its fuel efficiency and that the EU should benefit from the technological developments stimulated by the US standards (ICCT, 2015b).

As with the revisions of the LDV CO₂ emissions Regulations, one of the challenges for the forthcoming HDV standards will be to ensure that the stringency of the CO₂ emission standards strikes the appropriate balance. On the one hand, Regulations will bring additional compliance costs for industry, while on the other there are the benefits in terms of CO₂ emission reductions and fuel-cost savings. The need for long-term improvements in the fuel efficiency of HDVs, coupled with the indication that their fuel consumption has not improved in recent years, underlines the need for regulation and for standards to be sufficiently strong to meet long-term targets and deliver their potential benefits.

Other measures

As with LDVs (see Section 4.1.1), the inclusion of driver aids in vehicles has the potential to contribute to CO₂ emission reductions. Relevant measures include fuel-consumption meters, gear-shift indicators, tyre-pressure monitoring systems, low-rolling-resistance tyres and improved air-conditioning. Such measures are likely to be cost-effective and easy to implement. Stimulating the uptake of such measures is already encouraged by the Clean Vehicle Directive, Green Public Procurement criteria and the tyre-labelling Regulation, which also applies to tyres for HDVs. Further incentives could be provided by CO₂ labelling or

¹⁸ COM(2017) 279 of 31.5.2017.

efficiency standards for HDVs, e.g. by granting credits (such as the 'eco-innovations' in the CO₂ Regulation for cars).

Comparing the policy framework for HDVs with that for LDVs reveals one obvious gap: the provision of information to consumers on the fuel economy and CO₂ emissions of new vehicles. The numbers generated by VECTO provide a great opportunity to fill this gap and improve the information to potential consumers. For the many new HDVs that are designed to meet the demands of a specific customer, information will be shared between the manufacturer and customer on CO₂ emissions and fuel economy. However, the majority of freight operators are small, with roughly 85% having fewer than ten vehicles (AEA, 2011). If they buy new vehicles, they may not have the same resources to ensure that vehicles meet their needs, and if they buy second-hand vehicles, they would potentially benefit from having information on the vehicle's CO₂ emissions, and particularly its fuel economy, made available to them. Consideration should therefore be given to how best to ensure that information on the fuel economy and CO₂ emissions of HDVs is made available to prospective purchasers, particularly in the second-hand market.

4.1.3. Aviation

Flights departing from EU airports account for around 3% of EU GHG emissions. Although the emissions have been stable since 2006 because of fleet renewal programmes, they are projected to grow in the coming decades (EEA, 2016f). The EU is addressing these emissions through market-based measures and by encouraging the use of sustainable low-carbon fuels. At a global level, a market-based measure has been agreed upon and an efficiency standard is under development.

Market-based measures

Directive 2008/101/EC (EC, 2008b) integrated all flights leaving and arriving at EU airports into the EU ETS from 2012. It has been subject to various legal challenges, including from US airlines, but the European Court of Justice ruled that the EU had the right to regulate aviation emissions in this way (EJC, 2012). The Directive regulates that aviation will be granted allowances that equal 95% of the average total annual aviation emissions in the years 2004-2006. If aviation emissions are higher, allowances will have to be bought from other sectors.

As a result of political pressure from non-EU countries, the inclusion of flights involving airports outside the European Economic Area has been 'temporarily' suspended from the EU ETS since 2010 (Regulation (EU) No 421/2014). In early 2017, the Commission proposed to extend the current arrangements in light of the agreement that had been reached in ICAO and to give it time to consider how to implement ICAO's measure in the EU (EC, 2017a).

In 2016 ICAO agreed its 'Global Market-based Measure' (GMBM), known as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The main element of CORSIA is that operators will need to offset (not reduce) emissions above the baseline emissions level, which is the average of the total emissions covered by CORSIA in 2019 and 2020, for flights between countries that must comply with CORSIA. Various countries are exempt, including those that have a low proportion of global air traffic and the least developed countries. As a result, not all emissions above the baseline will need to be offset. CORSIA will begin with a pilot phase in 2021, followed by a first, voluntary phase from 2024, before participation becomes mandatory for developed countries and countries with a large share of air transport in the second phase from 2027 to 2035.

CORSIA will not reduce emissions as much as would have been achieved by applying the original scope of the ETS (i.e. to all flights leaving and arriving at EU airports) over the same time period (CE Delft; TAKS, 2017). This is largely due to the later

(and so higher) baseline used by CORSIA (2019-2020 instead of 2004-2006), which outweighs its wider emissions coverage. Since emissions on flights departing from EU airports are included in the EU's 2030 target, a lower contribution of the aviation sector to emission reduction implies that other sectors will have to do more.

While the European Parliament has only recently begun debating the extension of the exclusion of non-EEA flights from the EU ETS, separately it has voted to include more stringent provisions for aviation in the Commission's proposal for the fourth phase of the EU ETS post-2021, namely a reduction in the number of allowances to be allocated to aircraft operators to bring this more in line with caps for other sectors (EP, 2017).

It appears that ICAO's CORSIA falls short of what would be achieved by the inclusion of all flights leaving and arriving at EU airports in the EU ETS, as the EU originally planned from 2012. The way in which aviation is covered by the EU ETS should be reviewed in order to ensure that there continues to be a strong signal to reduce aviation GHG emissions. There are several options, including: keeping intra-EEA flights in the EU ETS after the implementation of CORSIA; re-including all flights to and from EU airports in the EU ETS, as this will ensure that GHG reductions are delivered before CORSIA begins to have an impact; including all flights to and/or from countries not participating in CORSIA in the EU ETS.

Efficiency standards

Within ICAO, a CO₂ standard for new aircraft has been developed, which will apply to 'new type' designs from 2020 and to 'in-production' aircraft that are subject to certain modifications from 2023. After 2028, manufacturers will not be allowed to produce aircraft that do not meet the CO₂ standard, which was adopted in March 2017 after consultation with ICAO's members (ICAO, 2016). On average, when the standard becomes mandatory it will require a 4% reduction in the 'cruise fuel consumption' of new aircraft compared with those delivered in 2015. The actual reduction required will depend on an aircraft's maximum take-off mass, and range from zero to 11% for the largest aircraft. Countries that have certifying bodies, which includes the EU (in the form of the European Aviation Safety Agency) and the US, are allowed to adopt ICAO's CO₂ standard or adopt more stringent CO₂ standards for aircraft if they consider that ICAO's standard is not sufficient (ICCT, 2017). While industry has supported the standards, NGOs have called for them to be rejected, arguing that they do nothing to influence the major aircraft manufacturers to reduce CO₂ emissions beyond what would have happened without the standard (T&E, 2016b).

The CO₂ standard will help airlines meeting the CORSIA and EU ETS requirements, but will not affect the net amount of emissions under either scheme. However, it will affect the emissions outside the scope of CORSIA, i.e. the emissions to and from exempted countries.

To put ICAO's CO₂ standard into a broader context, it should be noted that the average fuel burn of new aircraft has been declining since the 1960s. In the 1980s, the decade in which the rate of improvement was greatest, it averaged over 2% a year, whereas in the 2000s it was around half a percent a year (ICCT, 2015a). If the rate of reduction that was seen in the 2000s, which was lower than in the two previous decades, were to be seen between 2015 and 2028, there would be an improvement in the energy efficiency of new aircraft of 6.7%. Previously, ICAO had set itself 'fuel-burn technology goals' for 2020 and 2030. It considered that the 2020 goal would be met if an aircraft achieved a reduction of between 25 to 29% (depending on the number of aisles in the aircraft) compared to a baseline aircraft from the year 2000, while the 2030 goal would be met if the reduction compared to 2000 was between 34 and 35%. The latter corresponds to an **annual reduction** of 1.4%, which would equal 20% for the 2015-2028 period. This 1.4% is still less than ICAO's "aspirational goal" of an annual 2% improvement in fuel efficiency each year until 2050 (which would equal 29% for the 2015-2028 period) (ICAO, 2013). (ICCT, 2015a) developed a trend based on the fuel

efficiency of new aircraft up to 2014 and concluded that, unless the rate of improvement increased, both ICAO goals would be met twelve years behind schedule.

While ICAO's action to improve the environmental performance of aircraft is to be welcomed, the 4% efficiency improvement between 2015 and 2028 falls short of even its own goals of between 20 and 29% and is also less than the 6.7% that would be delivered if the relatively low annual efficiency improvements seen in the 2000s were to continue to 2028. As aircraft can have operational lifetimes of well over 20 years, many of the 2028 aircraft will be a minimum of only 4% better than 2015 models and will still be in use in 2050.

Demand management and taxation

The aviation sector is exempt from VAT under the VAT Directive (2006/112/EC) and from excise duties on fuel under the Energy Tax Directive (2003/96/EC). This is because the tax exemptions are enshrined in ICAO's policies on taxation and, subsequently, in the Air Service Agreements that govern commercial aviation between countries. Since there are a multitude of these Agreements between the EU or its Member States and other States, changing this set-up would be very cumbersome. However, several Member States levy ticket taxes on flights (CE Delft, 2017). These are generally levied on passengers departing from or arriving in a Member State; passengers transferring between flights at an airport in a Member State are generally exempt.

It has been argued that the absence of taxation of aviation results in overconsumption and an environmental impact that is higher than the social optimum (Krenek & Schratzenstaller, 2016). The International Monetary Fund (IMF) and the World Bank have shown that internalizing the social costs of carbon would reduce aviation emissions globally by 2-3%, while an optimal tax that requires the aviation sector to contribute proportionally to the fiscal budget would reduce global emissions by 7-9% (Keen et al., 2013). We expect the impacts to be similar at the EU level.

Sustainable low-carbon fuels

The 2011 White Paper sets an ambition of having 40% low-carbon sustainable fuels in the aviation fuel mix by 2050. In 2011 the European Commission, in partnership with Airbus and in cooperation with leading European airlines and biofuel producers, launched the European Advanced Biofuels Flightpath, with the goal of using 2 million tonnes of sustainable biofuels in Europe by 2020 (approximately 4-5% of projected fuel deliveries). Whilst the Biofuels Flightpath has brought together users, producers and governments and has contributed to the exchange of information, the goal currently seems to be beyond reach. One of the main barriers is the price difference between sustainable low-carbon fuels and fossil fuels (CE Delft, TAKS and LEI, 2017).

The EU can promote the use of low-carbon sustainable fuels in aviation in several ways, for example by subsidising the production, delivery or consumption of low-carbon sustainable fuels or setting blending obligations for low-carbon fuels in jet fuels.

4.1.4. Maritime

As noted in Section 2.3, the international maritime sector is unique amongst the transport modes in that the 2011 Transport White Paper identified a specific GHG reduction target for the sector (of 40% from 2005 levels by 2050), although it is not clear how 'EU CO₂ emissions' are defined in this respect. The 1997 Kyoto Protocol called on developed countries to take action to reduce maritime emissions through the IMO and the EU's Sixth Environment Action Programme called on the Commission to propose action to reduce GHG emissions from the sector if no action was forthcoming from the IMO by 2003 (Decision No. 1600/2002/EC) (EC,

2002). EU action on maritime GHG emissions has been slower than that on aviation and followed action at the IMO to improve the energy efficiency of new ships.

Efficiency standards

Since 2013 the IMO's Energy Efficiency Design Index (EEDI) has required that all new ships have an EEDI and that this demonstrates that the energy efficiency of the ship is better than a minimum standard. Initially, the minimum standard is a reference line based on the average efficiency of new ships between 1999 and 2008. The minimum standard gradually becomes more stringent: since 2015, new ships have to be 10% better than the reference line, which increases in the second stage to 20% from 2020 and to 30% from 2025. A recent study concluded that there was no evidence that the EEDI had influenced ship design yet. Prior to the EEDI being introduced, there had already been an improvement in ship design efficiency due to the high fuel prices (that were in place until mid-2014) and a decrease in freight rates (i.e. the cost of shipping freight) since 2008, both of which may have driven competition for more efficient ships. Historically, the efficiency of ships has decreased when oil prices have been low, so the EEDI could have prevented deterioration in the last couple of years and can be expected to have an impact as it becomes more stringent (CE Delft and UCL, 2016a). In 2016, the IMO confirmed the second-stage targets and committed itself to reviewing the third-stage targets for the post-2025 period, which will include the possibility of setting additional targets for future years (UNFCCC, 2016).

Monitoring, reporting and verification of emissions

While welcoming the EEDI, the Commission noted the need for additional action and proposed a three-step approach to integrate maritime transport emissions in the EU's GHG reduction policies (EC, 2013e). The steps were:

- implementing a system for monitoring, reporting and verifying (MRV) of emissions;
- defining reduction targets for the maritime transport sector; and
- applying a market-based measure.

As a first step, Regulation (EU) 2015/757 (EU, 2015a) established an MRV scheme for emissions on voyages to and from EU ports. In parallel, in 2016 the IMO adopted global reporting requirements for ships, to be collected nationally and reported to the IMO, which will produce a report summarising the information collected (UNFCCC, 2016). The Commission has welcomed the introduction of the IMO system, which requires reporting to begin one year later than the EU's system, but noted that the EU approach collected a wider range of data and would not be anonymised, unlike the IMO's approach. Once the legal framework for the IMO's global reporting requirements is clear, the Commission will undertake a review of the EU's system and propose amendments, as appropriate, to align with the IMO approach (EC, 2017b).

Target setting

The Low Emission Mobility Strategy welcomed the IMO's actions on GHG emissions from international shipping, but called for an "international agreement on an emission reduction objective" for the sector and for further measures to mitigate emissions. In 2016, the IMO approved a roadmap on GHG emissions reduction from shipping, which foresees an initial strategy to be adopted in 2018 and a revised strategy in 2023 (UNFCCC, 2016). The initial strategy should be based on an evaluation of emission scenarios and a discussion about the level of ambition, which both relate to GHG emissions targets (MEPC70/18/Add.1). It is unlikely that any additional action from the IMO will be forthcoming until the new strategy has been finalised.

Market-based measures

The European Parliament has pre-empted, to some extent, the Commission's call for further action on GHG emissions from shipping. It has voted to include provisions relating to maritime transport in the Commission's proposal for the fourth phase of the EU ETS (EP, 2017). While supporting efforts in the IMO, Parliament highlighted the urgency of more international action on maritime GHG emissions, including reduction targets. If these were not forthcoming by the end of 2021, Parliament has proposed including GHG emissions from maritime transport in the EU ETS, possibly as part of a 'Maritime Climate Fund' to which operators contribute and which ensures the compliance of those participating. The fund would be supplemented with a share of the proceeds from auctioning allowances to ship operators and be used to support investments in CO₂ reduction in the sector.

Parliament's proposals to include maritime GHG emissions in the EU ETS are a potentially important step to ensure that there will be suitable measures in place to reduce the GHG emissions of international maritime transport in the EU from 2021. If the IMO develops a sufficiently ambitious alternative, the inclusion of maritime transport in the EU ETS should be reviewed accordingly.

4.1.5. Other modes of transport

As noted in Section 2.2, together the modes discussed so far in Section 4.1 contribute 95% of the EU's GHG emissions from transport, and have thus justifiably been the focus of policy attention to date. The GHG emissions of both domestic aviation and shipping, which make up a further 3% of the EU's transport's GHG emissions, are likely to benefit from the technologies developed to meet international requirements, particularly in the case of ships (see Sections 4.1.3 and 4.1.4), while domestic aviation is covered by the EU ETS.

The other relevant sources are non-road mobile machinery, which includes engines used in railway locomotives, railcars¹⁹ and inland waterway vessels. Regulation (EU) 2016/1628 (EU, 2016), requires the manufacturers of engines for these modes to make the value of the CO₂ emissions measured in the course of the EU type-approval process available to their clients. For small passenger road transport vehicles, i.e. two- and three-wheeled motorcycles and quadricycles, Regulation (EU) 168/2013 (EU, 2013) includes reporting requirements on their CO₂ emissions. A vehicle's CO₂ emissions must be measured in the test cycle and provided in an appropriate format to the buyer of a new vehicle.

Given the relatively small contributions that these modes make to overall transport GHG emissions, there is no need, at least in the short-term, to develop legislation to require CO₂ reductions from these modes. However, making the information on energy efficiency more widely available would facilitate its monitoring, which could be used as the basis for future legislation, or another appropriate measure, if this is subsequently needed, as well as supporting consumers in their purchasing decisions. In doing so, lessons should be learned from other consumer information legislation, particularly the car labelling Directive and the tyre labelling Regulation (see Section 4.1.1).

¹⁹ Both locomotives and railcars have engines; the difference is that railcars, unlike locomotives, are also designed to carry passengers or goods.

4.2. Decarbonisation of transport fuels and energy sources

KEY FINDINGS

- A **robust strategy** to increase the use of renewable energy in transport (RES-T) in the medium and long-term **needs to be developed**.
- Over the past few years, the RES-T target in the Renewable Energy Directive (RED) and the implementation in Member State policies have **been effective** in increasing the share of biofuels in road transport fuels and in creating a market for biofuels. At the same time, however, recent inclusion of Indirect Land Use Change (ILUC) effects in the RED as well as uncertainty about future sustainability criteria and targets for biofuels in general **have hampered investments** in R&D and production capacity **for advanced, sustainable biofuels**. Besides, the RED has led to the production and use of large volumes of biofuels with limited or even negative GHG emission savings.
- To speed up RES-T growth after 2020, implementing **stable and effective sustainability criteria** is key, combined with equally stable targets for the future. To set these targets at the optimum level, a longer-term outlook is needed on the future transport energy mix with which the climate targets can be met.
- In view of the expected limited availability of sustainable biofuels, also in the long-term, future decarbonisation requires a **strong focus on increasing the share of electric and hydrogen vehicles** where possible (road transport, rail).
- Power-to-gas and power-to-liquid should be developed, to ensure the transport sector can also **benefit from the full potential** of decarbonisation of renewable fuels produced using wind and solar power.
- It is important to ensure **adequate integration of EVs** in the electricity system, to avoid the need for extensive investments in grid expansion to enable EV charging. This may include, for example, implementation of **smart charging systems** to enable charging of EV batteries in periods of high wind and solar electricity production and **policies that support local use** of renewable electricity for EV charging.
- The policies and strategies for RES-T should not be assessed and developed in isolation, but **together with the other sectors** that are working on decarbonisation of their energy supply, notably the power sector, industry and the built environment. These sectors will also have an increasing demand for sustainable biomass as a renewable energy source (and feedstock for chemical processes), for the renewable electricity produced and for renewable fuels from solar or wind power, to meet their decarbonisation targets and challenges. Because of the **potentially limited availability of sustainable biomass feedstocks**, the competition for these feedstocks and other sources of renewable energy is likely to increase cost, but could also provide opportunities for cooperation and synergies. In any case, demand from other sectors needs to be taken into account when developing future decarbonisation strategies and cost-effective policies for all the sectors involved.

This section describes the policies in place to decarbonise transport fuels and other energy sources used in the sector. The effectiveness of the policy instruments in place is discussed in terms of GHG impacts, growth in volumes of renewable energy, the transition towards

advanced biofuels and the role of various transport modes. At the end of the section we discuss what future policy action is required in light of the long-term GHG reduction targets.

4.2.1. Current policy framework

The current shares of renewable energy in transport are mainly the result of two European directives: the Renewable Energy Directive (2009/28/EC) and the Fuel Quality Directive (Directive 98/70/EC, as amended by Directive 2009/30/EC).

The **Renewable Energy Directive (RED)** sets a 20% overall binding EU target for renewable energy use by 2020, with specific individual targets for the Member States. In addition, the RED includes a binding target for the transport sector: 10% of final energy consumption in transport should consist of renewable energy by 2020. The 10% target is the same for each Member State. All types of renewable energy, including biofuels, biogas, electricity and hydrogen, count towards the target: in practice, it is mostly biofuels and renewable electricity in rail transport. Biofuels have to meet a set of sustainability criteria to count towards the target and biofuels from waste and residues count double towards the RED target.

The **Fuel Quality Directive (FQD)** has a double role in relation to the consumption of renewable energy and biofuels in the transport sector. Originally, the FQD laid down the specifications for motor fuels. Because of the growing share of biofuels, the Directive was amended in 2009 to include limits for the maximum biofuel content of diesel and petrol - in order to safeguard the quality of these fuels on the European market (Articles 3 and 4 of the Directive). In addition, the 2009 amendment included a provision (Article 7a) for a mandatory 6% reduction of the GHG intensity of fuels between 2010 and 2020. Biofuels counting towards this FQD target must meet the same sustainability criteria as laid down in the RED. The FQD also contains a voluntary target of 4% for reductions in the fuel supply sector, which can be met by implementing carbon capture and storage (2%) and via credits purchased through the Clean Development Mechanism of the Kyoto Protocol (2%).

The FQD applies to fuels used by road vehicles, non-road mobile machinery (including inland waterway vessels), agricultural and forestry tractors and recreational craft that are not used at sea. Both directives cover road transport and, until now, the national implementation of the RED and FQD targets has resulted mainly in a higher share of renewable energy in road transport (EC, et al., 2015). The FQD does not cover aviation and pipeline transport, while the RED does not include non-road mobile machinery. Only the renewable fuels used in aviation and maritime shipping are covered by the RED (the fossil fuel use of these sectors is not included in the total energy consumption of the transport sector to calculate the 10% target).

Owing to concerns about indirect land use change (ILUC) emissions (see Box 1), the European Commission published a proposal to account for these indirect emissions in October 2012. The final ILUC Directive was published in September 2015 (EU, 2015). It was not possible to reach agreement on inclusion of specific ILUC emission factors (CE Delft, 2015) in the calculation methodology. The current Directive does not therefore introduce emission factors, but instead introduces a cap on the contribution to the RED (and FQD) target that can be made by biofuels from food crops and certain energy crops. Member States are also required to set a sub-target to increase the use of advanced biofuels. Advanced biofuels are considered to be those produced from waste and residues, such as lignocellulose, municipal waste or algae, which all require more advanced conversion technologies.

Box 1: Indirect land use change (ILUC) emissions

ILUC emissions occur when biofuel production takes place on cropland which was previously used for other agricultural production, such as food and feed production. Because this agricultural production is still necessary (as demand does not reduce), the production might be displaced to non-cropland such as grasslands and forests. When these grasslands and forests are converted to agricultural land, additional GHG emissions occur. This process is known as indirect land use change (ILUC).

Despite the focus of the RED, FQD and national policy measures on road transport, there is also a strong need to decarbonise **non-road transport modes**, such as aviation and international and domestic shipping. This is, for example, stressed in the New Climate Economy working paper for the Global Commission on the Economy and Climate (Gengsü et al., 2015), but also in the various policy strategies described in Section 3, such as the 2011 Transport White Paper.

The EU has also invested significantly in **R&D activities** through the Horizon 2020 programme (and its predecessor, the FP7 programme) as have Member States in national research and innovation programmes. The fuel industry and other private actors have also contributed to research programmes. Although production capacity of advanced biofuels has grown, significant further growth is required in order to meet the 2030 and 2050 decarbonisation objectives and induce cost reductions.

While the targets of the 2020 policy framework still need to be met, the European Commission is also developing the **post-2020 framework**. On 22 January 2014, the European Commission set out its vision for the EU climate and energy policy framework up to 2030. This included drastic alterations in the policies that have driven biofuel uptake.

Initially, the European Commission was not in favour of extending the specific 10% transport target beyond 2020. It argued that it is more efficient and effective to have targets in place at the European level as well as a framework for the regulation of fuels and infrastructure, rather than putting these in place at the Member State level. Although this claim has merit, it may very well lead to a drop in the use of biofuels post-2020, bringing decarbonisation targets further beyond reach.

Further details of the post-2020 policy framework were published in the European Commission's so-called Winter Package. This Winter Package included a proposal for a revised Renewable Energy Directive (COM (2016) 767 final/2). See Section 3.1 for more details on the proposed revisions.

Given their various interests, some stakeholders think the proposed revisions are too strict, while others see them as weak and not stringent enough. For example, the overall share of 6.8% renewable energy in 2030 is being criticised, because this is lower than the 10% target for 2020 and will therefore result in replacement of less fossil fuels. Others welcome the shift from the focus on volumes to a focus on sustainability and thus quality, before further increasing the share of renewable energy. The bioethanol industry does not favour the cap on land-based biofuels. They see a role for bioethanol from food crops to sustainably decarbonise the transport sector. They claim that bioethanol on average performs better in terms of GHG reduction potential compared with biodiesel from food crops. Mainly non-governmental organisations (NGOs) argue that land-based biofuels that fall under the cap should be completely banned by 2030. They are therefore not happy with the 3.8% cap in 2030. The variable GHG performance of biofuels is discussed in more detail in the next section.

4.2.2. Variable GHG performance of conventional biofuels

Because biofuels, and especially conventional biofuels from food crops, are currently the most cost-effective way to meet the targets of the RED and FQD, both directives have mainly resulted in a higher share of these fuels. There is, however, much discussion on the GHG performance of biofuels. Their performance varies significantly, depending on the feedstocks used for their production. This is due mainly to differences in the emissions associated with feedstock production and ILUC emissions (see Box 1).

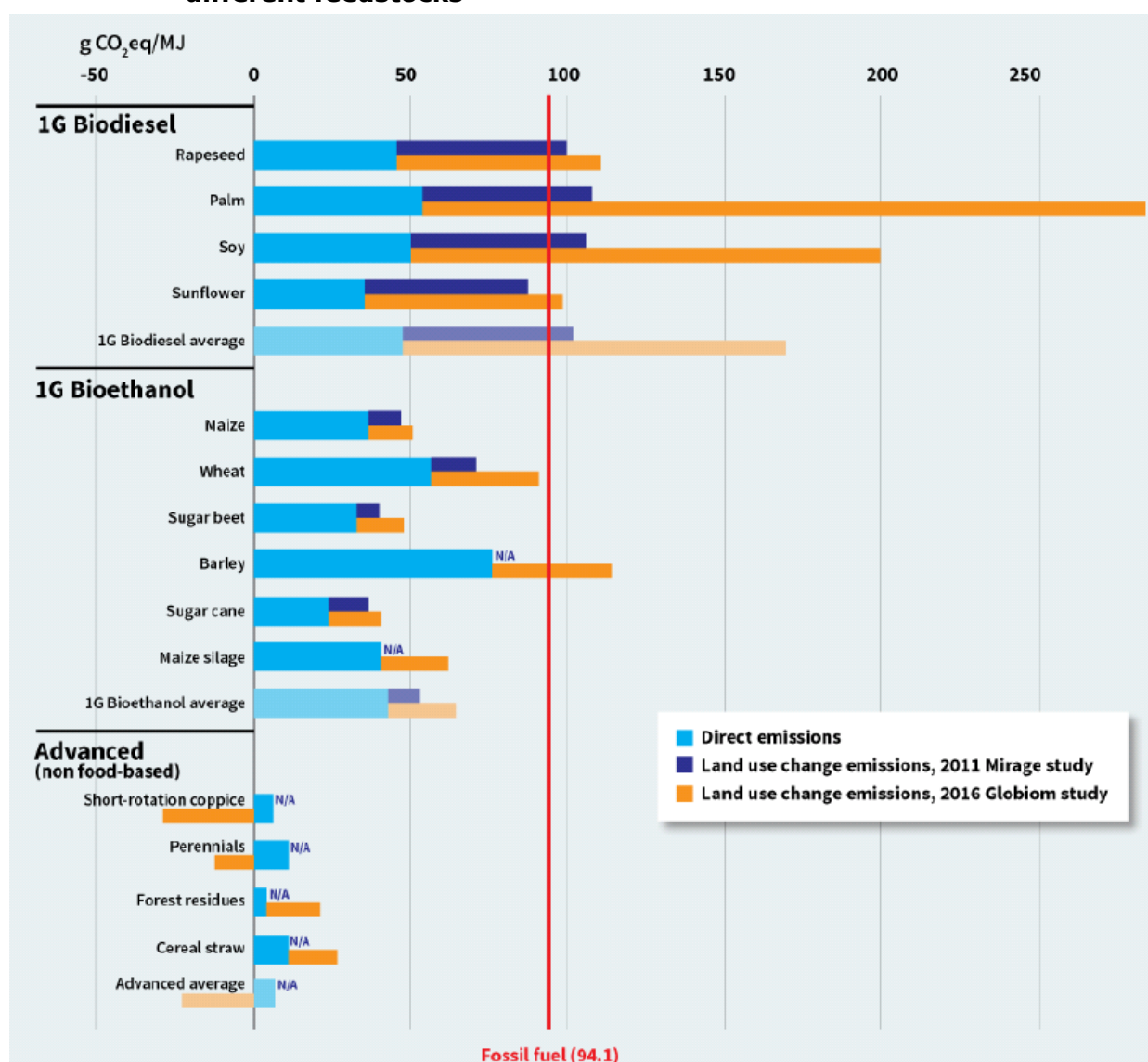
The GLOBIOM study (Valin et al., 2015) by Ecofys, IIASA and E4Tech, one of the leading studies on this subject, shows the variation of the GHG performance of biofuels as a result of ILUC emissions. The total emissions of biofuels are, however, determined by the sum of direct and indirect emissions. T&E has therefore combined the findings of the GLOBIOM study with the direct emission factors included in the Renewable Energy Directive. From this the following conclusions can be drawn (see Figure 12):

Concerning **direct emissions**, which are included in the RED and FQD sustainability criteria, it can be concluded that all commonly used biofuels result in GHG emission reduction compared with the fossil fuel reference (red line). In the case of 1G²⁰ biodiesel and 1G bioethanol, this reduction is about 50%. In the case of advanced biofuels, this can amount to 80 to 90%.

When the **indirect emissions** found in the GLOBIOM study are added, all 1G biodiesel results in an increase of GHG emissions compared with the fossil fuel reference, especially in the case of palm oil and soy. For advanced fuels, the indirect emissions are significantly less or even result in negative emissions. Note that there is no scientific agreement on the exact level of ILUC emissions. Outcomes of scientific studies show a wide range in indirect emissions, as can be seen by the results of the Mirage study, also presented in Figure 12. Owing to this uncertainty, the EC has decided to implement a cap on land-based biofuels rather than introducing emission factors in the calculation methodology.

²⁰ 1G refers to first-generation biofuels, which are mainly produced from sugar-, starch- and/or oil-rich crops and use of which will result in ILUC emissions.

Figure 12: Direct and indirect GHG emissions from biofuels produced from different feedstocks



Source: www.transportenvironment.org/sites/te/files/publications/2016_04_TE_Globiom_paper_FINAL_0.pdf

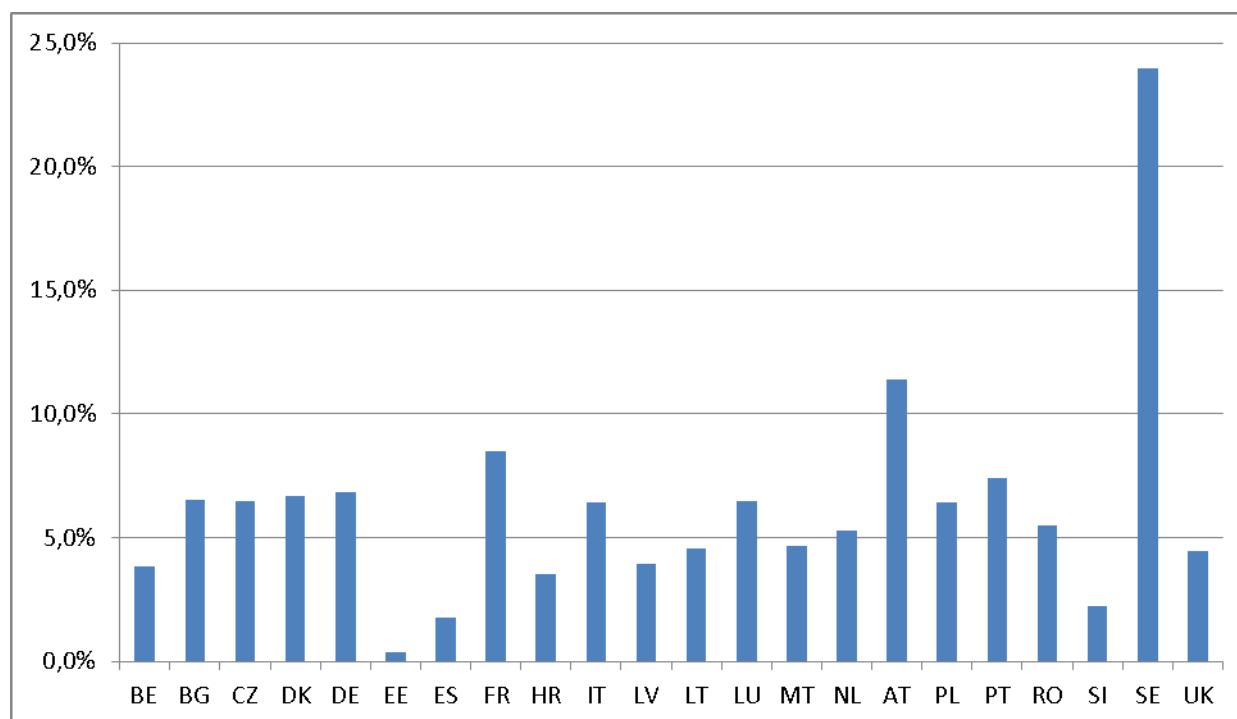
Based on the emission factors found, GLOBIOM defined various scenarios to estimate the overall impact of biofuels on GHG emissions in 2020. Results suggest that implementation of the ILUC Directive would limit the share of food-crop-based biofuels and increase the share of advanced biofuels. Moreover, it can be concluded that the current policy framework on fuel decarbonisation is unlikely to result in any actual emission reduction by 2020.

Efforts have, however, been made to improve the sustainability of biofuels. According to the REFIT evaluation of the RED (CE Delft, Ecologic Institute, Ricardo-AEA, REKK, E-Bridge, 2015), the sustainability criteria laid down in Articles 17-19 of the Renewable Energy Directive have been effective in preventing the direct environmental impacts of biofuel production. This conclusion does not include the environmental impacts of indirect land use change. The sustainability criteria have also proven the feasibility of obligatory criteria at the EU level. However, the sustainability criteria have not been able to provide an incentive to optimise the sustainability level and promote the most sustainable biofuels; they only ensure minimum criteria are met. A study by IEEP states that a new set of sustainability criteria is required, because of the expanding range of feedstocks used for biofuel production and the competing uses of these feedstocks (IEEP, 2016).

4.2.3. Developments of RES-T shares

Although the actual GHG emission reductions induced by existing RES-T policies are lower than expected, the RED and FQD have been effective in increasing the share of biofuels in road transport fuels and in creating a market for biofuels. The average share of renewables in transport was 6.2% in 2015, with the majority of Member States still only halfway towards the 10% target for 2020. Only a few countries have already met the 10% target (Austria and Sweden), as shown in Figure 13 (Eurostat Shares, 2015).

Figure 13: RES-T share in individual Member States (2015)



Source: (Eurostat Shares, 2015).

According to the European Commission's impact assessments for the post-2020 period, deployment of alternative fuels at the current pace will be insufficient to meet the 2030 climate and energy target and the long-term decarbonisation goals of the EU (EC, 2015d). Below we discuss two reasons for the limited uptake of RES-T:

- Market fragmentation as a result of varying growth paths in national implementation.
- Regulatory uncertainty.

Market fragmentation as a result of varying growth paths in national implementation

Differences in national implementation, such as different growth paths, different reporting requirements and different interpretations of definitions (of waste and residues, for example) might limit the uptake of RES-T. Compliance with the RED and FQ targets is further complicated by the large number of different blends on the market. In addition, differences between Member States have increased administrative costs for companies operating in multiple countries. Differences between the RED and FQD in terms of targets and incentives also add to administrative costs.

Regulatory uncertainty

The option included in the RED to modify the sustainability criteria over time has brought regulatory uncertainty (CE Delft, Ecologic Institute, Ricardo-AEA, REKK, E-Bridge, 2015). Among other things, it led to a lengthy decision-making process on the impact of ILUC emissions. As a result, the 2020 and post-2020 Member State policies have not yet been decided upon in many countries. Investments in R&D and biofuel production capacities have consequently been put on hold as long as the uncertainties remain.

In addition, publication of the specific calculation methodology to account for upstream emissions of fossil fuels for the FQD target has also been delayed significantly, thus delaying the introduction of policies that might be needed to meet this target. Although Directive 2015/652, which was supposed to address this issue, was adopted in April 2015, there are still provisions that require clarification by the European Commission and which will further delay implementation. The proposed RED II (see Section 3.1) extends the regulatory uncertainty even more, although it does provide some guidance on likely developments.

4.2.4. Transition towards advanced biofuels

According to the scenario of the GLOBIOM study, food-crop-based biofuels will dominate the biofuel mix until 2020. A shift towards more advanced biofuels is, however, essential for achieving net GHG emission savings and thus actual decarbonisation of transport fuels. Advanced conversion technologies are required to mobilise other sources of (sustainable) biomass that cannot currently be used. These can increase total biomass and thus the availability of biofuels.

The double-counting provision of the RED (Article 21(2)) states that the contribution made by sustainable biofuels produced from wastes, residues, non-food cellulosic material and lignocellulosic material shall be considered twice that of other biofuels. It has proven to be a strong driver for consumption of biofuels from wastes and residues. Although the shares are still limited, they are growing. Examples of Member States with a high share of biofuels from wastes and residues are the Netherlands, the United Kingdom, Italy and Germany (Pelkmans et al., 2014). To date, the double-counting provision has primarily assisted deployment of the inexpensive conversion of used oils, such as UCO (Used Cooking Oil), and waste fats. It has not boosted the production of more advanced biofuels, such as lignocellulosic ethanol (CE Delft, Ecologic Institute, Ricardo-AEA, REKK, E-Bridge, 2015). Because the double-counting provision allows the target to be met administratively, some argue that it had a negative impact on GHG savings, because it results in a lower actual share of renewable energy in transport. The current version of the RED also lacks a clear definition of wastes and residues. This will form a barrier to further investments and correct implementation of the waste hierarchy included in the Waste Framework Directive (2008/98/EC).

The REFIT evaluation and the public consultation held by the European Commission on revision of the RED both highlighted that the uncertainty about the post-2020 policy framework is one of the main barriers for future investments in advanced biofuels. This is particularly true in the case of the capital-intensive production plants needed for advanced biofuels. Without a stable EU policy framework, the required cost reductions will likely not be delivered within the next fifteen years. Note that advanced biofuel technologies, such as ethanol from lignocellulosics, pyrolysis oils, synthetic biofuels, biofuels from algae, biofuels from microbial conversion and other renewable fuels such as power-to-gas and power-to-liquid fuels are already *technologically* deployable on a commercial scale.

4.2.5. Future biofuel potential and use in different modes

Accurate estimates of sustainable biomass availability and the exact quantities of biomass that will be available for biofuel production in the coming decades are difficult to give, because

of the many determining factors involved. Overall, the availability of future advanced biofuels will be influenced by the following developments:

- **Availability of sustainable feedstocks:** the amount of sustainable biomass feedstocks is likely to be limited. In addition, in the case of waste-based biofuels the feedstocks may become more limited over time as a result of policy focused on the reduction of waste and on the reuse and recycling of resources.
- **Developments in (advanced) conversion technologies:** if technological developments enable easier conversion of, for example, woody biomass, biomass availability for biofuels could increase. The learning rates and efficiency gains achieved by these technologies are also important in this respect. In addition, there are potential technological developments in relation to biorefinery concepts, where the production of biofuels can be combined with the production of other biobased products. In this way, all fractions of the feedstock can be used, improving economic viability.
- **Stricter sustainability criteria,** on the other hand, will limit biomass availability, because less biomass will be labelled as sustainable. This can be illustrated by the implications of the implementation of the ILUC Directive and the further lowering of the cap over time as proposed in the new Renewable Energy Directive, which will limit 1G biofuel potential in the future.
- **Demand for sustainable biomass by other sectors** might result in competition between sectors for the same amount of biomass. A more integrated policy approach is therefore required to regulate the most efficient use of biomass. As stated before, biorefinery concepts can result in synergies between the various sectors.
- **Higher efficiencies of transport modes and efficiencies on the demand side** mean that more can be done with the same amount of biomass. This would increase the share of biofuels compared to other fuels used in transport (for a given level of production).

Different transport modes can compete for the available biomass. For example, biofuels in road transport might be the preferred option in terms of costs, but for other modes (notably aviation and shipping) biofuels might be the only RES-T option that is technologically viable.

Various sources argue that priority should be given to the use of biofuels in aviation and shipping, because the use of electricity and hydrogen will not be an option for these long-distance modes. Biofuels are currently seen as the only alternative for aviation and probably also for maritime and inland shipping. For road transport, the argument is often made that especially urban transport and light duty vehicles should be electrified, since this is more complicated for heavy duty vehicles used for long-haul transport. Furthermore, electrification of urban transport can offer both CO₂ reductions and a reduction of air pollutants and noise emissions, which are additional benefits in urban areas where air quality problems occur more often compared with non-urban areas and where poor air quality can do more harm because of denser populations.

4.2.6. Other renewable fuels and energy carriers for use in different modes

Besides biofuels, other renewable fuels and energy carriers might also play increasingly important roles in the coming decades. Wind and solar energy will become more important because of the limited availability of sustainable biomass feedstocks and the sustainability risks associated with biomass production. Without them the required decarbonisation levels are unlikely to be achieved. Their development and deployment is linked to the uptake of electric and hydrogen vehicles and to the development of charging and fuelling infrastructure

for these vehicles. The policy framework should also be geared towards developing power-to-X products (power-to-gas, power-to-liquid), which can be produced from (surplus) wind and solar power. Power-to-X products can be a solution for the transport modes that cannot be electrified in the short-term, such as heavy goods vehicles, aviation and maritime shipping.

To this end, a number of policy actions will be required in the coming years, most notably to address the following:

- Additionality of renewable energy production. For example, it can be questioned to what extent excessive electricity use in transport actually contributes to overall decarbonisation, since the RES-E can also be used in stationary applications, at lower cost and higher energy efficiencies.
- Adequate integration of EVs in the electricity system. There are various opportunities to benefit from synergies between the electricity sector and the transport sector, such as avoiding the need for grid expansion if RES-E is used locally, i.e. close to the production location, and by implementing smart charging that responds to the variation of electricity production over time.
- Support to R&D of renewable fuel production from large-scale solar/photovoltaic (PV) and wind farms, aiming for cost reductions and efficiency improvements.

Some of these points have already been mentioned in the high-level policy strategies of the European Commission, such as in the Energy Union package.

Note that, as with sustainable biomass, there will also be demand from other sectors for the RES-E that is produced, including the surplus energy at times of peak energy production: there will be more market actors keen to benefit from periods of low electricity prices. Likewise, renewable fuels produced using power-to-X technologies can also be used for decarbonising other sectors, for example as a replacement for natural gas in industry, for power generation in times of low wind and solar energy production and for heating in the built environment – all applications that could potentially induce significant demand for renewable liquid or gaseous fuels in a low-carbon, renewable energy system.

4.3. Efficiency of the transport sector

KEY FINDINGS

- There are a wide variety of measures that can **potentially increase the efficiency** of the transport sector, such as speed limits, environmental zones, energy taxation based on CO₂, road charging and spatial planning policy. Combined, these can contribute to meeting long-term climate goals. However, policy options aimed at improving the efficiency of the transport system are necessarily the responsibility of regional and local authorities. The EU could nevertheless look for ways to **encourage Member States to embrace these measures** more widely.
- Increasing logistic efficiency in freight transport **has significant potential** to reduce CO₂ emissions. Efficiency gains of up to 20% are feasible in the long run (2050), without structural changes in the logistics sector. The **promotion of C-ITS** is important in this respect, to offer better information on the location and timing of vehicles and shipments and options for cooperation.
- Adding or expanding infrastructure such as roads and airports **typically increases transport demand**, since it reduces transport cost and time. Decisions on infrastructure investments should therefore be more **closely integrated with climate** policies.

- Energy taxation based on CO₂ is **an efficient way** of reducing GHG emissions. The current minimum levels in the Energy Taxation directive **should be higher**.
- Modal shift policies can potentially reduce GHG emissions. However, it is **uncertain** how much EU policies have delivered in the past in terms of GHG emission reduction.
- Infrastructure policies that aim to promote more energy-efficient modes and reduce GHG emissions should be **carefully evaluated** prior to implementation to ensure there are net environmental benefits.
- Considering that decisions on infrastructure and spatial planning will have an impact on how transport is used **over many decades**, the linkage between these policy areas should be **an integral part** of GHG emission policy.

This section describes a series of policies and measures to improve the overall efficiency of the transport sector. Although it is difficult to give a comprehensive definition, under this heading we mean measures that, in some way or form, directly influence transport demand, vehicle use and/or modal split. There are various ways to do this. One way is to improve and expand transport infrastructure. More roads, railways, airports and shipping routes increase network capacity and the options for passengers and freight to reach their destinations. Increasing capacity may mean a trade-off with environmental and climate goals: increased transport infrastructure capacity may result in increased transport demand (EEA, 2017b). An increase in transport volumes will lead to higher energy consumption in the transport sector and unless the energy carriers are decarbonised (see Section 4.2) the result would be an increase in CO₂ emissions.

This increase in CO₂ emissions can be limited, however, if more energy-efficient transport modes are favoured over less energy-efficient ones. In terms of tonnes of goods transported, rail freight transport, for example, is less energy-consuming than road transport (CE Delft, 2017). Infrastructure investments that encourage a *modal shift* from road to rail may therefore lead to GHG reduction (see Section 4.3.1).

Pricing is another option for increasing the efficiency of the transport system. Although there are many different forms of pricing, the general principle is that it increases the efficiency of use of infrastructure networks, as it discourages parties with relatively low added economic value from using the network, allowing for shorter travel times for those businesses and individuals with the highest economic added value (see Section 4.3.2).

Other ways to improve the efficiency of the transport system are ITS (intelligent transport systems), spatial planning policy, environmental zones and speed regulation (see Section 4.3.3).

Many of the policy options aimed at improving transport system efficiency are necessarily the responsibility of regional and local authorities. The principle of subsidiarity also ensures that EU policy is only developed where it is appropriate to do so. As a result, there are limited actions that might be taken at the European level to increase efficiency (although there may be a need for the harmonisation of regional/national initiatives at EU level, to minimise the costs for transport users and avoid any unequal treatment of European citizens). These measures should nevertheless not be excluded from the policy overview in this report. Our aim is to cite all potentially effective measures to reduce transport GHG emissions, regardless of subsidiarity issues.

4.3.1. Infrastructure investment and modal shift

TEN-T

In 2009, the Green Paper *"Towards a better integrated trans-European transport network at the service of the common transport policy"* was published. It was the start of an extensive review process of the entire TEN-T (Trans-European Transport Networks) programme that started in the early nineties. It resulted in the current transport infrastructure policy adopted in December 2013. New to the infrastructure policy is the specific mention of sustainable growth and the combating of climate change, besides its primary aim of closing the gaps between Member States' transport networks.

Not much is known about the effects of TEN-T infrastructure investments and increased network capacity on GHG emissions in the EU (AEA, CE Delft, TNO, 2012). In general, additional network capacity will lead to additional traffic owing to so-called 'latent demand'. Roadway improvements that alleviate congestion reduce the generalised cost of driving (i.e. the price), which encourages more vehicle use. Put another way, most urban roads have latent travel demand, in the form of additional peak-period vehicle trips that will occur if congestion is relieved (VTPI, 2017). Estimates of the elasticity of increased road capacity range from 0.2 in the short-term to 0.8 in the long-term (Goodwin, 1996). This means that a 1% increase in road capacity leads to a 0.2 to 0.8% increase in road traffic. All other things being equal, this would mean a similar increase in CO₂ emissions.

Modal shift

In the present context, modal shift refers to policies that promote the use of energy-efficient transport modes, either passenger or freight. The extent to which modal-shift policies can aid in reducing CO₂ emissions depends on the suitability of the mode for the trip at hand. Needless to say, aircraft are by far the most superior mode for intercontinental passenger travel, inland ships are unsuitable for just-in-time and door-to-door deliveries and bicycles are most convenient for trips not generally exceeding 15 to 20 kilometres. Policy action to promote modal shift can be directed either towards creating additional or better infrastructure for energy-efficient modes, improving the (perceived) quality of energy-efficient modes (e.g. access to Wi-Fi in public transport, shorter door-to-door travel times) or incentivising/demoting the use of energy-efficient/inefficient modes through pricing. In this section we focus on modal shift through infrastructure investments.

The 2011 transport White Paper includes a number of objectives aimed at 'Optimising the performance of multi-modal logistic chains'. It specifically states that the use of energy-efficient modes should be encouraged in order to contribute to CO₂ emissions reduction. Policy initiatives aimed at changing the share of modes in passenger and freight transport are referred to as modal-shift policies.

The White Paper signals a direct link between modal shift and transport infrastructure investments (EEA, 2017b) and has set ambitious goals, including (EC, 2011c):

- 30% of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50% by 2050, facilitated by efficient and green freight corridors. To meet this goal will also require appropriate infrastructure to be developed.
- By 2050, complete a European high-speed rail network. Triple the length of the existing high-speed rail network by 2030 and maintain a dense railway network in all Member States. By 2050, the majority of medium-distance passenger transport should be by rail.
- A fully functional and EU-wide multi-modal TEN-T 'core network' by 2030, with a high-quality, high-capacity network by 2050 and a corresponding set of information services.
- By 2050, connect all core network airports to the rail network, preferably high-speed; ensure that all core seaports are sufficiently connected to the rail-freight and, where possible, inland-waterway systems.

Among the policies designed to encourage modal shift were the Marco Polo programme, which provided financial support to projects aiming to shift the transport of goods from road to other modes. Modal shift was also promoted by the three Railway Packages and the recast of the Interoperability Directive. Their collective aim was to encourage development of the internal market in rail transport by opening it up to regulated competition and by eliminating operational barriers. Finally, there have been initiatives to promote inland navigation through the so-called NAIADES I and II packages. These included measures that lower the regulatory burdens on the sector (EEA, 2015).

The impacts of the first Marco Polo programme are not fully clear. According to the European Commission, the modal shift realised in terms of distance of goods transported amounted to 21.9 billion tonne-kilometres (where a total shift of 47.7 billion tonne-kilometres (tkm) was targeted). For Marco Polo II, a shift of 87.7 billion tkm was expected.²¹ These claimed effects of the Marc Polo programmes are in contrast with the findings of the European Court of Auditors (ECA), who argued that the impact of both programmes on modal shift has been small (ECA, 2013). The ECA also concludes that the audited projects were of limited sustainability and they questioned whether the projects would have been carried out without EU financial support. The European Commission has disputed the ECA's findings (EEA, 2014).

A recent comparison of the environmental impact of different freight modes concluded that, for container transport, the well-to-wheel GHG emissions of rail are approximately six times lower for electric trains and three times lower for diesel trains compared with long-haul road vehicles (CE Delft, 2017). For bulk freight transport, the differences are a factor eight to four, respectively. (AEA, CE Delft, TNO, 2009) also give preliminary indicative estimates for the overall GHG reduction potential of modal shift for passenger transport ranging from 2 to 14%. These percentages apply to a shift from road to rail transport. The shift from aviation to rail transport has the potential to reduce GHG emissions from passenger transport by a few percent. For freight transport, GHG reduction in the range of 4 to 23% of total freight transport GHG emissions has been found, with most of the estimates being at the lower end of this range (AEA, CE Delft, TNO, 2009). It seems unlikely that the current EU policies are sufficient to harvest these potentials. (Ricardo-AEA, 2014) find no evidence that EU infrastructure charging policies have had an effect on modal shift since 1995.

²¹ As some projects will be running until 2020, no evaluation can yet be made of the actual achievements (EEA, 2014).

Others have argued that modal shift should not be a policy goal in itself. It would seem clearer to design and evaluate transport policy proposals directly on their possible contributions to meeting desired economic, social and environmental end goals using techniques like societal cost-benefit analysis and strategic environmental impact analysis (MNP, 2005). An example of such an integrated approach on 'sustainable mobility' can be found in the communication COM(2013)913 on Sustainable Urban Mobility Plans (see below).

Spatial policy (urban planning and infrastructure policy)

Spatial planning and land use are closely interlinked with infrastructure investment decisions. The primary aim of building a new road or railway is to increase the speed with which people and goods can get from A to B. Speed is not the only parameter that impacts the efficiency of the infrastructure network, however. Accessibility is also determined by the distance over which people and goods need to be transported. This means that reducing distances through spatial policies can add to the efficiency of the transport system, while at the same time it may reduce GHG emissions due to a drop in transport demand.

A major driver of spatial development and land use is urbanisation and urban sprawl. Over the past 50 years the urban population has grown steadily, with the strongest increase in towns and suburbs and in newly developed residential areas surrounding existing cities (EEA, 2016d). Basically, urban sprawl has led to the migration of people from densely populated areas (cities) to towns and settlements with a lower density around the major cities. This process has been fuelled by many factors, including a decrease in comparative costs, an increase in household income and the rapid growth of private car ownership (EEA, 2016d). It is expected that urban sprawl will be a continuing process in the future. Urbanisation is expected to lead to further pressure on air quality, noise levels, safety and liveability in general. These challenges are additional to the increasingly stringent climate goals, which may dramatically alter (urban) transport. It is safe to say that cities will play an important role in the transition towards sustainable transport. Sustainable Urban Mobility Plans (SUMPs) can function as an important tool in this respect (see next section).

The trend towards greater urban sprawl has led to increased travel, with adverse effects on transport GHG emissions. (Geurs & Wee, 2006) have shown that policies to counteract urban sprawl in the Netherlands have reduced the number of kilometres driven by approximately 2 to 3%. Examples of policies to prevent urban sprawl are increasing the density of cities (ensuring that homes and jobs are closer together) but also the abolition of subsidies to compensate for commuting expenses (Geurs & Wee, 2006); (EEA, 2015). (Banister, 2011) argues that travel distances have not received sufficient attention in spatial policy and infrastructure planning, even though reducing travel distances is key to achieving sustainable transport. Spatial policies that counteract urban sprawl and promote the density of urban areas, combined with development of housing and jobs in greater proximity to one another, can in theory reduce travel demand and therefore contribute to the decarbonisation of EU transport. Promoting the use of public transport and cycling in these spatial policies can also help decarbonisation.

Although in theory the contribution to decarbonisation of spatial planning policies that reduce travel distances is plausible, there is limited concrete, quantitative evidence that urban planning and infrastructure development can contribute to GHG emission reduction (AEA, CE Delft, TNO, 2009).

With respect to the subsidiarity principle, spatial planning and urban transport policies are largely considered the responsibility of Member States. However, the EU aims to support and facilitate sustainable developments in that area, through a number of papers and communications. In 2006 the European Commission published a Thematic Strategy on the Urban Environment (COM(2005)718 final). Furthermore, in 2014 the 7th Environmental

Action Programme (EAP) entered into force. One of the priority objectives of the programme is "to make the Union's cities more sustainable". The overall objective of this policy drive is to enhance the sustainability of EU cities to ensure that by 2050 all Europeans are "living well, within the limits of the planet" (see: http://ec.europa.eu/environment/urban/index_en.htm).

Nevertheless, the interaction between the TEN-T programme and the Urban Development programme mentioned above seems to be limited. In view of the strong linkage between these policy areas and the GHG emissions of transport, and specifically considering that decisions on infrastructure and spatial planning will have an impact for many decades, the linkage between these policy areas should be an integral part of GHG emission policy (CE Delft, 2012).

SUMPs and CIVITAS

In 2013, the European Commission published its communication on Sustainable Urban Mobility Plans (COM(2013)913). Sustainable Urban Mobility Plans (SUMPs) aim to improve the accessibility of urban areas and provide high-quality and sustainable mobility to, through and within the urban area. They also specifically aim to contribute to achieving the European climate and energy targets. The European Commission started promoting SUMPs through the 2009 Action Plan on Urban Mobility and the 2011 Transport White Paper (Rupprecht Consult – Forschung und Beratung GmbH, 2014).

The Commission has developed guidelines to provide local authorities with a clear framework for the development and implementation of such plans. Member States need to promote these practices at the national level and ensure appropriate legislative and support conditions for their local authorities (EC, 2017c). Funding for SUMPs is available through European Structural and Investment Funds and Horizon 2020, as well as other financial instruments (Eltis, 2017).

Related to SUMPs, and supported by Horizon 2020, is the CIVITAS Initiative, which helps cities across Europe to implement and test innovative and integrated strategies that address energy, transport and environmental objectives.

Typical measures that are part of SUMPs and which have gained much attention from local authorities in the past few years include environmental zones, car-sharing schemes (optimisation of vehicle utilisation), encouraging cycling, public transport and low-emission vehicles and spatial policies (see above).

4.3.2. Pricing

The 2011 Transport White Paper states that Europe's transport charges and taxes must be restructured so that the 'polluter pays' and 'user pays' principles are followed more closely. In other words, the White Paper advocates "to have user charges applied to all vehicles and on the whole network to reflect at least the maintenance cost of infrastructure, congestion, air and noise pollution", in order to align market choices with sustainability requirements (EEA, 2015).

There are several pricing instruments, sometimes also referred to as economic instruments, through which these principles can be adhered to. We here distinguish:

- fuel taxes;
- kilometre and congestion charges and tolls;
- parking fees;
- vehicle purchase and circulation taxes (see Section 4.1.1);
- emission trading scheme (ETS);
- excise duties and VAT for aviation (see Section 4.1.3).

The implementation of pricing policies is mostly left to the Member States, although the European Commission provides certain instruments and legal frameworks to ensure the functioning of the internal market (e.g. Eurovignette Directive, Energy Taxation Directive). Furthermore, the Commission is involved in promoting pricing policies through several directives and communications. The following subsections highlight these initiatives and how they might be developed; it also considers the (possible) impact on GHG emissions of pricing policies.

Fuel taxes

Road transport fuels are taxed in all European countries, mainly for fiscal reasons (CE Delft, 2010). In accordance with the Energy Taxation Directive (2003/96/EC) all Member States are obliged to have fuel taxes at a certain minimum level or higher; there is no maximum value. Fuels for international aviation and maritime shipping are not subject to taxes because of international agreements (see also Section 4.1.3).

The most recent proposed revision of the Energy Taxation Directive was withdrawn. The proposal aimed at “restructuring the way energy products are taxed, namely by taking into account both their CO₂ emissions and energy content. The objective was to promote energy efficiency and consumption of more environmentally friendly products and to avoid distortions of competition in the Single Market” (EU, 2014). In the proposal, the minimum level of fuel levies for diesel are to be increased in a stepwise approach so that it finally became higher than that for petrol. This is due to the lower energy content of diesel compared with petrol. Individual Member States would have retained the right to impose higher levies than the proposed minimum levels.

Since fuel taxes increase the cost of transport, they create an incentive to use less fuel. Short-term fuel savings result from reduced driving, a more fuel-efficient driving style and a shift towards use of the most fuel-efficient vehicles in multi-vehicle households. Over the long-term, higher fuel prices encourage consumers to purchase more fuel-efficient vehicles and reduce vehicle-kilometres by changing house or job, resulting in shorter commuting distances. Increasing fuel taxes can therefore contribute to meeting GHG targets (CE Delft, 2010). The impact of fuel taxes on GHG emission reductions obviously depends on the level of the increase. In general, a fuel price increase of 10% will result in the long-term in a 6 to 8% decrease in GHG emissions (PBL and CE Delft, 2010).

Currently, fuel taxes in the EU are on average substantially higher than electricity charges. This is an implicit incentive for the adoption of electric vehicles, which will add to the required transition to zero-emission vehicles (see Section 4.1). However, as the share of electric vehicles will increase, tax revenues from fossil fuels will decline and will not be compensated for by an increase in revenues from electricity charges. To prevent budget deficits, a different approach to maintaining government revenues from transport is likely to be required. Some form of kilometre charging (see next subsection) may well be appropriate.

Infrastructure charging (tolls, kilometre and congestion charges, vignettes)

Different types of infrastructure charging exist. A kilometre charge typically refers to a country-wide distance-based charge, or at least a charge that applies to a substantial portion of a country's road network, e.g. all motorways. Congestion charges apply only at certain times and on selected roads when congestion is high. Tolls usually refer to a system where the use of certain roads, tunnels or bridges is charged for. Finally, vignettes are time-based road charges applied on (part of) a national road network. These all have in common that they increase travel and transport costs and, in that sense, reduce transport demand, which consequently has an effect on GHG emissions. Unlike fuel taxes, however (see previous subsection), tolls, kilometre and congestion charges and vignettes do not create incentives for fuel-efficient vehicles unless tariffs are differentiated based on vehicle CO₂ emissions (CE Delft, 2010). Because of the scale of implementation, distance-based kilometre charges are the most effective of all these instruments in terms of reducing transport GHG emissions.

The Eurovignette Directive (Directive 1999/62/EC, amended by Directive 2006/38/EC and Directive 2011/76/EU) lays down the rules under which Member States can charge heavy goods vehicles for the use of road infrastructure (EEA, 2015). Since the 2006 and 2011 amendments, the Directive allows Member States to differentiate charges according to air pollution, noise and congestion. Differentiation according to CO₂ emissions is currently not allowed. However, the Commission recently proposed to broaden the scope of Directive 1999/62/EC (to include coaches and light vehicles) and to differentiate charging according to CO₂ emissions performance²².

Through COM (2013) 913 (Together towards competitive and resource-efficient urban mobility), the EC promotes road user charging to improve the accessibility and liveability of urban areas. The EC acknowledges that a fully harmonised European approach for road user charging is not appropriate "because it is crucial that the design and implementation of such schemes can be tailored to the specific situation in each urban area." Nevertheless, non-binding guidelines could aid Member States in implementing effective and efficient schemes, particularly when experiences from others are included.

Many countries have adopted motorway road tolls and/or road pricing schemes for heavy-duty vehicles. There is little evidence available on the effects of these pricing schemes. Based on Eurostat data, De Jong et al. (2010) conclude that in Germany, where a kilometre dependent Maut was introduced in January 2005, the average distance over which goods are transported did not increase over the period 2005 to 2008. In Austria, there has been a noticeable decrease in distances travelled. Moreover, a limited shift to rail has been reported (De Jong et al., 2010). Overall, studies estimate the impact on kilometres driven as being between 3 and 15% (MNP, 2007); (Ecorys; MuConsult, 2007); (CE Delft, 2009); (Significance; CE Delft, 2010); (TML, 2009). Furthermore, the network-wide tolls differentiated by Euro class in Germany are thought to have had a significant effect on the use of cleaner vehicles (Ricardo-AEA, 2014).

To date, no Member State has adopted a country-wide distance-based road pricing scheme for passenger car transport. However, the Netherlands has considered implementing a kilometre charge and came close to actual implementation, but it was ultimately abandoned in 2010. The proposed system was subjected to a Societal Cost Benefit Analysis in which many different pricing schemes were assessed, including several with differentiation according to the environmental performance of vehicles. In a comparison of different schemes (MNP, 2007) it was concluded that the emissions from passenger car transport (including GHG emissions) would drop by 10 to 20%, mostly as a result of a reduction in the number of kilometres driven. In more recent work, CPB and PBL have concluded that despite

²² COM(2017) 0275 and COM(2017) 276 of 31.5.2017.

an approximately 10% reduction in traffic volumes, the societal benefits of a nation-wide distance-based fee would not exceed the societal costs (CPB and PBL, 2015). This is primarily the result of increased costs, which lead to fewer kilometres being driven and consequently welfare losses due to reduced accessibility.

There are several examples of cities that have adopted congestion charging. Well-known examples are London, Stockholm, Milan and Singapore. The reduction in car traffic amounts to 15-20% in all four cities (Li and Hensher, 2012), with use of public transport increasing substantially. No figures on the impact on GHG emissions were found, but the relatively small scale on which these congestion charging schemes have been implemented imply that GHG emission reductions will be limited.

Parking fees

Parking fees can have a significant impact on travel demand. If they are applied on a large scale (and not just in a few cities), parking policies can be potentially effective in reducing car use and energy consumption (CE Delft, 2010). However, CE Delft estimates that of the 95% of employees who commute by car, only 5% pay full parking costs, while 9% pay a subsidised rate, the remaining pay no parking costs. Furthermore, parking is unpriced for over 98% of non-commute trip destinations (CE Delft, 2010).

Even modest parking fees can affect travel patterns. A 10% increase in parking fees can lead to a 1 to 3% reduction in travel demand depending on demographic, geographic, travel-choice and trip characteristics (CE Delft, 2010). There are no studies that report effects on CO₂ reduction through parking schemes. However, if applied to a larger region, the reduction in kilometres mentioned above is likely to result in roughly the same reduction in vehicle emissions, including GHG emissions. Particularly in urban areas, parking fees can be an element in an overall strategy for limiting car use, limiting overall transport growth and stimulating a shift to other transport modes (cycling, walking, public transport) (CE Delft, 2010).

It stands to reason that parking policies should be integrated into SUMPs (see Section 4.3.3). The European Commission can initiate research into the effectiveness of different parking schemes and include them in the guidelines drawn up for SUMPs.

ETS for road transport

A specific instrument which can be viewed as a pricing policy is an Emission Trading Scheme for (road) transport (ETS for shipping and aviation are discussed in Section 4.1). Subjecting the transport sector to emissions trading would incentivise carbon-saving behaviour in all its aspects, such as fuel carbon intensity, fuel economy in cars, driving behaviour and demand for vehicle miles travelled. This is different from the setting of technology or fuel standards, for example, which focus on one aspect of transport only. Simultaneously, the very nature of an emissions trading scheme stimulates continuous innovation, in contrast to the setting of standards.

In essence, there are two ways in which road transport could be subjected to CO₂ trading:

- inclusion in the existing European ETS;
- a separate trading scheme for road transport.

According to CE Delft (2014), the inclusion of road transport²³ in the EU ETS would provide a financial incentive to end-users to reduce fuel consumption and thereby emissions. The precise impacts would depend on the allowance price. Assuming a price range of € 20–40

²³ The study looks at total transport but defines road transport as comprising over 95% of total transport emissions. This entails that the conclusions drawn will hold for both road transport and the transport sector as a whole.

per tonne of CO₂, average EU retail prices would result in a reduction of transport emissions by 3 to 5% in the long-term (CE Delft, SQ Consult, Cambridge Econometrics, 2014) (Cambridge Econometrics, 2014). ICCT (2014) concludes that in order to reach a similar level of technology innovation as expected for the EU's 2021 CO₂ target of 95 g/km, a price of about € 370 per tonne of CO₂ would be required. Cambridge Econometrics (2014) arrives at lower costs and shows that, "in order to achieve the level of emission abatement in the road transport sector required meeting the EU's long-term goals (approximately 60g/km for cars in 2030), an average carbon price of € 217/tCO₂ would be required over the 2020-2030 period". Nevertheless, it is clear that in order for the EU to achieve the targets set for the transport sector using the ETS alone, extortionate prices for emission allowances are required. The price signal that the EU ETS currently delivers is too weak to achieve the reductions required (Transport & Environment, 2014).

A major concern regarding inclusion of road transport into the existing EU ETS is the feasibility of harmonised monitoring, reporting and verification (MRV) standards between the industry and transport sectors. It might prove harder to monitor road transport CO₂ emissions compared with those from the fixed installations in industry. Given that it may be difficult to impose the same type of MRV standards on road transport as those that must be complied with by other sectors under the EU ETS, it is unlikely that an emission unit from the transport sector would be fully comparable with an emission unit from another sector (Desbarats, 2009). This concern would not be an issue in a separate ETS for road transport.

One concern with a separate ETS system for road transport are the high allowance prices needed to incentivise the desired reductions (Swedish Environmental Research Institute, 2006).

(CE Delft, 2006) conclude that if end consumers are the trading entity, transaction costs may be very high. Similarly, (Institute for Public Policy Research, 2006) recommend making the fuel suppliers the trading entity, as a relatively small number of companies account for almost all the road fuel supplied, resulting in relatively low transaction costs for the scheme.

Finally, numerous authors have concluded that emission trading alone will be insufficient to achieve very substantial GHG emission reductions and that an ETS should be complemented by other measures (Iankov & Zito, 2008; Stanley et al., 2011; Institute for Public Policy Research, 2006)

All in all, emission trading in either form could put the EU on a path towards decarbonisation of the transport sector. The inclusion of road transport in the EU ETS would be more efficient than a separate trading scheme. However, the effectiveness in terms of GHG emission reductions of a separate system is far greater. In the long-term, a well-functioning global system in which all sectors pay an equal price for CO₂ emissions and which includes a cap that ensures climate targets are met seems to be very efficient and fair. Nevertheless, such a large-scale trading system is currently far from realisation and it is questionable whether Europe, at this point in time, should actively pursue this goal.

Car-sharing

A shift from an ownership-based to a sharing-based system for car use is gaining in importance in European cities, accompanied by a strong resurgence in cycling and walking (EEA, 2016d). These developments have gained momentum through Information technologies (IT) that allow both companies and citizens to share and find vehicles through the internet. Apart from car-sharing, there are also other forms of 'shared mobility', such as ride-sharing and on-demand ride services such as Lyft and Uber. The working principle underlying car-sharing and shared mobility is to reduce the under-use of vehicles. When in

use the occupancy rates of cars are low, and they are not used at all for a substantial part of the day.

Car-sharing may lead to environmental benefits on three levels. First, fewer cars need to be produced, which saves on the materials and energy required for vehicle production. Second, users of shared cars are more directly confronted with the costs of individual trips, which may lead to reduced car use. Finally, since shared vehicles are used more often, they will be written off faster, leading to more rapid replacement of older, less energy-efficient (and more polluting) cars by new vehicles (EEA, 2016d); (Firnkorn & Shaheen, 2015). Car-sharing may, however, also lead to increased emissions if people who do not own a car start using cars where previously they used public transport or cycled. From the perspective of sustainable cities, increased urban car travel would seem less favourable than an increase in public transport, walking and cycling. In the long-term, though, if electric driving could be combined with automated vehicles, car-sharing could even replace local bus and taxi services (ITF, 2016).

4.3.3. Other measures

ITS

In the Action Plan for the deployment of ITS in Europe, the European Commission sees an important role for Intelligent Transport Systems (ITS) in order to further green transport, improve transport efficiency, transport safety and security, by applying various information and communication technologies to the various modes of passenger and freight transport (EC, 2008a). Furthermore, the Commission expects ITS to significantly contribute to improving the competitiveness of European industry (European Commission, 2016), resulting in the creation of additional jobs and turnover. The Action Plan identifies four priority areas:

- optimal use of road, traffic and travel data;
- continuity of traffic and freight management services;
- ITS road safety and security applications;
- linking the vehicle with transport infrastructure.

The European Commission is working to find common solutions for Intelligent Transport Systems within a European framework. In 2010, Directive 2010/40/EU was adopted. It set the framework for how deployment of Intelligent Transport Systems in the field of road transport should interface with other modes of transport.

The European Union is promoting the ITS Action Plan in a variety of ways, including through 'Horizon 2020'. In 2016, a European Strategy specifically for Cooperative ITS (C-ITS) was launched, with a stronger focus on accelerated deployment of automated and connected vehicles that 'cooperate' with one another. This cooperative element is expected to increase the contribution of ITS to the four priority areas given above. In addition, these digital technologies can support the realisation of a truly integrated multimodal transport system, which will increase logistics efficiency and allow people and cargo to travel smoothly and efficiently from origin to destination.

There is a wide range of ITS services that can contribute to reducing GHG emissions, from cooperative traffic lights to the platooning of trucks on major roads. The ITS Mobility Forum (ITS Mobility Forum, 2013) provides an overview of ITS services that contribute to clean and efficient mobility. Services with a GHG emissions reduction potential of over 10% include on-

trip eco-driving support, cooperative traffic lights, synchromodality²⁴ and dynamic trip-planning schemes.

Speed limits

Lowering speed limits on motorways and provincial roads can be an effective way to reduce CO₂ emissions, although traffic safety is usually the main driver. There are several reasons why lower speed limits reduce CO₂ emissions (CE Delft, 2010):

- At lower constant speeds, vehicle fuel consumption is lower (for most vehicles optimal fuel efficiency is at speeds around 70-80 km/h). A speed reduction from 100 to 80 km/h reduces the CO₂ emission per kilometre by approximately 6%. However, reducing speed from 120 to 100 km/h reduces CO₂ emissions by almost 9% (TNO, 2015). The non-linear effect is explained by air friction, which increases exponentially with speed.
- The number of kilometres driven decreases. This is because at lower speeds trip duration increases. People generally value time savings, which means that increased travel times are valued negatively. This creates an incentive to seek shorter travel times, for example by looking for a different job closer to home or moving closer to the workplace. People may also choose to use a different mode (train or bus), with lower CO₂ emissions per kilometre than car transport, to reach their destination.
- At lower speeds road capacity increases, since the distance between vehicles can be smaller. On the one hand, a decrease in congestion reduces CO₂ emissions, since there will be less acceleration and deceleration of vehicles, both of which are relatively energy-inefficient. On the other hand, reduced congestion allows for higher average driving speeds, which increases energy consumption.

Although reducing speed limits is an effective way to reduce CO₂ emissions, there are considerable negative side-effects. Most significant are the increased travel times, which reduce accessibility.

Generally speaking, it is local and regional road authorities that determine the speed limit on a particular road, within a framework set at the national level. Current speed limits vary across Member States. The application of variable speed limits related to traffic and weather conditions also varies across Member States (EC, 2017d).

Closely related to this measure are the use of speed limiters on HDVs. Directive 92/6/EEC required speed-limitation devices to be installed on large Heavy Goods Vehicles (HGVs) and buses (N3 and M3 vehicles). In 2002, this "Speed Limitation Directive" was amended by Directive 2002/85/EC, which obliged all Heavy Commercial Vehicles (HCVs), i.e. also N2 and M2 vehicles, to be equipped with speed limiters. (TML, TNO, CE Delft, TRT, 2013) have evaluated this Directive and found that the introduction of speed limiters resulted in a reduction of the total CO₂ emissions of HDVs by about 1%. Introducing an obligation for speed limiters on LCVs as well may result in a maximum CO₂ reduction for these vehicles of 4-5%.

²⁴ Synchromodality is about improving logistic efficiency where the whole network of intermodal services is used based on an optimisation of distance, time, cost and emissions.

5. SYNTHESIS OF PREVIOUS SECTIONS

In the preceding sections we have discussed many aspects of transport decarbonisation. We have looked at trends in GHG emissions and targets, reviewed current EU and industry strategies to decarbonise transport, and considered the potential of the three key pathways to decarbonisation: vehicle efficiency, fuel decarbonisation and transport system efficiency. In this Section, we provide a synthesis of all of these elements.

In Section 5.1, we focus on the combined potential of the three pathways to decarbonise transport. This integrative approach is important for several reasons. First, the contribution of the three pathways to CO₂ reduction potential may not be evenly dispersed. If technical mitigation measures are more effective in reducing CO₂ emissions than demand-side measures, this should lead to a different prioritisation of decarbonisation policies than would be appropriate if the finding were the other way around. Second, a measure taken in one pathway will affect the remaining emissions reduction potential in another. For example, if heavy-duty trucks become more fuel-efficient, less renewable fuel is required to ensure they transport the same amount of goods over the same distance. Besides, the impact of, for example, a kilometre charge will be smaller in terms of absolute CO₂ emissions reduction if the vehicles to which it applies are more energy-efficient. In a world with only zero-emission cars, a kilometre charge for passenger cars would have no additional effect on CO₂ emissions.

Based on this assessment, we conclude this section with a number of arguments that illustrate the need for additional policy action in the coming years.

5.1. Effectiveness of existing policy efforts

Assessing the effectiveness of implemented policies ex-post is challenging. Answering the question “how much higher would GHG emissions have been if no decarbonisation policies had been implemented” would require an analysis encompassing numerous factors. It is often difficult to distinguish the effects of the policy measure itself from other developments such as economic and population growth, changes in energy prices and interaction with policies in other domains. It is therefore (far) beyond the scope of this study to examine the effectiveness of all the directives and legislation put into place to decarbonise EU transport. We have seen in Section 4, however, that some of the policies or initiatives have delivered less than the initially intended GHG reduction. We recall four of these policy areas which have been particularly important in EU decarbonisation policy over the last 10 to 15 years:

- regulation of vehicle emissions;
- the renewable energy target for transport;
- policies targeting modal shift;
- climate policies for aviation and maritime shipping.

Regulation of vehicle emissions

Regulation of vehicle emissions can be an effective means of improving vehicle efficiency. CO₂ emissions legislation is widely recognised as one of the most (cost-)effective measures to reduce CO₂ from road vehicles.

The CO₂ regulation of passenger cars has led to a decrease in CO₂ emissions per kilometre of new cars, as measured in the test cycle. Since 2007, these CO₂ emissions per kilometre have dropped from 159 g/km to 120 g/km in 2015, a reduction of almost 25%. This reduction is slightly more than the target set by the legislation. Stricter targets for the year 2021 are already in place. Since the implementation of the 130 g/km target for passenger cars in

2009, standards have been agreed upon for light commercial vehicles. The EC is currently developing CO₂ standards for heavy-duty vehicles.

However, the effectiveness of the regulation of passenger car CO₂ emissions has been limited by the fact that the real-world emissions reduction has been much smaller, owing to the increasing gap between type-approval emissions and real-world emissions. (ICCT, 2016c) estimates that real-world emissions in the EU fell from 182 g/km in 2009 to 167 g/km in 2015, which is a reduction of only 8% rather than the 25% measured on the test cycle.

The gap between test-cycle and real-world emissions has been on the policy agenda for some time now. The EC is working with international stakeholders on a new test cycle called the 'Worldwide harmonized Light vehicles Test Procedure' (WLTP). The WLTP is a step in the right direction, but will not close the gap on its own.

The point we are seeking to make here is that, based on past results, future stricter vehicle regulations may prove to be less effective than anticipated. Moreover, regulations apply solely to new vehicles, which means it takes roughly ten to fifteen years (depending on vehicle lifetime) for the full effect to kick in. For trains, ships and airplanes the lifespan can be more than double this. Although these are hardly revolutionary insights, they are important to keep in mind for policy-makers. As we shall see in the next section, vehicle efficiency measures are a potentially very effective way to reduce transport GHG emissions. However, if they are less effective in the real world than assessed before implementation, it will leave a substantial gap which needs to be bridged with alternative measures.

The renewable energy target for transport

Another of the more important strategies of the EU to decarbonise transport was to increase the share of renewable energy in the final energy consumption of the transport sector. Although the EC did not formulate a concrete CO₂ emissions reduction objective for the 10% renewable energy target for transport, obviously it intended to reduce these emissions substantially. In the impact assessment of the ILUC Directive, the 'do nothing' scenario (which does not take account of indirect land use change) provides an estimate for total direct emission savings of 42 Mt in the year 2020. That is an average emissions reduction of 61% (EC, 2012). Taking into account the indirect land use change emissions, the average emissions reduction is limited to only 15%. This would equal roughly 10 Mt CO₂ emissions savings.

In terms of the entire transport sector, the 10% biofuels target with a 61% CO₂ emissions reduction would lower overall transport emissions by roughly 6%. This is in line with the 6% reduction target of the FQD. In the case of an average reduction of 15%, this will be limited to 1.5%. Note that this depends strongly on the assumptions made for indirect land use change emissions, which are still the subject of scientific debate.

We have seen in Section 4.2 that this target has mainly been a driver for biofuels and that the GHG performance of conventional biofuels varies greatly. When only direct emissions resulting from the production of the current biofuels are included, the overall GHG savings achieved is on average 50%. However, if indirect emissions resulting from land use changes are also included, a large part of current biofuels consumption may well lead to a well-to-wheel increase in CO₂ emissions. Moreover, the design of the RED created uncertainty in the market and thus hampered investments in R&D and production capacity for advanced, sustainable biofuels that could potentially be more effective in reducing GHG emissions.

The recent proposal for the revision of the RED will correct some of the negative side effects discussed above. Nevertheless, many uncertainties about the actual GHG performance and sustainability of biofuels will remain, potentially reducing the effectiveness of this policy in achieving GHG reductions in the future, too.

Policies targeting modal shift

Promoting modal shift to more environmentally-friendly transport modes was already a policy objective of the 2001 White Paper on transport. At that time, modal shift policies were aimed at preventing air pollution rather than GHG emissions. The 2011 White Paper added specific targets for the promotion of energy-efficient modes to contribute to climate targets. In 2030, 30% of road freight transport over 300 km should have shifted to either rail or waterborne transport. Although no specific CO₂ reduction targets for modal shift are mentioned, it is clear that modal shift would contribute to meeting the overall GHG reduction target of 60% in 2050.

Although 2030 is still far in the future, we would expect the continuous policy efforts over the past 10 to 15 years to have had delivered results by now. This is difficult to ascertain, however, as there is little concrete evidence that infrastructure policy aimed at promoting modal shift has had the intended effect. Most estimates found in the literature are ex-ante evaluations and examine the potential contribution of modal shift to GHG reductions (among other things). A complicating factor is that the construction of new infrastructure induces traffic and transport, which in turn results in higher GHG emissions. Moreover, some argue that modal shift should not be a policy goal in itself. Transport policy proposals should, rather, incorporate all possible contributions to meeting desired economic, social and environmental end goals. Techniques like societal cost-benefit analysis and strategic environmental impact analysis are well suited for this purpose and incorporate the benefits of modal shift as one of the relevant parameters.

Climate policies for aviation and maritime shipping

Both the aviation and maritime shipping sectors are difficult to tackle owing to their international nature. Nevertheless, there have been EU policy initiatives to speed up GHG reduction in the EU from both sectors. EU policy documents have continuously stressed that aviation and maritime shipping should be the subject of special attention. The Commission has worked (and is still working) on the inclusion of aviation in the EU's emissions trading scheme (EU ETS) in a manner consistent with the ICAO CORSIA mechanism. It also encourages the use of sustainable low-carbon fuels in aviation. For the maritime sector, the European Parliament has pre-empted, to some extent, the Commission's call for further action on GHG emissions from shipping. It has voted to include provisions relating to maritime transport in the Commission's proposal for the fourth phase of the EU ETS. Although these are important steps to reduce GHG emissions from these sectors in the future, they have so far contributed very little to actual emission reduction. As both the aviation and maritime sectors are expected to grow substantially between now and 2050, a large part of the 'permissible' remaining GHG emissions will be taken up by these sectors. Additional policy efforts to tackle GHG emissions from aviation and maritime shipping are therefore needed.

Résumé

The EU's GHG emissions have been decreasing over time as a result of policy measures and a reduction in transport demand following the economic crisis. The EU policies that potentially had the largest impact on decarbonisation were CO₂ standards for passenger cars and RES-T policies. However, in both cases, real-world emission reductions have been much smaller than the intended reduction. The increasing discrepancy between real-world CO₂ emissions and those measured in the NEDC test cycle has had an important impact on the effectiveness of CO₂ standards. The use of biofuels might even have led to a net increase in CO₂ emissions if indirect emissions are taken into account. The effectiveness of modal shift to date has not been properly assessed, but may very well have been limited. The policy impact on GHG emissions from aviation and maritime shipping has so far been limited and needs to be stepped up.

5.2. Overall potential for decarbonisation

The overall decarbonisation potential and the relative contribution of the three pathways have been the subject of several studies on future GHG reduction in the transport sector. These studies typically conclude that technical measures with respect to vehicle fuel efficiency in combination with low-carbon fuels should deliver the largest contribution to decarbonisation (PBL, 2009); (AEA, CE Delft, TNO, 2010). This is in line with the Roadmap that identified cost-effective GHG emissions for each sector (EC, 2011). For transport, it concluded that overall GHG emission reductions of between 54% and 67% could be delivered largely from improved vehicle efficiency, increased electrification and increased use of biofuels for heavy-duty vehicles and in aviation.

The combination of vehicle efficiency and low-carbon fuels is important. This becomes clear if we look at electric or fuel-cell cars, for example. These can result in nearly zero emissions from passenger car transport, but rely on the production of sustainable (low-carbon) electricity and hydrogen. Most studies also argue that biofuels should be reserved for those transport modes for which there are no or limited alternatives. Aviation, maritime shipping and long-haul road transport are the main candidates in this respect (PBL, 2009); (AEA, CE Delft, TNO, 2010).

(PBL, 2009) and (AEA, CE Delft, TNO, 2010) both argue that technical measures alone are insufficient if GHG reductions above roughly 60% compared to 1990 are required in the transport sector. In that case, policy measures to increase the efficiency of the transport sector are also needed. This can be achieved through a combination of taxation and (road) pricing, modal shift, improved spatial planning, lowering of speed limits and improving logistics efficiency with the aid of ITS.

Although both the Low Carbon Economy Roadmap (EC, 2011a) and the White Paper (EC, 2011b) include measures aimed at improving the efficiency of the transport sector (e.g. internalisation of external costs and CO₂-differentiated taxes), the White Paper contains the explicit notion that “curbing mobility is not an option”. Although no explicit mention of this was found, this may be an indication that demand-side measures are looked at with some reservation. Caution with measures that influence travel demand is indeed warranted. On the one hand, there may be many cost-effective measures that reduce energy use and have little impact on the travel and transport needs of citizens and companies. Good examples are improving logistics efficiency through C-ITS, congestion charges and optimising spatial planning and infrastructure planning. On the other hand, as the impact of policies on travel demand increases, costs to society will also rise. An extreme example can illustrate this. It would be possible to fully decarbonise transport if mobility were forbidden or made extremely expensive. Obviously, this would be detrimental for the functioning of societies. At the same time, transport is likely to become more expensive once new low-carbon fuels and low-emission vehicles become more common. This will also have an effect on travel demand. The challenge for policy-makers is to identify those measures that improve the efficiency of the transport sector which have the most limited impact on the travel needs of citizens and companies. As climate policy goals become more ambitious, preventing the ‘curbing of mobility’ will become less and less viable.

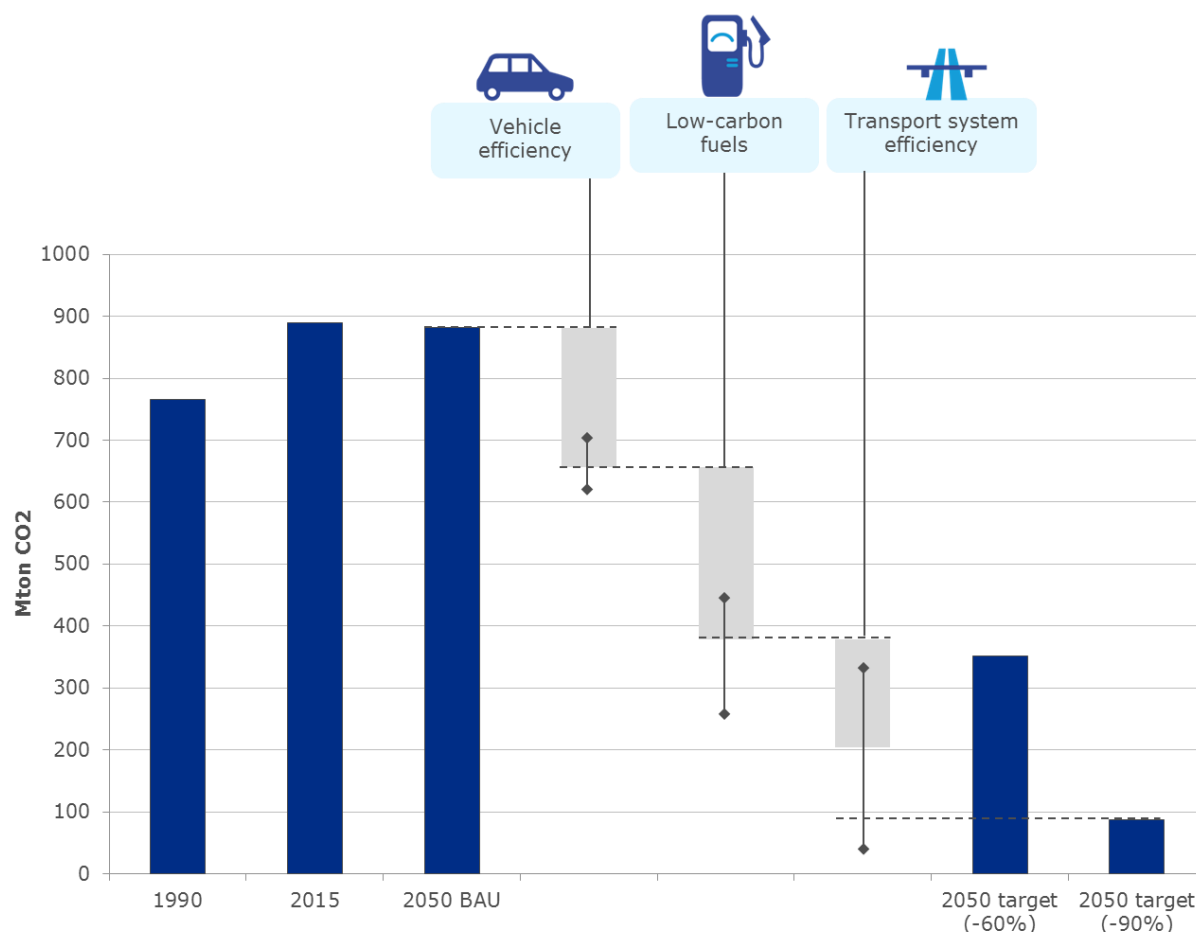
The potential of the technical options (the combination of low-carbon fuels and vehicles) and demand-side routes is not the same for the different transport modes. As already argued, passenger car transport can be made nearly zero-emission through technical measures alone. The same holds for light commercial vehicles and the bulk of vehicles used in city logistics. For heavy-duty road vehicles, particularly those used for long-haul transport, the electric and hydrogen routes are less viable. These transport modes rely more heavily on demand-side measures and low-carbon fuels and less on vehicle efficiency. More or less the same holds for the aviation and maritime sectors.

What does this all mean for the long-term targets to decarbonize EU transport? To answer that question we constructed the diagram shown in Figure 14. It shows the potential CO₂ reduction in the transport sector of the three pathways (including the margin of error derived from the different estimates of the potential in different studies). From the expected level of CO₂ emissions in 2050 we can derive the reduction targets for 2050 (we assumed a growth in CO₂ emissions of 15% compared to 1990 levels, based on EEA (2016)). The 60% and 90% targets²⁵ are depicted on the right-hand side of the diagram.

The diagram shows that, based on existing studies, roughly a 60% reduction in CO₂ emissions compared to 1990 is attainable by improving vehicle efficiency in combination with introduction of low-carbon fuels. This would require that the maximum potential of both pathways is delivered. If measures prove to be less effective in practice (which is conceivable, as we saw in Section 5.1) additional reductions would need to come from demand-side measures. In theory, a 90% reduction compared to 1990 levels would then be attainable.

It is also important to realise that the large-scale availability of high-quality sustainable renewable fuels is crucial to meet future targets, whereas current production levels of sustainable biofuels are very limited and there is still significant debate and thus uncertainty about their future effects. Alternatives such as renewable fuels from wind and solar energy are still very costly (and not yet on the market). The figure clearly illustrates the associated risks: if the future potential of (reasonably priced) low-carbon fuels is lower than expected, either the GHG reduction will be lower than needed from a climate policy point of view, or vehicle efficiency and transport efficiency both need to contribute more than planned for.

²⁵ The 90% target for transport corresponds to the 95% target sector-wide; similarly, the 60% transport target corresponds to the 80% reduction sector-wide.

Figure 14: Illustration of the contribution of three pathways to reach long-term climate targets of -60 and -90%

Source: Based on (PBL, 2009); (AEA, CE Delft, TNO, 2010).

5.3. Discussion

Despite the fact that the 2020 targets are on course to be met, policies will need to become more ambitious from now onwards. Below we provide a number of reasons and arguments why this is the case.

The first reason why policy efforts need to be stepped up is the fact that **the Paris Agreement sets more ambitious targets for all sectors** than the current targets based on the 2011 Roadmap. Although there are no EU-wide, long-term sectoral targets (yet), it is safe to say that the 60% reduction of GHG emissions that was assumed by the Transport White Paper will have to be made more stringent. If we assume that the Paris Agreement will lead to an adjustment of the 80% overall reduction target for all sectors to 95%, this would lead to a proportional target for transport of 90% in 2050 compared to 1990 levels.

The second argument for additional policy action is that we have seen in this report that **some of the potentially more effective measures for GHG reduction have not delivered their potential**. This certainly does not mean these policy actions have been unsuccessful and should be discontinued. It does illustrate, however, that current policies need to be improved and that it is wise to anticipate possibly lower than expected emission reductions from recently adopted and future measures. Put differently, implementing measures that could potentially result in an overshoot of the long-term climate targets may be needed to achieve those targets.

A third argument is that currently cost-effective **measures to improve the efficiency of the transport system are largely overlooked** in EU policy. Measures such as improving logistics efficiency through C-ITS, congestion charges and optimising spatial planning and infrastructure planning might be more cost-effective than certain vehicle efficiency and low-carbon fuel measures. It should be noted, however, that with the increasingly stringent climate targets measures that will impact travel demand might also be necessary. The much more stringent targets that follow from the Paris Agreement beg the question whether the notion “curbing mobility is not an option” from the Transport White Paper can be maintained indefinitely.

Rebound effects of climate policy are a fourth reason why policy efforts need to be stepped up. Rebound effects have the potential to undermine the GHG reduction potential of many policy instruments. Efficiency measures will result in lower cost per kilometre in both passenger and freight transport. These lower costs will induce additional travel demand, potentially resulting in additional GHG emissions. In addition, the shift of journeys from more GHG-intensive to less GHG-intensive modes (modal shift) has the potential to stimulate demand for travel as infrastructure capacity is freed up (AEA, CE Delft, TNO, 2010). Related to rebound effects is the probable future **decrease in oil prices and fossil transport fuels** as a result of global climate policies - these policies typically aim to reduce fossil fuel consumption. If not countered by taxation or other policies, the decrease in oil prices will have adverse effects on the policies aiming to promote the use of low-carbon fuels as well as increase transport demand.

Fifth, environmental pressure groups such as Transport and Environment have expressed **concerns about the further development of biomass-based fuels** (T&E, 2016a). If this leads to diminished public support for the use of (sustainable) biofuels, the effectiveness of biofuel policies may well be reduced. As a consequence, the full potential of low-carbon fuels as depicted in Figure 14 will be smaller, which will have to be compensated by other measures.

Finally, the targets set out in the Roadmap for 2050 and the Transport White Paper are based on setting reduction percentages in a specified target year compared to a base year, e.g. a 60% drop in CO₂ emissions from transport in 2050 compared to 1990 levels. This approach neglects the fact that **the timing of emission reductions, not just their long-term annual levels, impacts the rise in global temperature**. This is because the long-term global temperature is mainly determined by cumulative GHG emissions. This means that swift policy action will lengthen the time available before the carbon budgets are depleted.

6. MAIN CONCLUSIONS AND RECOMMENDATIONS

6.1. Main conclusions

- Very significant GHG reductions are still necessary in the transport sector to meet the terms of long-term climate agreements. Unlike in most other sectors, GHG emissions from transport continued to increase until the financial crisis of the late 2000s. For the first time since this crisis, transport GHG emissions increased in 2014 compared to the previous year. More policies are needed to put transport back on course to delivering its medium- and long-term targets.
- The EU is focusing on delivering a 60% GHG reduction from transport between 1990 and 2050 to contribute to an economy-wide GHG reduction of 80%, which is at the lower end of the 80 to 95% range needed from developed countries to keep warming within 2°C.
- Limiting warming to 1.5°C as proposed in the Paris Agreement requires net zero emissions globally at some point between 2040 and 2060. The Intended Nationally Determined Contributions delivered by countries before Paris are insufficient to limit warming to 1.5°C.
- A wide range of measures is available to reduce the CO₂ emissions of the transport sector. The greatest potential comes from technological options to improve the energy efficiency of vehicles, ships and planes. The second greatest potential comes from renewable fuels and low-carbon energy carriers for the various transport modes. A more limited impact may be expected from measures that improve the efficiency of the transport system itself.
- Meeting the longer-term decarbonisation targets for the transport sector still **requires extensive technology and policy development**. With current policies, the EU's 2050 GHG emissions of transport (including aviation, excluding maritime shipping) are expected to be 15% above 1990 levels.
- **Current technologies are insufficient to meet the future transport GHG reduction targets**. Large-scale innovations and investments are needed, in a range of areas. The following **key technological challenges** are identified:
 - Reduction of cost and improvement of the performance of electric vehicles and fuel-cell vehicles, with simultaneous roll-out of charging/fuelling infrastructure for these vehicles. For battery electric vehicles, an additional challenge is integration into the electricity system (with regard to grid capacity and stability, flexible demand and energy storage, etc.).
 - Technologies for large-scale production of affordable, low-carbon and renewable fuels, from biomass but also from wind and solar power. There is a strong need for sustainable advanced biofuels that can be used in aviation, shipping and HDV road transport, and there may be significant future potential for renewable fuels produced from wind and solar power (power-to-gas, power-to-liquid).
 - Further development of fuel-efficient technologies in heavy-duty vehicles, airplanes and ships, to reduce their energy use per kilometre or tonne-kilometre.

- **Current policies are also insufficient to meet future transport GHG targets.**
The following **key policy challenges** were identified:
 - Adoption of a framework, or regulations, to achieve large-scale uptake of electric and hydrogen-powered vehicles, to reduce demand for both fossil fuels and biofuels in road transport.
 - Agreement and implementation of effective, long-term decarbonisation policies for aviation and maritime shipping. Progress in these areas has been limited and decarbonisation policies are still largely lacking.
 - Ensuring adequate sustainability, security of supply and affordability of the large volumes of renewable fuels that are likely to be produced for the transport sector in the long-term.
 - A stable policy framework that provides an attractive market environment for financing the R&D and investments is needed to meet the medium and long-term targets. Ensure cost-effectiveness of these developments, focusing on cost reductions, through innovation, R&D and economies of scale.
 - Aim for a level playing field between transport modes. Currently, for example, aviation and shipping are exempt from fuel taxes and renewables obligations, whereas these policy measures do apply to road transport.

6.2. Recommendations for future EU policy

General recommendations

- To further decarbonise the transport sector, it is recommended to continue and strengthen the existing range of policies targeting the fuel efficiency of vehicles, the decarbonisation of transport fuels and the efficiency of the transport system as a whole. The challenges ahead are very substantial, and an effective and stable policy framework that provides a clear outlook for a sustainable future of the sector is essential to ensure adequate investments by the industry, to trigger the innovations needed and to create support from NGOs and citizens. This policy framework should cover all transport modes, including aviation and maritime shipping, and address a wide range of sustainable, renewable and low-carbon energy carriers.
- In designing a strategy and policies for transport decarbonisation, it is important not to focus solely on the 2050 emission target, but also on the cumulative GHG emissions over time, since the timing of emission reductions influences the global temperature increase. Therefore, from a climate change mitigation point of view, early action and GHG reduction is preferred.
- The various decarbonisation options will have financial and non-financial impacts on businesses and EU citizens. Costs for the transport of goods and people are likely to increase, depending on the transport mode and the policies that are implemented. Oil refineries will be faced with significant demand reduction, or a need to switch to biofuel production, whereas producers of sustainable renewable fuels and energy carriers (e.g. electricity, hydrogen) can benefit from equally large demand increases. To ensure broad support for the actions taken throughout the EU, it is important to adequately communicate the reasoning behind the policies and have a transparent decision process in place.

Recommendations regarding vehicle efficiency

- Vehicle efficiency measures are typically more cost-effective than renewable energy options. Further improvement to the efficiency of vehicles used in all transport modes is key to decarbonisation. Although CO₂ regulations for vehicles have resulted in a drop in CO₂ emissions per kilometre from cars and LCVs, the effectiveness of these regulations could have been far greater if the gap between test and real-world CO₂ emissions of cars had not increased as it did. It is recommended to continue and strengthen the CO₂ regulations of vehicles over time, to introduce regulations for HDVs, and to ensure that emissions under test conditions are in line with real-world emissions.
- For the post-2020 policy framework, various reports have considered a 2025 target of around 70 gCO₂/km and have underlined the benefits of the early introduction of electric vehicles for compliance costs and consumers. The targets chosen need to be those that deliver cost-effective CO₂ emissions reductions in line with long-term CO₂ reduction targets. A mandate for low or zero-emission vehicles has the potential to bring additional benefits, but it must ensure that the overall target is not weakened.
- The discrepancy between real-world CO₂ emissions and those measured on the NEDC test cycle has been increasing in recent years. It is expected that the new WLTP test cycle will reduce but not eliminate this gap. In order to ensure that the gap does not grow in future years, a framework for monitoring real-world CO₂ emissions should be put in place.
- Efficiency policies should take into account possible rebound effects: efficiency measures reduce costs per kilometre, which may induce additional demand. To consider rebound effects, it is necessary to assess their impact and adopt appropriate mitigation measures, e.g. by adjusting energy taxes accordingly. In addition, a decrease in demand for fossil fuels could lower oil prices, which would reduce the cost-competitiveness of renewable fuels.
- The provision of adequate information for consumers about real-world energy benefits can overcome important barriers in purchase behaviour. An improvement of the Car Labelling Directive could serve this purpose.

Recommendations regarding decarbonisation of transport fuels and energy sources

- A robust strategy for RES-T growth in the medium and long-term needs to be developed. Over the past years, the RES-T target in the RED and ensuing implementation in Member State policies have been effective in increasing the share of biofuels in road transport fuels and in creating a market for biofuels. At the same time, however, the recent inclusion of ILUC effects in the RED as well as uncertainty about future sustainability criteria and targets for biofuels in general have hampered investments in R&D and production capacity for advanced, sustainable biofuels.
- To speed up RES-T growth after 2020, implementing stable and effective sustainability criteria is key, combined with equally stable targets for the future. To set these targets at an optimum level, a longer-term framework is needed for the future transport energy mix with which the climate targets can be met.
- In view of the expected limited availability of sustainable biofuels, also in the long-term, future decarbonisation requires a strong focus on increasing the share of electric and hydrogen vehicles where possible (road transport, rail). It is also important to ensure that decarbonisation policies be geared towards developing the potential for renewable fuels produced from wind and solar power (power-to-gas, power-to-liquid).

- EVs must be integrated into the electricity system, to avoid extensive investments in grid expansion that might otherwise be required to enable electric-vehicle charging. This may include, for example, implementation of smart charging systems to enable the charging of batteries in periods of high wind and solar electricity production and of policies that support the local use of renewable electricity for EV charging.
- The policies and strategies for RES-T should not be assessed and developed in isolation, but together with the other sectors that are working on decarbonisation of their energy supply, notably the power sector, industry and the built environment. These sectors will also have increasing demand for sustainable biomass as a renewable energy source (as well as a chemical feedstock), for the renewable electricity produced and for renewable fuels from solar or wind power, to meet their decarbonisation targets and challenges.

Recommendations regarding efficiency of the transport sector

- Climate policies for transport need to anticipate the possibility that vehicle efficiency measures and the availability of sustainable fuels may be insufficient to meet long-term climate targets. It is recommended to investigate which measures can potentially reduce transport demand cost-effectively.
- Although such measures are often the responsibility of regional and local authorities, the EU should look for ways to further encourage Member States to implement measures directed at improving the efficiency of the transport sector.
- There are a wide variety of measures that can potentially achieve this aim, such as speed limits, environmental zones, energy taxation based on CO₂ emissions, road charging and spatial planning policy. Combined, they can contribute to meeting long-term climate goals.
- Considering that decisions on infrastructure and spatial planning will have an impact for many decades, the EU should see these both as being an integral part of GHG emissions policy.
- Energy taxation based on CO₂ emissions is an efficient way of tackling these emissions. The current minimum levels in the Energy Taxation Directive should be higher.
- Although modal shift policies can potentially reduce GHG emissions, infrastructure policies that aim to promote more energy-efficient modes and reduce GHG emissions should be carefully evaluated prior to implementation to ensure there will be net environmental benefits. Currently, the effectiveness of such policies is under discussion.
- Since there is significant potential to improve logistics efficiency in freight transport, climate policies should aim to unlock this potential through pricing policies and ITS services such as on-trip eco-driving support, cooperative traffic lights, synchromodality and dynamic trip planning schemes.

Recommendations regarding aviation and maritime shipping

- It has been estimated that ICAO's global market-based measures (CORSIA) would deliver less in terms of GHG emissions than including all flights leaving and arriving at EU airports in the EU ETS. Moreover, ICAO's CO₂ standards for aircraft would deliver less than has historically been delivered without a standard. The EU policy framework should recognise these weaknesses and ensure that aviation makes a fair and appropriate contribution to long-term GHG reduction efforts, including potentially re-

including aviation in the EU ETS in the short-term and ensuring that an enhanced CORSIA is implemented as necessary.

- IMO has taken initial action to improve the energy efficiency of ships, which could deliver benefits in the medium-term, while the European Parliament has proposed that GHG emissions from international maritime transport be included in the EU ETS if the IMO has not put in place further measures, including targets, to reduce the sector's GHG emissions. Parliament's proposal is an important step in ensuring that action is taken to reduce GHG emissions from the maritime sector post-2021.
- Promoting the use of renewable fuels in both aviation and maritime transport is required to ensure the decarbonisation of these modes. One of the main barriers to be overcome is the price difference between sustainable low-carbon fuels and fossil fuels.
- The EU should maintain its course to include maritime GHG emissions in the EU ETS, which is a potentially important step to ensure that there will be suitable measures in place to reduce the GHG emissions from international maritime transport from 2021.

Recommendations regarding innovation

- There are still many uncertainties regarding the development of a future decarbonised transport system. It is known, however, that current low-carbon technologies are insufficient to meet the longer-term climate goals. Research and development is still needed in many areas to ensure that the targets can be met cost-effectively, whilst reducing or preventing negative impacts.
- Innovation policies should target the development of:
 - Advanced biofuels that can be produced sustainably in large volumes, preferably drop-in, for aviation, maritime shipping and HDV road transport.
 - Sustainable feedstocks for these biofuels with potential for upscaling (to produce a significant share of fuels for these three modes).
 - Transport fuels from other renewable sources (wind, solar, i.e. power-to-gas, power-to-liquid).
 - Batteries for electric vehicles.
 - Charging infrastructure for electric vehicles (including charging points, induction charging, overhead wiring for HDV, etc.).
 - Integration of EVs into the future electricity system and grid (including smart charging for flexible demand, integration with decentralised power production with solar photovoltaic, energy storage).
 - Fuel-cell vehicles and filling infrastructure.

Efforts should aim to significantly reduce costs and increase the performance of those technologies that have the potential to be scaled up to the large scale required in a decarbonised future of the transport sector. Just as important as measures directed towards the production side are policy actions that stimulate demand: growth in demand for innovative products (vehicles and fuels) is crucial for industry and companies to develop and invest in the required innovations.

REFERENCES

- ACEA, 2016. *CO2 tax overview – 2016 : CO2 Based Motor Vehicle Taxes in the EU in 2016*, Brussels: European Automobile Manufacturers Association.
- AEA, CE Delft, TNO, 2009. *EU Transport GHG: Routes to 2050? Infrastructure and spatial policy, speed and traffic management (Paper 8)*, London (UK): AEA.
- AEA, CE Delft, TNO, 2009. *EU Transport GHG: Routes to 2050? Modal split and decoupling options: Paper 5*, London (UK): AEA.
- AEA, CE Delft, TNO, 2010. *EU Transport GHG: Routes to 2050? Towards the decarbonisation of the EU's transport sector by 2050*, London (UK): AEA.
- AEA, CE Delft, TNO, 2012. *Final Report Appendix 2: The role of GHG emissions, from infrastructure construction, vehicle manufacturing, and ELVs in overall transport sector emissions, Final Task 2, Paper.* [Online] Available at: www.eutransportghg2050.eu/cms/assets/Uploads/Reports/EU-Transport-GHG-2050-II-Task-2-FINAL-30Apr12.pdf
- AEA, TNO, CE Delft, TEPR, 2012. *Developing a better understanding of the secondary impacts and key sensitivities for the decarbonisation of the EU's transport sector by 2050, Report produced under the 'EU Transport GHG emissions: Routes to 2050 II' project for European Commission DG Cli*, Harwell, Didcot: AEA.
- AEA, 2011. *Reduction and Testing of Greenhouse Gas (GHG) Emissions from Heavy Duty Vehicles – Lot 1: Strategy, Final Report to the European Commission*, Didcot (UK): AEA Technology plc.
- AEA, 2012. *EU Transport GHG: Routes to 2050 II : SULTAN Illustrative Scenario Tool - User Guide: 2012 Update*, Brussels: European Commission Directorate-General Climate Action.
- ANEC; BEUC, 2014. *Empower EU consumers through visible and clear labelling information on CO2 emissions from new passenger cars : ANEC & BEUC call for a review of the car labelling Directive 1999/94/EC*, Brussels: European Association for the Co-ordination of Consumer Representation in Standardisation ANEC; European Consumer Organisation (BUEC).
- ARB, 2017. *California's Advanced Clean Cars Midterm Review*, Air Resources Board of the California Environmental Protection Agency. [Online] Available at: www.arb.ca.gov/msprog/acc/mtr/acc_mtr_finalreport_full.pdf
- Banister, 2011. 'The trilogy of distance, speed and time. *Journal of Transport Geography* (19(4)) 950-959.
- Cambridge Econometrics, 2013. *The effectiveness of CO2-based 'feebate' systems in the European passenger vehicle market context: An analysis of the Netherlands and the UK, Report for the International Council on Clean Transportation*, s.l.: Cambridge Econometrics.
- Cambridge Econometrics, 2014. *The Impact of Including the Road Transport Sector in the EU ETS*, Cambridge: Cambridge Econometrics.
- CCC, 2016. *Meeting Carbon Budgets - 2016 Progress Report to Parliament*, London: Committee on Climate Change.
- CE Delft and UCL, 2016a. *Historical trends in ship design efficiency: the Impact of Hull Form on Efficiency*, Delft: CE Delft.
- CE Delft, Ecologic Institute, Ricardo-AEA, REKK, E-Bridge, 2015. *Mid-term evaluation of the Renewable Energy Directive*, Delft: CE Delft.
- CE Delft, SQ Consult, Cambridge Econometrics, 2014. *Emissions trading for transport and the built environment*, Delft: CE Delft.

- CE Delft; TAKS, 2017. *A comparison between CORSIA and the EU ETS for Aviation*, Delft: CE Delft.
- CE Delft, 2006. *Dealing with transport emissions : An emission trading system for the transport sector, a viable solution*, Stockholm: The Swedish Environmental Protection Agency (Naturvårdsverket).
- CE Delft, 2009. *Milieudifferentiatie van de kilometerprijs : Effecten van verschillende milieudifferentiaties van de kilometerprijs voor vrachtauto's, bestelauto's en autobussen*, Delft: CE Delft.
- CE Delft, 2010. *EU Transport GHG : Routes to 2050? : Economic instruments (Paper 7)*, Brussels: European Commission.
- CE Delft, 2011. *Climate rating of transport infrastructure projects*, Delft: CE Delft.
- CE Delft, 2015. *Assessing progress towards implementation of the ILUC directive*, CE Delft: Delft.
- CE Delft, 2016. *Consideration of the role of speed limiters in light commercial vehicle CO2 regulation, draft report DG Climate Action*, Delft: CE Delft.
- CE Delft, 2017. *Stream Passenger Transport 2016*, Delft: CE Delft.
- CPB; PBL, 2015. *Maatschappelijke Kosten en Baten Prijsbeleid Personenauto's, notitie*, Den Haag: Centraal Planbureau (CPB), Planbureau voor de Leefomgeving (PBL).
- CPB, 2015. *Fiscal policy and CO2 emissions of new passenger cars in the EU*, The Hague: Economic Policy Analysis (CPB).
- Desbarats, 2009. *An analysis of the obstacles to inclusion of road transport emissions in the European Union's Emissions Trading Scheme*, s.l.: Institute for European Environmental Policy.
- E4tech, 2013a. *A harmonised Auto-Fuel biofuel roadmap for the EU to 2030, final report*, London: E4tech (UK) Ltd.
- E4tech, 2013b. *A harmonised Auto-fuel biofuel roadmap for the EU to 2030 : Appendices*, London: E4tech (UK) Ltd.
- EC, 1995. *Communication from the Commission to the Council and the European Parliament : A Community strategy to reduce CO2 emissions from passenger cars and improve fuel economy COM(95)689 final*, Brussels: European Commission.
- EC, 2000. Directive 1999/94/EC of the European Parliament and of the Council of 13 December 1999 relating to the availability of consumer information on fuel economy and CO2 emissions in respect of the marketing of new passenger cars. *Official Journal of the European Communities*, L12(18. 1. 2000), pp. 16-23.
- EC, 2002. Decision No 1600/2002/EC of the European Parliament and of the Council of 22 July 2002 laying down the Sixth Community Environment Action Programme. *Official Journal of the European Communities*, L242(10.9.2002), pp. 1-15.
- EC, 2005. *Proposal for a Directive on passenger car related taxes, COM(2005) 261*, Brussels: European Commission.
- EC, 2007. *Communication from the Commission to the Council and the EP results of the review of the Community Strategy to reduce CO2 enmissions from passenger cars/ light-commercial vehicles Impact Assessment COM (2007)19 final*, Brussels: European Commission.
- EC, 2008a. *Action Plan for the Deployment of Intelligent Transport Systems in Europe*. Brussels: European Commission.
- EC, 2008b. Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities

in the scheme for greenhouse gas emission allowance trading within the Community. *Official Journal of the European Union*, L8(13.1.2009), pp. 3-21.

- EC, 2009a. Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO₂ emissions from light-duty vehicles.. *Official Journal of the European Union*, L140(5.6.2009), pp. 1-15.
- EC, 2009b. Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles (Text with EEA relevance). *Official Journal of the European Union*, L120(15-5-2009), p. 5.
- EC, 2010. *Final report of the Expert Group 3 'Intelligent Transport Systems and New Technologies' within the framework of TEN-T, 2010 TEN-T Policy review*, Brussels: European Commission, DG for Mobility and Transport.
- EC, 2011a. *Communication from the Commission to the European Parliament, The Council, the European Economic and Social Committee and the Committee of the Regions : a roadmap for moving to a competitive low carbon economy in 2050 (COM 2011/ 0112 final)*, Brussels: European Commission (EC).
- EC, 2011b. *White paper, Roadmap to a single European Transport Area : Towards a competitive and resource efficient transport system COM(2011)0144 final*, Brussels: European Commission (CE).
- EC, 2011c. *Commission Staff Working Paper : Impact Assessment Accompanying document to the White Paper : Roadmap to a Single European Transport Area : Towards a competitive and resource efficient transport system, SEC(2011) 358 final*, Brussels: European Commission.
- EC, 2012. *Commission Staff Working Document. Impact assessment. Accompanying the document. Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70/EC and Directive 2009/28/EC*, Brussels: European Commission.
- EC, 2013a. *ANNEX a concept for sustainable Urban Mobility Plans to the Communication from the Commission (...)of the Regions : Together towards competitive and resource-efficient urban mobility COM(2013)913 final*, Brussels: European Commission (EC).
- EC, 2013b. *Communication from the Commission to the European Parliament, The Council , The European Economic and Social Committee and the Committee of the Regions : Together towards competitive and resource-efficient urban mobility COM(2013)913 final*, Brussels: European Commission (EC).
- EC, 2013c. *Communication from the Commission to the European Parliament , the Council, the European Economic and Social Committee and the Committee of the Regions Clean Power for Transport: A European alternative fuels strategy (COM (2013) 17 final)*, Brussels: European Commission.
- EC, 2013d. *Proposal for a regulation of the European Parliament and of the Council on the monitoring and verification of carbon dioxide emissions from maritime transport and amending Regulation (EU) No 525/2013, COM(2013)480 final*, Brussels: European Commission.
- EC, 2013e. *Integrating maritime transport emissions in the EU's greenhouse gas reduction policies COM(2013)479*, Brussels: European Commission.
- EC, 2014a. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions : a policy framework for climate and energy in the period from 2020 to2030 , COM/2014/015 final*, Brussels: European Commission (EC).

- EC, 2014b. *Commission SWD, Impact Assessment, Accompanying the document Communication from the Commission to the EP and the Council, The EESC of the Regions : a policy framework for climate and energy in the period from 2020 to 2030 (SWD(2014)15 final*, Brussels: European Commission (EC).
- EC, 2014c. *Proposal for a Regulation of the European Parliament and of the Council amending Regulations (EC) No 715/2007 and (EC) No 595/2009 as regards the reduction of pollutant emissions from road vehicles COM(2014)28 final*, Brussels: European Commission (EC).
- EC, 2014d. *Communication from the Commission to the Council and the European Parliament: Strategy for Reducing Heavy-Duty Vehicles Fuel Consumptions and CO2 Emissions, COM (2014) 285 final*, Brussels: European Commission.
- EC, 2015a. *Energy Union Package Annex Roadmap for the Energy Union to the Communication from the Commission (...) and the European Investment Bank : a Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy, COM (2015) 80 Annex 1*, Brussels: European Commission (EC).
- EC, 2015b. *Energy Union Package : Communication from the Commission (.....) and the European Investment Bank : A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy COM(2015) 80 final*, Brussels: European Commission (EC).
- EC, 2015c. *Evaluation of Regulations 443/2009 and 510/2011 on CO2 emissions from light-duty vehicles : final report*, Brussels: European Commission (EC).
- EC, 2015d. *Inception Impact Assessment. Renewable Energy Package: new Renewable Energy Directive and bioenergy. ENER – C.1 – AP 2016/ENER/025. [Online]*
Available at: http://ec.europa.eu/smart-regulation/roadmaps/docs/2016_ener_025_cwp_renewable_energy_package_en.pdf
- EC, 2016a. *Communication from the Commission to the EP, The Council, the EESC and the Committee of Regions : A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility COM(2016) 766 final*, Brussels: European Commission (EC).
- EC, 2016b. *Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the regions : A European Strategy for Low-Emission Mobility COM(2016) 501 final*, Brussels: European Commission.
- EC, 2016c. *EU Reference Scenarios 2016 : Energy, transport and GHG emissions Trends to 2050*, Luxembourg: Publications Office of the European Union,.
- EC, 2016d. *Communication from the Commission to the EP, the Council, the European Economic and Social Committee and the Committee of the Regions. Commission Work Programme 2017 : Delivering a Europe that protects, empowers and defends, COM(2016)710 final*, Brussels: European Commission.
- EC, 2016e. *SWD Accompanying the document Communication from the Commission to the EP, the Council , the European Economic and Social Committee and the Committee of the Regions : A European Strategy for Low-Emission Mobility, COM(2016) 501 final*, Brussels: European Commission (EC).
- EC, 2017a. *Proposal for a Regulation of the European Parliament and of the Council amending Directive 2003/87/EC to continue current limitations of scope for aviation activities and to prepare to implement a global market-based measure from 2021, COM(2017)54 final*, Brussels: European Commission.
- EC, 2017b. *70th session of the Marine Environment Protection Committee (MEPC70) at the international Maritime Organisation, Press release 28/10/2016. [Online]*
Available at: <https://ec.europa.eu/transport/media/media-corner/70th-session->

[marine-environment-protection-committee-mepc-70-international_en](#)
[Accessed 9 February 2017].

- EC, 2017c. *Sustainable Urban Mobility Plans*. [Online] Available at: https://ec.europa.eu/transport/themes/urban/urban_mobility/urban_mobility_actions/sump_en
- EC, 2017d. *Current speed limit policies*. [Online] Available at: https://ec.europa.eu/transport/road_safety/specialist/knowledge/speed/speed_limits/current_speed_limit_policies_en
- EC, JRC & IATSTU, 2015. *The impact of biofuels on transport and the environment, and their connection with agricultural development in Europe*, Brussels: s.n.
- Ecofys, 2013. *Analysis of the operation of the mass balance system and alternatives*, S.l.: Ecofys.
- Ecorys; MuConsult, 2007. *Effecten vormgeving kilometer-prijs bij variabelisatie van BPM, MRB en Eurovignet*, Rotterdam: ECORYS Nederland BV.
- EEA, 2014. *Focusing on environmental pressures from long-distance transport : TERM 2014: transport indicators tracking progress towards environmental targets in Europe*, Luxembourg: Publications Office of the European Union.
- EEA, 2015. *Evaluating 15 years of transport and environmental policy integration : TERM 2015: Transport indicators tracking progress towards environmental targets in Europe*, Luxembourg: Publications Office of the European Union.
- EEA, 2016a. *Electric vehicles in Europe*, Luxembourg: Publications Office of the European Union.
- EEA, 2016b. *Explaining road transport emissions : A non-technical guide*, Luxembourg: Publications Office of the European Union.
- EEA, 2016c. *Monitoring CO2 emissions from new passenger cars and vans in 2015*, Luxembourg: Publications Office of the European Union.
- EEA, 2016d. *Transitions towards a more sustainable mobility system : TERM 2016: Transport indicators tracking progress towards environmental targets in Europe*. [Online] Available at: www.eea.europa.eu/data-and-maps/indicators/passenger-transport-demand-version-2/assessment-6; www.eea.europa.eu/data-and-maps/daviz/freight-transport-volume-3#tab-chart_1 [Accessed 31 January 2017].
- EEA, 2016e. *Trends and projections in Europe 2016 - Tracking progress towards Europe's climate and energy targets*, Copenhagen: European Environment Agency.
- EEA, 2016f. *Greenhouse gas emissions from transport, Prod-ID: IND-111-en, Also known as: TERM 002*. [Online] Available at: www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-6
- EEA, 2017a. *EEA Greenhouse gas - data viewer*. [Online] Available at: www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer [Accessed 9 February 2017].
- EEA, 2017b. *Investments in transport infrastructure*. [Online] Available at: www.eea.europa.eu/data-and-maps/indicators/infrastructure-investments

- EJC, 2012. *ECJ Judgement 03/12/2012 Case C-366/10*. [Online] Available at: <http://eur-lex.europa.eu/legal-content/en/TXT/PDF/?uri=uriserv%3AOJ.C.2012.049.01.0007.01.ENG>
- Element Energy, 2016a. *Low carbon cars in the 2020s : Consumer impacts and EU policy implications*, Brussels ; Cambridge ; Lille ; London: Elementenergy.
- Element Energy, 2016b. *Toward a European Market for Electro-Mobility, Final report for Transport & Environment*, Cambridge (UK): Elementenergy.
- Eltis, 2017. *The SUMP concept*. [Online] Available at: <http://www.eltis.org/mobility-plans/sump-concept>
- Environmental Advisory Council, 2016. *A Climate and air pollution control strategy for Sweden, part 1 (in Swedish)*, Stockholm: Statens Offentliga Utredningar.
- EP, 2015. *Report on the proposal for a regulation of the European Parliament and of the Council amending Regulations (EC) No 715/2007 and (EC) No 595/2009 as regards the reduction of pollutant emissions from road vehicles, COM(2014)0028-C7-0027/2014-2014/0012(COD)*, Brussels: European Parliament (EP).
- EP, 2017. *Cost-effective emission reductions and low-carbon investments : Amendments adopted by the EP on 15 February 2017 (...) amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments (P8_TA-PROV(2017)0035)*, Brussels: European Parliament (EP).
- ETC/ACM, 2012. *Use and effectiveness of economic instruments in the decarbonisation of passenger cars : ETC/ACM Technical paper*, Bilthoven: The European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM).
- EU, 2009. Regulation (EC) No 1222/2009 of the European Parliament and of the Council of 25 November 2009 on the labelling of tyres with respect to fuel efficiency and other essential parameters. *Official Journal of the European Union*, L342(22.12.2009), pp. 46-58.
- EU, 2011. Regulation (EU) No 510/2011 of the EP and of the Council of 11 May 2011 setting emission performance standards for new light commercial vehicles as part of the Union's integrated approach to reduce CO₂ emissions from light-duty vehicles (Text with EEA..). *Official Journal of the European Union*, L 145(31.5.2011), pp. 1-18.
- EU, 2013. Regulation (EU) No 168/2013 of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles. *Official Journal of the European Union*, L60(2.3.2013), pp. 52-128.
- EU, 2014. *Progress Report : Proposal for a Council Directive amending Directive 2003/96/EC restructuring the Community framework for the taxation of energy products and electricity (10417/14)*, Brussels: Council of the European Union.
- EU, 2014. *Proposal for a Council Directive amending Directive 2003/96/EC restructuring the Community framework for the taxation of energy products and electricity*, Brussels: Council of the European Union.
- EU, 2015a. Regulation (EU) 2015/757 of the European Parliament and of the Council of 29 April 2015 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport, and amending Directive 2009/16/EC (Text with EEA relevance). *Official Journal of the European Union*, L123(19-5), pp. 55-76.
- EU, 2015b. *Submission by Latvia and the European Commission on behalf of the European Union and its Member States Intended Nationally Determined Contribution of the EU and its*, Riga: Latvian Presidency of the Council of the European Union (EU).
- EU, 2015. *Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015*, Brussels: European Parliament.

- EU, 2016. Regulation (EU) 2016/1628 of the EP and of the Council of 14 September 2016 on requirements (...) emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Reg. (EU) No 1024/2012 and (EU) No 167/2013, (...). *Official Journal of the European Union*, L252(16.9.2016), pp. 53-117.
- EUCO, 2011. *The conclusions of the European Council (4 February 2011)*, Brussels: European Council (EUCO).
- Firnkorn & Shaheen, 2015. Generic time- and method-interdependencies of empirical impact-measurements: A generalizable model of adaptation-processes of carsharing-users' mobility-behavior over time. *Journal of Cleaner Production*.
- Gençsü et al., 2015. *Raising Ambition to Reduce International Aviation and Maritime Emissions. Contributing paper for Seizing the Global Opportunity: Partnerships for Better Growth and a Better Climate*, London and Washington: New Climate Economy.
- Geurs & Wee, 2006. Ex-post evaluation of thirty years of compact urban development in the Netherlands. *Urban Studies* 43(1): 139-160.
- Goodwin, 1996. Empirical evidence on induced traffic. *Transportation*, pp. 23: 35-54.
- Harding, 2014. Personal Tax Treatment of Company Cars and Commuting Expenses: Estimating the Fiscal and Environmental Costs. In: *OECD Taxation Working Papers No. 20*. Paris: OECD Publishing.
- Hille et al., Forthcoming. "Best in Class or Simply the Best? The Impact of Absolute Versus Relative Eco-Labeling Approaches". *Journal of Public Policy and Marketing*.
- ICAO, 2013. *ICAO Environmental report 2013 Destination Green : Aviation and Climate chance*, Montréal: International Civil Aviation Organization.
- ICAO, 2016. *On Board a Sustainable future : ICAO 2016 Environmental Report*, Montréal: International Civil Aviation Organization.
- ICCT ; IEEP ; NNFC, 2014. *Wasted: Europe's untapped Resource : an Assessment of Advanced Biofuels from Wastes & Residues*, S.l.: European Climate Foundation.
- ICCT, 2011. *A Review and Comparative Analysis of Fiscal Policies Associated with New Passenger Vehicle CO2 emissions*, s.l.: International Council on Clean Transportation (ICCT).
- ICCT, 2014. *Road transport in the EU Emissions Trading System: An engineering perspective*, Washington DC: The International Council on Clean Transportation (ICCT).
- ICCT, 2015a. *Fuel efficiency trends for new commercial jet aircraft : 1960-2014*, Washington DC: International Council on Clean Transportation (ICCT).
- ICCT, 2015b. *Overview of the heavy-duty vehicle market and CO2 emissions in the European Union*, Washington DC: International Council on Clean Transportation (ICCT).
- ICCT, 2016a. *2020-2030 CO2 standards for new cars and light-commercial vehicles in the European Union*, Berlin: International Council on clean Transportation.
- ICCT, 2016b. *CO2 Reduction Technologies for the European Car and Van Fleet, a 2025-2030 assessment : Methodology and summary of compliance for potential EU CO2 standards*, Berlin: International Council on Clean Transportation Europe (ICCT).
- ICCT, 2016c. *From Laboratory to road : A 2016 update of official and 'real-world' fuel consumption and CO2 values for passenger cars in Europe*, Berlin: International Council on Clean Transportation Europe (ICCT).
- ICCT, 2016d. *A Review and Evaluation of Vehicle Fuel Efficiency Labeling and Consumer Information Programs*, Singapore: Asia-Pacific Economic Cooperation.

- ICCT, 2017. *International Civil Aviation Organization's CO2 Standard for New Aircraft*, Washington: International Council on Clean Transportation (ICCT).
- IEA, 2011. *Biofuels for Transport Roadmap (foldout)*, Paris: OECD/IEA.
- IEA, 2016. *World Energy Outlook 2016 : Executive Summary*, Paris: OECD/IEA.
- IEEP, 2014. *Re-examining EU Biofuels policy : a 2030 perspective*, London ; Brussels: Institute for European Environmental Policy (IEEP).
- IEEP, 2016. *Sustainability criteria for biofuels made from land and non-land based feedstocks*, London (UK): Institute for European Environmental Policy.
- Institute for Public Policy Research, 2006. *Tailpipe trading: How to include road transport in the EU Emissions Trading Scheme*, London: Institute for Public Policy Research.
- IPCC, 2007. *Climate Change 2007 : Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*, Cambridge: Cambridge University Press.
- IPCC, 2014. Transport. In: *Climate Change 2014 : Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge: Cambridge University Press, pp. 599-670.
- ITF, 2016. *Shared Mobility. Innovation for liveable cities*, s.l.: International Transport Forum.
- ITF, 2017. *Transport demand and CO2 emission in 2050, in ITF Outlook 2017*, Paris: OECD Publishing.
- ITS Mobility Forum, 2013. *Identifying the most promising ITS solutions for clean and efficient mobility*. s.l.:s.n.
- JRC; TEPR; CE Delft, 2016. *Revision of the EU Green Public Procurement Criteria for Transport: Preliminary report (Draft)*, Brussels: European Commission.
- Keen et al., 2013. Planes, ships and taxes: charging for international aviation and maritime emissions. *Economic Policy* 28.76, pp. 701-749.
- Krenek & Schratzenstaller, 2016. *Sustainability-oriented EU Taxes: The Example fo a European Carbon-based Flight Ticket Tax*, Vienna: Austrian Institute of Economic Research.
- Ministry of Infrastructure and the Environment, 2016. *Dutch position on future co2 standard passenger vehicles (only in Dutch)*, The Hague: Ministry of Infrastructure and the Environment.
- MNP, 2005. *Effectiveness of the EU White paper: 'European transport policy for 2010'*, Bilthoven: Netherlands Environmental Assessment Agency (MNP).
- MNP, 2007. *Milieueffecten Eerste Stap Anders Betalen voor Mobiliteit*, Bilthoven: Planbureau voor de Leefomgeving (voorheen Milieu en Natuur Planbureau MNP).
- PBL and CE Delft, 2010. *Effecten van prijsbeleid in verkeer en vervoer, kennisoverzicht*, S.l.: PBL.
- PBL; Significance, 2014. *Options for the Road Freight Sector to Meet Long Term Climate Targets. Contribution tot the 2014 European Transport Conference*. Henley-in-Arden (UK), Association for European Transport (AET).
- PBL, 2009. *Getting into the Right Lane for 2050. A primer for EU debate*, Bilthoven: Planbureau voor de Leefomgeving.

- PBL, 2012. *Shifting Gear: Beyond Classical Mobility Policies and Urban Planning*. In: B. v. Wee, ed. *Chapter in Keep Moving, Towards Sustainable Mobility*. Den Haag: EEAC/RLI, pp. 151-178.
- PBL, 2016. *Wat betekent het Parijsakkoord voor het Nederlandse lange-termijn-klimaatbeleid?*, The Hague: Planbureau voor de Leefomgeving.
- Pelkmans et al., 2014. *Impact of promotion mechanisms for advanced and low-ILUC biofuels on biomass markets: Used cooking oil and animal fats for biodiesel (case study)*. IEA, Bioenergy Task 40, s.l.: s.n.
- Ricardo and TEPR, 2016. *Evaluation of Directive 1999/94/EC ("the car labelling Directive")*; final report, Brussels: European Commission.
- Ricardo Energy & Environment; TEPR, 2015. *Ex-post evaluation of Directive 2009/33/EC on the promotion of clean and energy efficiency road transport vehicles*, Brussels: European Commission (EC), Directorate-General for Mobility and Transport.
- Ricardo-AEA; TEPR; TU Graz; Cardiff Business School, 2015. *The potential for mass reduction of passenger cars and light commercial vehicles in relation to future CO2 regulatory requirements*, Didcot (UK): Ricardo-AEA.
- Ricardo-AEA, 2014. *Evaluation of the implementation and effects of EU infrastructure charging policy since 1995, final report*, London: Ricardo-AEA.
- Rupprecht Consult – Forschung und Beratung GmbH, 2014. *Guidelines : Developing and Implementing a Sustainable Urban Mobility Plan.*, Brussels: European Union.
- Scientific Advice Mechanism (SAM), 2016. *Closing the gap between light-duty vehicle real-world CO2 emissions and laboratory testing*, Brussels: European Commission, Directorate-General for Research and Innovation.
- Significance; CE Delft, 2010. *Price sensitivity of European road freight transport : towards a better understanding of existing results*, s.l.: Significance; CE Delft.
- Skinner, 2015. The mitigation of transport's CO2 emissions in the EU: policy successes and challenges. In: G. V. Calster, W. Vandenberghe & L. Reins, eds. *Research Handbook on Climate Change Mitigation Law*. challenges: Edward Elgar Publishing Ltd, pp. 103-125.
- State of California, 2016. *Zero emission vehicle standards for 2018 and subsequent model year passenger cars, light-duty trucks and medium-duty vehicles, California Code of Regulations paragraph 1962.2*. [Online] Available at: www.arb.ca.gov/msprog/zevprog/zevregs/1962.2_Clean.pdf
- Swedish Environmental Research Institute, 2006. *Greenhouse gas emissions trading for the transport sector*, Stockholm: Swedish Environmental Research Institute.
- T&E, 2014. *CO2 emissions from new cars in Europe: Country Ranking – How national car tax systems helped boost sales of lower-carbon cars across Europe in 2013*, s.l.: Transport and Environment (T&E).
- T&E, 2016a. *Globiom: the basis for biofuel policy post-2020*, Brussels: Transport & Environment.
- T&E, 2016b. *NGO letter to European Commission Vice President Šefčovič, Commissioners Bulc and Arias Cañete and to European Transport & Climate Ministers (25 April 2016)*., Brussels: Transport and Environment (T&E).
- TML, TNO, CE Delft, TRT, 2013. *Evaluation study on speed limitation devices*, Brussels: European Commission.
- TML, 2009. *Effecten van een kilometerheffing voor vrachtwagens : Eindrapport*, Leuven: Transport & Mobility Leuven (TML).

- TNO, 2013. *Study on Tyre Pressure Monitoring Systems (TPMS) as a means to reduce Light-Commercial and Heavy-Duty Vehicles fuel consumption and CO2 emissions*, Delft: TNO.
- TNO, 2015. *CO2-emissiefactoren voor de snelweg*, Delft: TNO.
- TNO, 2016. *Supporting analysis on real-world light-duty vehicle CO2 emissions*, Delft: TNO, Earth, Life & Social Sciences.
- Transport & Environment, 2014. *Including transport in the Emissions Trading Scheme: Counterproductive and legally questionable*, Brussels: Transport & Environment.
- UNEP, 2016. *The Emissions Gap Report 2016*, Nairobi: United Nations Environment Programme (UNEP).
- UNFCCC, 2016. *Methodological issues under the Convention Emissions from fuel used for international aviation and maritime transport*, Marrakech: United Nations Framework Convention on Climate Change (UNFCCC).
- US EPA, 2016. *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2016*, s.l.: United States Environmental Protection Agency (US EPA).
- Valin et al., 2015. *The land use change impact of biofuels consumed in the EU Quantification of area and greenhouse gas impacts*, s.l.: s.n.
- Viegand Maagøe A/S, 2015. *Review study on the Regulation (EC) No 1222/2009 on the labelling of tyres, final report*, Brussels: European Union.
- VTPI, 2017. *Generated Traffic and Induced Travel. Implications for Transport Planning*, Victoria (Canada): Victoria Transport Policy Institute.

DIRECTORATE-GENERAL FOR INTERNAL POLICIES

POLICY DEPARTMENT **B** STRUCTURAL AND COHESION POLICIES

Role

The Policy Departments are research units that provide specialised advice to committees, inter-parliamentary delegations and other parliamentary bodies.

Policy Areas

- Agriculture and Rural Development
- Culture and Education
- Fisheries
- Regional Development
- Transport and Tourism

Documents

Visit the European Parliament website:

<http://www.europarl.europa.eu/supporting-analyses>

PHOTO CREDIT: iStock International Inc., Photodisk, Phovoir



ISBN 978-92-846-1276-5 (paper)
ISBN 978-92-846-1277-2 (pdf)

doi:10.2861/97712 (paper)
doi:10.2861/840058 (pdf)