EU Transport GHG: Routes to 2050 II

Developing a better understanding of the secondary impacts and key sensitivities for the decarbonisation of the EU's transport sector by 2050

Nikolas Hill (AEA)
Charlotte Brannigan (AEA)
Richard Smokers (TNO)
Arno Schroten (CE Delft)
Huib van Essen (CE Delft)
Ian Skinner (TEPR)

29 July 2012
Final Report
Developing a better understanding of the secondary impacts and key sensitivities for the decarbonisation of the EU's transport sector by 2050


This paper is the copyright of the European Commission and has been prepared under a contract between the European Commission and AEA Technology plc dated 16 December 2010 (contract 070307/2010/579469/SER/C2). This project work follows on from previous work under European Commission contract ENV.C.3/SER/2008/0053, which completed in June 2010. This paper has been prepared by one of the partners in the project, i.e. AEA Technology plc (lead), CE Delft, TNO or TEPR (as indicated above). The contents of this paper may not be reproduced in whole or in part, nor passed to any organisation or person without the specific prior written permission of the European Commission. AEA Technology plc and its partners accept no liability whatsoever to any third party for any loss or damage arising from any interpretation or use of the information contained in this paper, or reliance on any views expressed therein.

Contact details

Nikolas Hill  Ian Hodgson
AEA  Transport and Ozone Unit
The Gemini Building, Fermi Avenue  Climate Action Directorate General
Harwell, Didcot  European Commission
OX11 0QF  CLIMA.C.2 Brussels
United Kingdom  Belgium

T +44 (0)870 190 6490  T +32 (0)2 298 6431
E EUTransportGHG2050@aeat.co.uk  E Ian.Hodgson@ec.europa.eu
E Nikolas.Hill@aeat.co.uk

Report Approved By:  Signed:
Sujith Kollamthodi  
(AEA Practice Director - Transport)  
Date:
29 July 2012

Project  Partners
www.eutransportghg2050.eu  www.aeat.co.uk
www.cedelft.nl  www.tno.nl
www.tepr.co.uk
Executive Summary

Objectives:
The purpose of this work was to:

- Develop an enhanced understanding of the wider potential impacts of transport GHG reduction policies, as well as their possible significance in a critical path to GHG reductions to 2050.
- Further develop the SULTAN illustrative scenarios tool to enhance its usefulness as a policy scoping tool and carry out further scenario analysis in support of the new project;
- Use the new information in the evaluation of the sensitivities for transport GHG reduction to 2050, in the context of transport’s 54-67% reduction target from the European Commission’s Roadmap for moving to a competitive low carbon economy in 2050;

The European Commission, DG Climate Action contracted a team led by AEA and including TNO, TEPR and CE Delft to carry out further analysis directly building on the work previously completed under the ‘EU Transport GHG: Routes to 2050?’ project. This new work (dubbed EU Transport GHG: Routes to 2050 II) started in January 2011 and was completed in March 2012. The outputs from this new project are intended to help the Commission in prioritising and developing the key future policy measures that will be critical in ensuring that GHG emissions from the transport sector can be reduced significantly in future years.

The project work is based around eight core technical tasks and two tasks supporting the stakeholder engagement activities, as summarised in Figure 1.1.

Figure ES1: Outline schematic of the EU Transport GHG: Routes to 2050 II project
This Final Report provides a summary of the work completed in the contract, with greater detail provided in the various papers relating to the individual tasks. These papers have been submitted at different points during the project, and the final versions are supplied alongside this report. They are also available from the project website (www.eutransportghg2050.eu), which will be online at least until 31st December 2015. The following sub-sections present a summary of the principal findings from each of the technical tasks. In addition, throughout the project stakeholders were consulted for their views on the different topics via a series of focus group meetings, two large stakeholder conferences and draft task papers made available from the project website.

General tasks and approach

The purpose of this project was to develop further areas that could not be assessed in detail and new areas that were not covered at all in the previous project. The required output of this work was to produce a series of Task papers that would explore each of the subject areas in detail, plus a final overall report bringing together a summary of the work in general (this report). As in the previous project the need to engage stakeholders was a fundamentally important element of this project. In order to achieve this objective a series of stakeholder meetings were to be organised (Task 9), plus the further development and maintenance of the project’s website (Task 10) in order to facilitate engagement and access to project outputs during the project and beyond the completion of the technical work. Finally, in order to allow for the coverage of topics not foreseen at the time of the work specification, an ad-hoc budget was provided (Task 11). The following is a summary of these three tasks:

⇒ Stakeholder Engagement (Task 9): A series of four focus group meetings and two large stakeholder conferences were successfully organised and held in order to facilitate discussion with stakeholders on the project’s key results and conclusions. Overall, the meetings helped to engage stakeholders, improve the work in the other tasks and reveal the key dilemmas;

⇒ Project Website (Task 10): The project website has been consistently maintained throughout the contract with new materials from the project. Provision has been made to ensure the website is available until 31st December 2015, as required by the contract;

⇒ Ad-hoc Requests (Task 11): Four pieces of work were commissioned under the ad-hoc budget, including three technical papers and some additional work carried out to further expand SULTAN functionality. Details on these elements are provided elsewhere in this report, together with the full papers as appendices (also available from the website).

Knock-on consequences of GHG reduction policies and measures

The purpose of Task 3 of the project was to explore likely knock-on consequences, for the road vehicle fleet, of three relevant potential policies: (i) speed-related instruments; (ii) fiscal instruments; and (iii) vehicle CO\textsubscript{2} legislation for passenger cars. Where possible, the work also investigated the impact of these changes on the effectiveness of measures to mitigate GHG emissions from the transport sector. The following is a summary of the main findings:

Main Findings regarding speed limit related instruments:

⇒ Speed limits can have significant impacts on GHG emissions of transport.

⇒ The impact on transport demand and modal split is the most significant knock-on effect, enhancing the net GHG emission impact of the measure. It can be of the same order of magnitude as the direct impact on fuel efficiency of vehicles.

⇒ Other knock-on consequences for GHG emissions are poorly understood, but likely to be relatively small.
EU Transport GHG: Routes to 2050 II
Contract 070307/2010/579469/SER/C2

Developing a better understanding of the secondary impacts, sensitivities for the decarbonisation of EU transport by 2050

Main Findings regarding vehicle CO\textsubscript{2} legislation:

⇒ Given the relatively short payback time of required technical reduction measures, the 130 g/km target for 2015 is likely to generate small negative knock-on consequences or rebound effects, reducing its effect and very likely its cost-effectiveness.

⇒ Based on the main cost curves from a recent study in support of defining the modalities for the 2020 target\textsuperscript{1}, the payback time of the technical reduction measures required for going from 130 gCO\textsubscript{2}/km to the 95 gCO\textsubscript{2}/km target in 2020 is significantly longer. As a result the 95 gCO\textsubscript{2}/km target is expected to lead to small but net positive knock-on consequences enhancing the effect and effectiveness of the legislation.

⇒ However, strong indications exist that the costs for meeting the 95 gCO\textsubscript{2}/km target could be lower that estimated using the main cost curves from the above mentioned study. Scenarios exploring the consequences of these indications lead to payback times that are equal to or shorter than what was estimated for the 130 gCO\textsubscript{2}/km target. Under these assumptions the 95 gCO\textsubscript{2}/km should be expected to result in small negative knock-on consequences, i.e. a rebound that reduces the impact and effectiveness of the legislation.

⇒ Due to strongly non-linear cost curves for CO\textsubscript{2} reduction through technical measures on the vehicle, CO\textsubscript{2} legislation to be developed for the period beyond 2020 will likely not suffer from rebounds, while positive knock-on consequences may enhance its effect and effectiveness.

⇒ Note: These assessments assume that the application of efficiency improving technology does lead to a net increase in purchase price.

Main Findings regarding fiscal instruments:

⇒ As with first order effects, the second-order impacts from instruments targeting car purchasing are likely to be significantly greater than those targeting ownership.

⇒ The knock-on consequences would vary depending on whether an instrument has been designed to raise revenue or to be revenue neutral (or even to reduce revenue).

⇒ The net effect on CO\textsubscript{2} emissions of the knock-on consequences is likely to be negative (against the intended policy impact), or at best neutral for revenue raising instruments.

⇒ The net impact of first and second order impacts is unclear and will depend on the elasticities used.

Risks and uncertainties of GHG reduction policies and measures

The purpose of Task 5 of the project was to: (a) explore and identify key risks and uncertainties associated with the achievability of relevant decarbonisation policies and measures, including lead times for policy implementation and time lags to the resulting impact on emissions; (b) assess the extent to which key factors outside the transport sector will affect decarbonisation of transport; (c) Develop approaches to address those risks and uncertainties and optimize achievability. The following is a summary of the main findings:

Main Findings regarding biofuels:

⇒ There are significant risks and uncertainties related to the conditions that need to be met if the full potential of GHG reduction with biofuels is to be realised: the availability of low-carbon biomass and biofuels, the GHG reduction they actually achieve, their cost and market uptake, biomass demand from other sectors.

⇒ In the coming years, realistic policy strategies should be developed for biofuels use in transport. These strategies should be part of a broader strategy on the most effective use of biomass, assessing how to optimise the supply and use of non-food biomass for the

\textsuperscript{1} [TNO/AEA/CE Delft/IHS/Ökopol/Ricardo/TML 2011], see Chapter 3.
Developing a better understanding of the secondary impacts, EU Transport GHG: Routes to 2050 II sensivities for the decarbonisation of EU transport by 2050 Contract 070307/2010/579469/SER/C2

Various potential applications in a sustainable future: transport, electricity, heat, materials and chemicals.

⇒ Policy implementation should focus on effective implementation and improvement of the biofuels GHG emission reduction and other sustainability criteria. Prevention of negative impacts due to ILUC is key in this development. Research into new (2nd generation) biofuels production processes and a diverse and reliable supply of biomass that does not cause negative impacts should be promoted, to ensure a diverse biomass supply in the future, prevent competition with the food sector and reduce negative impacts from land use change.

⇒ Market response to policies and the outcome of technological developments may differ from what was envisaged. The effects and broader impacts of the policy strategy and measures should therefore be monitored critically, and policies should be adapted when necessary.

⇒ In parallel, efforts should also be put into global initiatives that can reduce land use change and biodiversity loss due to biomass cultivation for biofuels, for example within the IPCC and CBD framework.

Main Findings regarding electricity and hydrogen in transport:

⇒ The implementation of electricity and hydrogen as GHG reduction options for the transport sector is a transition that involves drastic and structural changes in both the transport and the energy sector and that will take several decades to start up, roll out and complete.

⇒ Governments and stakeholders in the market need endurance and a long term vision to manage this transition in an effective way. Mitigating risks and taking away uncertainties is an important and unavoidable part of that.

⇒ Proactive steps are required in the short term in laying the ground work for longer term policy instruments, in early market formation and in setting up and managing a process that timely delivers the insights that are necessary to develop a suitable dominant design for the energy distribution infrastructure. For example, in the case of electric vehicles this dominant design relates to the roles of home charging, public slow charging, fast charging and battery swapping and the integration of this charging infrastructure in the future electricity grid, possible in combination with smart grids.

⇒ Important risk and uncertainties that require short term action relate to:

  o Impact of zero-emission vehicles under the CO₂ legislation for LDVs in combination with the need for a methodology on how to account for GHG intensity of energy carriers. Determining appropriate metrics is essential to make sure that post 2020 targets provide the right incentives to manufacturers and energy suppliers.

  o Uncertainty about the business case. This issue is closely linked with development of costs of vehicles and infrastructure, consumer acceptance and the role of supply and demand oriented policy measures on the business case.

  o Interaction with the energy system. This issue partly concerns developing a more mature view on the dominant design of the charging infrastructure for electric vehicles in interaction with grid-related developments on the local and regional scale, but also concerns interaction on a (trans)national level regarding how electric and hydrogen-fuelled vehicles on the one hand require decarbonisation on the energy supply system and on the other hand influence investments in generation infrastructure that may or may not be consistent with the need for decarbonisation.

Main Findings regarding economic instruments, particularly usage pricing:

⇒ If road usage charging is to be introduced, it should take place in addition to, rather than instead of, fuel taxation.


At the strategic, or conceptual, level, the main risks relate to the acceptability by the public and business of the introduction of road user charging, and the associated political risk.

These strategic risks are linked to, and based on, a number of other economic, social and environmental risks. These include business concerns about the impact on trade or costs, and the social concerns relating to the impact on mobility, particularly for the poorer sections of society.

Some of the risks are perceived, but many are real, and could be addressed either in the design of the charging scheme, or by the introduction of complementary policy instruments (which could even be introduced in advance of the charging scheme itself).

Co-benefits associated with GHG reduction policies and measures

The purpose of Task 1 of the project was to develop a better understanding of the air quality, energy security, environmental noise, and health co-benefits associated with possible transport sector GHG reduction policies. Additional investigations on the interaction of GHG policy for transport with congestion and accessibility policies was also included under the Task 11 ad-hoc budget. The following is a summary of the main findings:

**Air Quality**

GHG reduction options can have varying effects on emissions of air pollutants

GHG reduction options likely to have a positive impact on reducing air pollutant emissions include hydrogen (when produced from natural gas reformation and coal gasification); electric vehicles where non-fossil energy is used; hybrid electric and PHEVs when used in urban environments; measures affecting driving style (e.g. eco-driving, speed limits); non-technical measure (e.g. economic instruments and spatial policy – affecting transport activity and modal split); and technologies such as regenerative braking that can reduce non-exhaust air pollutant emissions.

GHG reduction options which are likely to have a negative effects on reducing air pollutant emissions include hydrogen (produced by water electrolysis, although predicted to decrease in future); electric vehicles using electricity generated using average European grid mix; hybrid and PHEVs when used in non-urban locations; and biofuels (tend to emit same or higher air quality pollutant emissions over fuel lifecycle)

**Noise**

GHG policies aimed at reducing emissions in urban areas by access restriction have potentially large traffic noise reductions and take immediate effect both for road and rail.

Introduction of electric, fuel cell and hybrid powertrains will generally reduce environmental noise, but take 12 years to reach full impact on average road traffic noise levels, mostly in urban areas. For railways the effect is smaller to the predominance of rolling noise. The effect will mainly be for lower speeds and in acceleration and stationary idling conditions.

**Energy Security**

The results suggest that energy demand reduction is consistently the best option for energy security.

In the short-term, conventional fuels score well because a high proportion of the vehicle fleet is able to use them and prices are currently low. Costs are projected to increase over time, and indicators for surplus capacity show that oil-derived fuels become less secure as global stocks are depleted.

In the longer term, oil-derived liquid fuels also become more susceptible to supply disruptions. Biofuels also show a reduction in energy security due to increasing resource concentration, poorer supply resilience and a lack of surplus capacity.
Developing a better understanding of the secondary impacts, EU Transport GHG: Routes to 2050

Electricity and hydrogen are the only fuels that become more secure, due to increased contributions from renewable technology production.

Modelling results suggest that GHG policies could lead to significant benefits for transport energy security. Under the core reduction scenario (broadly consistent with the Transport White Paper targets), the energy security rating shows a drop of only 5% between 2010 and 2050.

Health – Accidents

Reduction in speed levels (speed limits), introduction of road charging, reduction in average vehicle mass (vehicle standards), and a shift from car to public transport are likely to have positive effects on accidents (number and/or severity).

Health – Physical Activity

Where more active modes are stimulated, more people will cycle and walk.

Per km health benefits from increased physical activity from cycling varies from €0.30 to around €1.20.

In terms of potential benefits in the EU, if 10% inactive people become active through increased cycling and walking, the health benefit could be in the range of €9 to €37 billion. This could increase to €31 to €122 billion if one third of the inactive population became active.

Congestion

Win-neutral policies: Many instruments to tackle GHG only have small impact on congestion (e.g. technology options that are not tied to location or time);

Win-lose policies: Instruments aimed at reducing congestion often have potential for increasing GHG (mostly related to capacity expansion). Therefore it is important to consider both short-term (flow) and long-term impacts (induced demand);

Win-win policies: These include taxes and charges make car travel less attractive and shifts to more footprint efficient modes (e.g. bus) or non-road modes.

Policy implications: It is important to take into account the risk of adverse effects in the decision making process. There should be a focus on policy instruments related to the reduction of congestion, since congestion reducing instruments might significantly increase GHG. Where infrastructure expansion is considered, there is a general need to investigate whether the same congestion reduction can be achieved in other ways that do not lead to a GHG increase.

Relative values of different co-benefits and conclusions

Currently of all transport externalities congestion and accidents are estimated to have the highest costs, although by 2050 the combined cost impacts of GHG, air quality pollutants and energy security are likely to be at least of a similar size under business as usual conditions;

Monetised co-benefits for different scenarios show combined co-benefits of GHG policy actions could be very significant – up to €243 billion per annum by 2050 (also including GHG savings) under the core GHG reduction scenario (R1-a) and total benefits could potentially be as high as €384 billion per annum by 2050 if all modelled mitigation options were implemented (scenario C5-a).

Non-technical measures can have the largest co-benefits per tonne GHG abated - particularly for those leading to increases in walking and cycling (due to health benefits).
Cost effectiveness of different GHG reduction policies and measures

The purpose of this task was to develop a better understanding of the cost effectiveness of different technical and behavioural measures and policy instruments. The following is a summary of the main findings:

⇒ In the short term, several technical measures for passenger cars and heavy good vehicles with negative abatement costs are available.

⇒ With respect to behavioural measures, fuel efficient driving and probably also teleworking result in negative abatement costs. The purchase of an electric or smaller car (i.e. instead of a regular car), on the other hand, will probably result in positive abatement costs.

⇒ For some of the GHG policies (e.g. vehicle standards, fuel taxes, road user charges) it was found that they could be implemented in a cost effective way. However, the cost effectiveness of these policies is strongly case dependent due to the large dependency on local/national characteristics and the design of the instrument.

GHG emissions from infrastructure construction, vehicle manufacturing, and end of life vehicles (ELVs)

The purpose of Task 2 of the project was to develop a better understanding of the role and significance of GHG emissions resulting from infrastructure construction and use, vehicle manufacturing, and end of life vehicles (ELVs). In particular, a key objective was to ascertain if consideration of these aspects might influence the optimal pathway to transport sector GHG reduction by 2050. The following is a summary of the main findings:

General

⇒ The key materials and components influencing the overall GHG footprint for the construction of new transport infrastructure and vehicles (and factoring in recycling benefits) include: iron/steel, aluminium, plastics, cement/concrete and batteries.

⇒ The potential GHG intensity of European production of these key materials is anticipated to reduce by between 30% and 55% from 2010 to 2050, depending on the material. However, these materials will be sourced globally (particularly where vehicle construction occurs outside of the EU) where the improvement rate may not be as great.

Infrastructure construction and use

⇒ There is relatively little information in the literature that provides significant detail on the GHG footprint of infrastructure in relation to overall GHG emissions, except for rail transport. However, there are a range of studies that explore specific aspects in more detail for both road and rail infrastructure.

⇒ The contribution of GHG emissions from the development and use of transport infrastructure varies significantly between different transport modes (though typically 15-30% over the overall GHG footprint), and is highly dependant on a range of factors, such as: (i) how intensively specific infrastructure is used, (ii) the lifetime activity of the vehicles using them, and (iii) the GHG intensity of the energy used to power the infrastructure and vehicles. This makes it difficult to assess the impacts of future infrastructure development at an EU level without local context.

⇒ A scoping analysis of the potential contribution of GHG emissions resulting from land use change (LUC) on rail and road infrastructure impacts concluded that these LUC were unlikely to contribute significantly to total infrastructure emissions.

⇒ Considering the available information for different modes, it appears unlikely that factoring in GHG emissions from infrastructure development and use will significantly influence the selection of optimal pathways to GHG reduction at the EU level. However, such considerations are likely to have an important effect on specific development projects at a local level, so should ideally be factored into their impact assessments.
Vehicle manufacturing and end of life vehicles

⇒ For road and rail, GHG emissions vehicle manufacturing and disposal is predominantly due to the use of materials (around 60% for current technologies, and larger for battery electric and fuel cell vehicles). For aviation, most of the GHG emissions are due to energy consumption resulting from the manufacturing process (including electricity, as well as diesel for vehicles transporting components). Very little information is available in the literature for ship production and disposal, preventing a more detailed assessment.

⇒ For vehicle production and disposal, some future technologies have significantly higher GHG emissions (e.g. for battery electric and hydrogen fuel cell cars). However, indicative analysis carried out under Task 2 of this project suggests their net benefits in terms of GHG savings over conventional technologies are still anticipated to be significant factoring in the operational energy use of vehicles.

Overall conclusions

⇒ GHG emissions due to transport infrastructure and vehicle manufacturing and disposal are significant components of the current overall transport GHG footprint that are likely to significantly increase in their importance in the long term.

⇒ Policy action should therefore be taken to minimise the degree to which future GHG emissions from infrastructure development and use, vehicle production and disposal erode the GHG savings benefits due to the improved operational energy use of vehicles.

SULTAN development and scenario analysis

The purpose of Task 6 of the project was to: (a) Further develop the SULTAN Illustrative Scenarios Tool to further improve its usefulness for scoping possible impacts of policies on transport GHG emissions and to facilitate analysis to feed into other project tasks; (b) update the baseline scenario to be consistent with Commission modelling and develop additional policy scenarios and packages to feed into other project tasks. The findings of the Task 11 ad-hoc paper 2 considering future road vehicle GHG emission targets are also considered here. The following is a summary of the main findings:

SULTAN Development

The SULTAN tool and its results viewer have been updated to provide a new baseline (business as usual) scenario, consistent with the latest Commission modelling, and with additional functionality to assist with scenario definition and impact analysis (including tables on biofuel use, energy security indicators, monetisation of emission impacts, etc).

Scenario Analysis

The analysis has illustrated the need for a balanced mix of well integrated policy actions to reduce the risk of failure to reach targets (maybe also with an extra safety margin). In addition, the following conclusions were drawn from the analysis:

⇒ Co-benefits (Task 1):
  – There is the potential for air quality, energy security and health co-benefits generating savings of up to €177bn annually by 2050 versus business as usual for scenario R3-b in the case of low biofuel and electricity GHG savings (with total benefits rising to up to €323bn, including GHG savings);
  – The greatest co-benefits per tonne GHG are achieved for actions that reduce overall vkm or shift to more efficient modes (particularly for increasing walking and cycling);

⇒ Embedded GHG emissions (Task 2):
  – Vehicle production and disposal related GHG emissions are currently a significant component of the vehicle lifecycle GHG footprint (particularly for LDVs) – accounting for an estimated 11% of all in-year transport GHG emissions. It is expected this
proportion will increase substantially versus vehicle use GHG emissions in the future (potentially doubling on average, and more than tripling for some modes).
- It is therefore important to take action to ensure potential erosion of the GHG reduction benefits of policy actions is minimised as far as possible;
- However, it appears that this aspect is unlikely to alter the preferred or optimal pathway to total GHG reduction (e.g. there are still significant net GHG benefits for increasingly electrified road transport).

⇒ **Knock-on consequences (Task 3):**
- Negative knock-on consequences, or rebound effects, are one of the reasons why many policy instruments as well as the actual implementation of GHG reduction options may not yield the beforehand expected GHG savings. One exception to this are speed limiting measures which tend to have positive knock-on consequences that enhance the net GHG reduction.
- Therefore it may be desirable err on the side of caution in setting paths, for example through the application of more stringent new road vehicle GHG standards.
- Stronger GHG standards would also provide additional air quality pollutant and energy security co-benefits and reduce the biofuel volumes required to meet targets.

⇒ **Decoupling of transport demand and GDP (Task 4):**
- One of the conclusions of Task 4 was that decoupling seems unlikely without implementation of a limited number of specific policies (speed, pricing, land use). This could mean that the baseline assumptions of decoupling are over-optimistic.
- The exploration of sensitivities in demand showed that higher demand implies that additional or stronger actions may be needed to build contingency, e.g. in setting trajectories for new vehicle GHG standards or applying non-technical measures;

⇒ **Risks & Uncertainties (Task 5):**
- Significant uncertainties around GHG savings from biofuel and electricity were identified in Task 5 and assessed in the core sensitivity analysis.
- These pose a risk of leading to very large gaps versus GHG targets if over-reliance is placed on these options or action is not taken to mitigate the risks.
- Alternative options require a lead time for sufficient deployment by 2050, so need to be factored in early.

**Potential impacts of policies that could be put in place by 2020**

The purpose of Task 7 of the project was to: (a) examine the long-term emissions impacts of policies that could be introduced prior to 2020 through SULTAN scenario analyses; (b) identify additional policy measures that may need to be implemented prior to 2020 to achieve long term emissions reductions; (c) investigate the impacts of these policies on cumulative GHG emissions out to 2050; and (d) Explore the emissions trajectories and emissions budgets that may be required. The following is a summary of the main findings:

⇒ Weakening of biofuel GHG performance criteria could result in significantly increased GHG emissions, and unless compensated for could lead to missing the 2050 target by as much as 100 MtCO₂e (scenario P4-b).

⇒ Action on external costs and shipping/aviation has been shown to be very important. If less action than anticipated is taken in these areas (scenarios P2-b and P6-b), then the 2050 60% GHG reduction target could be missed by 35 / 60 MtCO₂e respectively.

⇒ Should existing policies fail to deliver or be weakened, additional actions would have to be implemented in order to make up for the shortfall in GHG emission reductions. Actions that could be necessary include:
  - Additionally tightened GHG targets for road vehicles;
  - Strong levels of speed enforcement and motorway speed reductions;
  - Eco-driver training; and
  - Measures that significantly improve vehicle loading and reduce demand vs BAU.
Both policy design and timing are important. Policies may result in higher transport costs, less perceived freedom and infringement of perceived rights – reserved attitude from politicians, industry and public may result. Therefore early action and well developed communication required. Delay of policy can also lead to the need to take stronger actions to catch up in later years (increased cost, reduced feasibility);

Potential emissions budgets to achieve 2030 and 2050 GHG emission reduction targets may be developed through identifying the cumulative emissions over 5-year periods in emissions trajectory to 2050.

Potential emissions budgets for R1-a and 2050 Roadmap (low) ensure that WP 2050 targets are met (ahead for 2030). Both scenarios have an increased rate of emissions reduction after 2030, which is necessary in order to meet the 2050 60% reduction target. It is also increased in later years due to the reliance on applying low carbon technologies to significant portions of the vehicle fleet - initially limited by the fleet turnover rates.

The average annual rate of GHG reduction for the BAU is just 0.31%. The R1-a scenario has an average annual rate of reduction of 2.55%, compared to 3.01% and 2.26% for the low and high 2050 Roadmap scenarios respectively (and all are lower than the current UK carbon budgets, at 3.3%).

In setting carbon budgets, it is generally recognised that it is desirable to set more stringent budgets in earlier periods to help ensure actions required to meet long-term targets start happening as soon as possible.

The potential for less transport-intensive paths to societal goals

The purpose of Task 4 of the project was to provide an overview of alternative development paths that could be less transport intensive, but still deliver increasing levels of prosperity and show preconditions for such development paths, particular ways of redefining ‘economic growth’ (e.g. ‘Green GDP’). The following is a summary of the main findings:

Over the last decades no clear indication of a decoupling of freight transport from economic growth in the EU has been found. For passenger transport the evidence is less clear; there has been a decoupling of land-based transport from GDP growth, but this decoupling is (at least partly) reduced by a coupling of air passenger transport and GDP growth. Also for the (near) future no significant decoupling is expected.

Important potential drivers of decoupling freight transport are a reduction of spatial concentration of the production of goods (although it should be considered to what extent reductions in transport volumes are undone by reductions in GDP growth) and a shift to less transport intensive economic sectors (although leakage effects should be considered). Important drivers of decoupling passenger transport are a change in consumption patterns (less consumption of transport) and urban re-densification.

The aim of both alternative welfare indicators and a more fundamental transition towards a more sustainable economy is to change the relative balance of environmental and social considerations compared to economic considerations.

Both have similar implications for transport’s GHG emissions, as the impact will depend on the combined effect of the likely net benefit from greater consideration of environmental impacts and the net change in emissions due to an improved consideration of social issues.

However, an important difference is that a more fundamental change to a sustainable economy implies meeting economic and social objectives within environmental boundaries.
Considerations relating to the co-evolution of regulation and economic instruments

The Task 11 ad-hoc paper 3 explored how regulation and economic instruments might work together in order to reduce GHG emissions from transport. The following is a summary of the main findings:

⇒ The most appropriate combination of regulation and economic instruments strongly depends on the evolution of the total costs of ownership and the longer-term behavioural responses to policies, which are as yet unknown.

⇒ There are a number of benefits of using regulation and economic instruments together to deliver GHG reductions from transport. This, along with the uncertainty associated with specific instruments, suggests that using a range of instruments is important to reduce transport’s GHG emissions.

⇒ Additionally, it might be wise, from the perspective of increasing the chances that transport delivers significant reductions in CO₂ emissions, to make sure that policy is able to cater for a pessimistic longer-term scenario in which some or all alternative technologies do not become competitive. Such policy instruments require time to be prepared and implemented, which argues for early action.

Overall conclusions

A number of important conclusions were reached at the end of the previous project with regards to decarbonising the EU transport sector, as summarised in the final project report under three key headings, which were:

i. The need to stimulate a broad range of technical and non-technical options;

ii. The need for a wide range of complementary policy instruments;

iii. The urgent need for action.

There was also a range of further work previously identified to help further enhance the overall picture that has formed the basis of many of the tasks carried out under this new project as discussed above. Overall the new work has broadly reinforced the previous high-level findings, whilst demonstrating there are likely to be significant co-benefits from GHG reduction policies which help to improve cost-effectiveness for society. The work clearly shows that there is a need for a balanced mix of well integrated policy actions to reduce the risk of failure to reach the desired long-term GHG reduction targets. Considering the risks and uncertainties associated with the delivery of key options it may also be beneficial to build in a level of contingency or safety margin. The likely increasing future significance of GHG emissions from development and use of transport infrastructure and the production and disposal of vehicles mean it will also be important to take action to ensure these do not significantly erode the benefits of GHG reductions in vehicle operational energy use. Finally, setting 5-year cumulative GHG budgets for the EU transport sector could be an effective way to encourage timely action and minimise total cumulative GHG emissions in the long term.

Table of Contents

Executive Summary ........................................................................................................ iii

1 Introduction ................................................................................................................ 1
  1.1 The contribution of transport to GHG emissions .............................................. 2
  1.2 Background to the project and its objectives .............................................. 6
  1.3 Structure of the paper ..................................................................................... 8

2 General tasks and approach ..................................................................................... 9
  2.1 General Approach .......................................................................................... 9
  2.2 Stakeholder Engagement ............................................................................. 10
  2.3 Project Website .......................................................................................... 11
  2.4 Ad-hoc Tasks .............................................................................................. 11

3 Knock-on consequences of GHG reduction policies and measures .............. 13
  3.1 Introduction .................................................................................................. 14
  3.2 Relevance of acknowledging knock-on consequences .................................. 15
  3.3 Conclusions .................................................................................................. 16
  3.3.1 Speed related instruments .................................................................... 16
  3.3.2 Vehicle CO₂ legislation ......................................................................... 17
  3.3.3 Fiscal instruments .................................................................................. 18

4 Risks and uncertainties of GHG reduction policies and measures ........... 20
  4.1 Introduction .................................................................................................. 21
  4.2 Risks and uncertainties in different steps of the policy process .................. 24
  4.2.1 Conception of the policy strategy ......................................................... 24
  4.2.2 Implementation of the policy strategy by means of policy instruments .... 24
  4.2.3 Implementation of technologies and behavioural changes in response to incentives provided by the policy instruments .................................................. 25
  4.2.4 Other impacts, related to the sustainability or other aspects of the implemented technologies and behaviours ......................................................... 26
  4.3 Conclusions .................................................................................................. 27
  4.3.1 Biofuels .................................................................................................. 27
  4.3.2 Electricity and hydrogen in transport ..................................................... 27
  4.3.3 Economic instruments, particularly usage pricing .................................. 29

5 Co-benefits associated with GHG reduction policies and measures .......... 30
  5.1 Introduction .................................................................................................. 31
  5.2 Air Quality .................................................................................................... 32
Developing a better understanding of the secondary impacts, sensitivities for the decarbonisation of EU transport by 2050

5.3 Noise
5.4 Energy Security
5.5 Health
5.5.1 Health - Accidents
5.5.2 Health - Physical activity
5.6 Congestion
5.6.1 Understanding the GHG impacts of congestion
5.6.2 Impacts of policy instruments
5.6.3 Policy recommendations
5.7 Relative values of different co-benefits
5.8 Conclusions

6 Cost effectiveness of different GHG reduction policies and measures .... 40
6.1 Introduction
6.2 Technical measures
6.3 Behavioural measures
6.4 Policy instruments
6.5 Conclusions

7 GHG emissions from infrastructure construction, vehicle manufacturing, and end of life vehicles (ELVs) ............................................. 45
7.1 Introduction
7.2 General considerations
7.3 Transport infrastructure
7.4 Vehicle manufacturing and ELVs
7.5 Overall comparisons, scenario analysis and conclusions
7.5.1 Infrastructure
7.5.2 Vehicle production and disposal
7.5.3 General Conclusions

8 The potential for less transport-intensive paths to societal goals .......... 57
8.1 Introduction
8.2 Decoupling of transport and GDP growth
8.3 Alternative welfare measures and their implications for transport
8.4 Policy implications

9 Considerations relating to the co-evolution of regulation and economic instruments .............................................................................. 61
9.1 Introduction
9.2 Exploration of the impacts of potential single instrument solutions
9.3 The benefits of using different instruments in an evolving policy framework
9.4 Conclusions on the co-evolution of regulation and economic instruments ........63

10 SULTAN development and scenario analysis ........................................ 64
   10.1 Introduction ...................................................................................65
   10.2 SULTAN Development ..................................................................65
   10.2.1 Update of baseline and original scenarios .................................65
   10.2.2 New Functionality .....................................................................67
   10.3 Scenario Development and Analysis ...............................................67
   10.3.1 New simple scenarios ...............................................................67
   10.3.2 Central ‘Routes to 2050’ scenarios ...........................................68
   10.3.3 Sensitivity analysis on alternate new road vehicle GHG trajectories ....75
   10.4 Summary and Conclusions ............................................................79

11 Potential impacts of policies that could be put in place by 2020........... 80
   11.1 Introduction ..................................................................................81
   11.2 Results of the scenario analysis ......................................................82
   11.3 Exploration of potential EU-level transport GHG emission budgets ....84
   11.4 Conclusions ..................................................................................85

12 Overall Conclusions ............................................................................86

Appendices .............................................................................................89
List of Tables

Tables in the main body of the report

Table 2.1: Summary of the work allocated and completed under the Task 11 ad-hoc budget ................................................................. 11
Table 6.1: Example estimates of the cost effectiveness figures of certain policy instruments based on some specific case studies ................................................. 44

List of Figures

Figures in the main body of the report

Figure 1.1: Outline schematic of the EU Transport GHG: Routes to 2050 II project .......... 1
Figure 1.2: EU27 greenhouse gas emissions by sector and mode of transport, 2009 .... 2
Figure 1.3: Business as usual projected growth in transport’s lifecycle GHG emissions by mode ........................................................................................................ 5
Figure 1.4: EU overall emissions trajectories against transport emissions (indexed) ...... 6
Figure 5.1: Comparison of potential air quality pollutant emission costs for different individual measures and policy/scenario packages in 2050 ........................................ 33
Figure 5.2: Comparison of the relative energy security of different scenarios ................. 35
Figure 5.3: Comparison of the combined monetised benefits of reduced GHG and air quality pollutant emissions, improved energy security and the health benefits of walking and cycling for different individual measures and scenario packages versus the BAU scenario in 2050 ........................................................................ 39
Figure 6.1: Indicative ranges of short term (2020) abatement costs of various technical and behavioural GHG reduction options for passenger cars and HGVs .......... 41
Figure 7.1: Estimates of future GHG intensity of key materials and current production of key materials in Europe compared to the rest of the world ......................... 47
Figure 7.2: Transoceanic lifecycle emissions of CO₂ (adapted from Walnum 2011) ......... 49
Figure 7.3: Life-cycle emissions in aviation (Simonsen, 2011) ........................................ 50
Figure 7.4: Comparison of the relative significance of GHG emissions from infrastructure development and operation as a proportion of overall lifecycle GHG emissions (including vehicle energy consumption and vehicle production and disposal) for different modes of transport ........................................................................ 53
Figure 7.5: Comparison of the GHG emissions breakdown from vehicle manufacture and disposal by material for different modes of transport ........................................ 53
Figure 7.6: Comparison by transport mode of the proportion of GHG emissions from vehicle manufacture and disposal versus emissions resulting from in-use energy consumption .................................................................................. 54
Figure 7.7: Potential impacts on total annual lifecycle GHG emissions of factoring in emissions from the production and disposal of new vehicles – comparison of cars versus all modes of transport for the core GHG reduction scenario (R1-a) ..................................................................................................................................... 55
Figure 7.8: Comparison of the total annual GHG emissions including vehicle production and disposal in 2050 for passenger cars for the different project Routes to 2050 scenarios ........................................................................... 56
Figure 10.1: Comparison of the SULTAN business as usual scenarios from current and previous projects ...................................................................... 66
Figure 10.2: Comparisons of the overall time series trajectories of GHG emissions for the different simple scenarios developed under Task 6 of the project

Figure 10.3: Comparisons of the overall timeseries trajectories of GHG emissions for the different Routes to 2050 sensitivity scenarios developed under Task 6 of the project (unadjusted*)

Figure 10.4: Comparison of the decomposition of impacts by scenario versus the baseline (BAU-a)

Figure 10.5: Comparison of differences in annual lifecycle GHG emissions and demand for different Routes to 2050 scenarios relative to the core reduction scenario (R1a) for 2050

Figure 10.6: Biofuel use in different Routes to 2050 scenarios in comparison to the baseline (BAU-a) and core reduction scenario (R1a)*

Figure 10.7: Summary of the impacts of the Routes to 2050 sensitivity scenarios with respect to total air quality pollutant emissions from transport versus the BAU scenario

Figure 10.8: Comparison of the estimated impacts on energy security of the adjusted Routes to 2050 sensitivity scenarios with the baseline (BAU-a) scenario

Figure 10.9: Summary of the total monetised co-benefits of the adjusted Routes to 2050 GHG reduction sensitivity scenarios versus the BAU scenario

Figure 10.10: Comparison of the lifecycle GHG impacts of different scenarios on LDV and HDV GHG standard trajectories versus the core GHG reduction scenario (R1-a) / 2050 target

Figure 10.11: Comparison of the relative volumes of biofuels needed to achieve low and high new vehicle GHG standard trajectories

Figure 10.12: Comparison of technology deployment rates needed to achieve low and high new vehicle GHG standard trajectories (V6-a and V7-a respectively)

Figure 10.13: Comparison of the lifecycle GHG trajectories for the MIN (V6-a) and MAX (V7-a) GHG standard trajectories versus BAU and R1-a, and the corresponding direct and indirect vehicle emissions per km for passenger cars

Figure 10.14: Comparison of the total annual GHG emissions including vehicle production and disposal in 2050 for passenger cars for the adjusted new vehicle GHG standard scenarios versus R1-a

Figure 11.1: Deviation from core scenario as a result of strengthening or weakening of single measures: cumulative emissions

Figure 11.2: Deviation from core scenario as a result of strengthening or weakening of single measures: 2050 emissions
## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU</td>
<td>Business as usual, i.e. the projected baseline of a trend assuming that there are no interventions to influence the trend.</td>
</tr>
<tr>
<td>BEV</td>
<td>Battery electric vehicle, also referred to as a pure electric vehicle, or sometimes simply a pure EV. A vehicle powered solely by electricity stored in on-board batteries, which are charged from the electricity grid.</td>
</tr>
<tr>
<td>Biofuels</td>
<td>A range of liquid and gaseous fuels that can be used in transport, which are produced from biomass. These can be blended with conventional fossil fuels or potentially used instead of such fuels.</td>
</tr>
<tr>
<td>Biogas</td>
<td>A gaseous biofuel predominantly containing methane which can be used with or instead of conventional natural gas. Biogas used in transport is also referred to as biomethane to distinguish it from lower grade/unpurified biogas (e.g. from landfill) containing high proportions of CO₂.</td>
</tr>
<tr>
<td>Biomethane</td>
<td>Biomethane is the term often used to refer to/distinguish biogas used in transport from lower grade/unpurified biogas (e.g. from landfill) used for heat or electricity generation. Biomethane is typically purified from regular biogas to remove most of the CO₂.</td>
</tr>
<tr>
<td>CNG</td>
<td>Compressed Natural Gas. Natural gas can be compressed for use as a transport fuel (typically at 200bar pressure).</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide, the principal GHG emitted by transport.</td>
</tr>
<tr>
<td>CO₂e</td>
<td>Carbon dioxide equivalent. There are a range of GHGs whose relative strength is compared in terms of their equivalent impact over one hundred years to one tonne of CO₂. When the total of a range of GHGs is presented, this is done in terms of CO₂ equivalent or CO₂e.</td>
</tr>
<tr>
<td>DG TREN</td>
<td>European Commission’s Directorate-General on Transport and Energy. This DG was split in 2009 into DG Mobility and Transport (DG MOVE) and DG Energy.</td>
</tr>
<tr>
<td>Diesel</td>
<td>The most common liquid transport fuel, which is used in various forms in a range of transport vehicles, e.g. heavy duty road vehicles, inland waterway and maritime vessels, as well as some trains.</td>
</tr>
<tr>
<td>EEA</td>
<td>European Environment Agency.</td>
</tr>
<tr>
<td>EV</td>
<td>Electric vehicle. Sometimes used to denote a BEV, but also used as a general term for vehicles with electric propulsion, including FCEV, BEV, PHEV, etc. A vehicle which is able to propel itself over substantial distances using electric power.</td>
</tr>
<tr>
<td>FCEV</td>
<td>Fuel cell electric vehicle. A vehicle powered by a fuel cell, which uses hydrogen as an energy carrier.</td>
</tr>
<tr>
<td>GHGs</td>
<td>Greenhouse gases. Pollutant emissions from transport and other sources, which contribute to the greenhouse gas effect and climate change. GHG emissions from transport are largely CO₂.</td>
</tr>
<tr>
<td>HEV</td>
<td>Hybrid electric vehicle. A vehicle powered by both a conventional engine and an electric battery, which is charged when the engine is used.</td>
</tr>
<tr>
<td>ICE</td>
<td>Internal combustion engine, as used in conventional vehicles powered by petrol, diesel, LPG and CNG.</td>
</tr>
<tr>
<td>IWW</td>
<td>Inland Waterway</td>
</tr>
</tbody>
</table>

*Terms highlighted in bold have a separate entry.*
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerosene</td>
<td>The principal liquid fuel used by aviation, also referred to as jet fuel or</td>
</tr>
<tr>
<td></td>
<td>aviation turbine fuel in this context.</td>
</tr>
<tr>
<td>Lifecycle</td>
<td>In relation to fuels, these are the total emissions generated in all of the</td>
</tr>
<tr>
<td>emissions</td>
<td>various stages of the lifecycle of the fuel, including extraction, production,</td>
</tr>
<tr>
<td></td>
<td>distribution and combustion. Also known as WTW emissions when limited</td>
</tr>
<tr>
<td></td>
<td>specifically to the energy carrier or fuel.</td>
</tr>
<tr>
<td>LNG</td>
<td>Liquefied Natural Gas. The liquefied form of Natural gas that can be</td>
</tr>
<tr>
<td></td>
<td>used as a transport fuel.</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas. The liquefied form of propane which can be</td>
</tr>
<tr>
<td></td>
<td>used as a transport fuel.</td>
</tr>
<tr>
<td>MtCO(_2)e</td>
<td>Million tonnes of CO(_2)e.</td>
</tr>
<tr>
<td>Natural gas</td>
<td>A gaseous fossil fuel, largely consisting of methane, which is used at low</td>
</tr>
<tr>
<td></td>
<td>levels as a transport fuel in the EU.</td>
</tr>
<tr>
<td>NGV</td>
<td>Natural Gas Vehicle. Vehicles using methane as a fuel, including in its</td>
</tr>
<tr>
<td></td>
<td>compressed and liquefied forms.</td>
</tr>
<tr>
<td>NO(_x)</td>
<td>Oxides of nitrogen. These emissions are one of the principal pollutants</td>
</tr>
<tr>
<td></td>
<td>generated from the burning of fossil and biofuels in transport vehicles.</td>
</tr>
<tr>
<td>Options</td>
<td>These deliver GHG emissions reductions in transport and can be</td>
</tr>
<tr>
<td></td>
<td>technical or non-technical.</td>
</tr>
<tr>
<td>Petrol</td>
<td>Also known as gasoline and motor spirit. The principal fuel used in light</td>
</tr>
<tr>
<td></td>
<td>duty transport vehicles, such as cars and vans. This fuel is similar to</td>
</tr>
<tr>
<td></td>
<td>aviation spirit also used in some light aircraft in civil aviation.</td>
</tr>
<tr>
<td>PHEV</td>
<td>Plug-in hybrid electric vehicle, also known as extended range electric</td>
</tr>
<tr>
<td></td>
<td>vehicle (ER-EV). Vehicles that are powered by both a conventional</td>
</tr>
<tr>
<td></td>
<td>engine and an electric battery, which can be charged from the electricity</td>
</tr>
<tr>
<td></td>
<td>grid. The battery is larger than that in an HEV, but smaller than that in a</td>
</tr>
<tr>
<td></td>
<td>BEV.</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate matter. These are one of the principal pollutant emissions</td>
</tr>
<tr>
<td></td>
<td>generated from the burning of fossil and biofuels in transport vehicles.</td>
</tr>
<tr>
<td>Policy</td>
<td>These may be implemented to promote the application of the options for</td>
</tr>
<tr>
<td>instrument</td>
<td>reducing transport’s GHG emissions.</td>
</tr>
<tr>
<td>TTW emissions</td>
<td>Tank to wheel emissions, also referred to as direct or tailpipe emissions.</td>
</tr>
<tr>
<td></td>
<td>The emissions generated from the use of the fuel in the vehicle, i.e. in its</td>
</tr>
<tr>
<td></td>
<td>combustion stage.</td>
</tr>
<tr>
<td>WTT emissions</td>
<td>Well to tank emissions, also referred to as fuel cycle emissions. The total</td>
</tr>
<tr>
<td></td>
<td>emissions generated in the various stages of the lifecycle of the fuel prior</td>
</tr>
<tr>
<td></td>
<td>to combustion, i.e. from extraction, production and distribution.</td>
</tr>
<tr>
<td>WTW emissions</td>
<td>Well to wheel emissions. Also known as lifecycle emissions when limited</td>
</tr>
<tr>
<td></td>
<td>specifically to the energy carrier or fuel.</td>
</tr>
</tbody>
</table>
1 Introduction

The European Commission, DG Climate Action contracted a team led by AEA and including TNO, TEPR and CE Delft to carry out further research directly building on the work previously completed under the ‘EU Transport GHG: Routes to 2050?’ project. This new work (given the working title EU Transport GHG: Routes to 2050 II) started in January 2011 and is scheduled to complete in March 2012. The outputs from this new project are intended to help inform the Commission in prioritising and developing the key policy measures that will be critical in ensuring that GHG emissions from the transport sector can be reduced significantly in future years.

The project work is based around eight core technical tasks and two supporting tasks supporting the stakeholder engagement activities, as summarised in Figure 1.1.

Figure 1.1: Outline schematic of the EU Transport GHG: Routes to 2050 II project

This Draft Final Report provides a summary of the work completed in the contract, with greater detail provided in the various papers relating to the individual tasks. These papers have been submitted at different points during the project, with the most recent versions being supplied alongside this report. They are also available from the project website (www.eutransportghg2050.eu), which will be online at least until 31st December 2015.
1.1 The contribution of transport to GHG emissions

Transport is responsible for a quarter of EU greenhouse gas emissions making it the second biggest greenhouse gas emitting sector after energy (see Figure 1.2). Road transport accounts for almost three-quarters of EU transport-related greenhouse gas emissions and over one-fifth of the EU’s total emissions of carbon dioxide (CO₂), the main greenhouse gas. However, there are also significant emissions from the aviation and maritime sectors and these sectors are experiencing the fastest growth in emissions, meaning that policies to reduce greenhouse gas emissions are required for a range of transport modes.

Figure 1.2: EU27 greenhouse gas emissions by sector and mode of transport, 2009

While greenhouse gas emissions from other sectors are generally falling, decreasing 24% between 1990 and 2009, those from transport have increased by 29% in the same period. This increase has happened despite improved vehicle efficiency because the amount of personal and freight transport has increased. The exception for this general upward trend in emissions is the 5% decrease in overall transport emissions between 2007 (where they peaked) and 2009. This decrease is generally viewed as being primarily a result of the impacts of the global recession, and indications are that emissions began to rise again in 2010 as the European economy recovered somewhat.

The European Commission (EC) has over the past year embarked on a number of programmes as part of the Europe 2020 Strategy, including the launch of Roadmap for moving to a competitive low carbon economy in 2050 (EC, 2011a) – further referred as 2050 Roadmap) and Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system (EC 2011b – further referred to as Transport White Paper) – both published in March 2011.

---

6 Based on historic data from the EEA’s GHG data viewer, downloaded from EEA’s website 10/02/12: http://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer
---
The 2050 Roadmap is a strategy that seeks to define the most cost-effective ways to reduce GHG emissions based on the outcome from modelling to meet the long-term target of reducing overall emissions by 80% domestically. The Roadmap considers the pathways for each of the sectors, identifying the magnitude of reductions required in each sector in 2030 and 2050 (shown as ranges) in a variety of scenarios ranging from under global co-operation on climate action to fragmented action. For the transport sector (which includes CO$_2$ from aviation but excludes CO$_2$ from marine shipping), the targets for 2030 are between +20% and -9%, and the 2050 targets are -54% to -67%. The Roadmap anticipates that the transport sector targets could be achieved through a combination of fuel efficiency, electrification and consideration of transport prices. These are explored further in the White Paper on Transport on the basis of the Effective Technology scenario (with low fossil fuel prices) of the Roadmap which shows a -61% reduction for the transport sector.

The Transport White Paper presents the European Commission’s vision for the future of the EU transport system and defines a policy agenda for the next decade to begin to move towards a 60% reduction in CO$_2$ emissions and comparable reduction in oil dependency by 2050. As part of this it defines ten aspirational goals as indicators for policy action (Box 1.1). These goals can be categorised as developing and deploying new and sustainable fuels and propulsion systems; optimising the performance of multimodal logistic chains, including by making greater use of more energy efficient modes; and increasing the efficiency of transport and of infrastructure use with information systems and market-based incentives.

**Box 1.1: Goals from the 2011 Transport White Paper**

<table>
<thead>
<tr>
<th>EC Transport White Paper Goals (2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Halve the use of ‘conventionally-fuelled’ cars in urban transport by 2030; phase them out in cities by 2050; achieve essentially CO$_2$-free city logistics in major urban centres by 2030.</td>
</tr>
<tr>
<td>• Low-carbon sustainable fuels in aviation to reach 40% by 2050; also by 2050 reduce EU CO$_2$ emissions from maritime bunker fuels by 40% (if feasible 50%).</td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• 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 go by rail.</td>
</tr>
<tr>
<td>• A fully functional and EU-wide multimodal TEN-T ‘core network’ by 2030, with a high quality and capacity network by 2050 and a corresponding set of information services.</td>
</tr>
<tr>
<td>• 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 system.</td>
</tr>
<tr>
<td>• Deployment of the modernised air traffic management infrastructure (SESAR) in Europe by 2020 and completion of the European Common Aviation Area. Deployment of equivalent land and waterborne transport management systems (ERTMS, ITS, SSN and LRIT, RIS). Deployment of the European Global Navigation Satellite System (Galileo).</td>
</tr>
<tr>
<td>• By 2020, establish the framework for a European multimodal transport information, management and payment system.</td>
</tr>
<tr>
<td>• By 2050, move close to zero fatalities in road transport. In line with this goal, the EU aims at halving road casualties by 2020. Make sure that the EU is a world leader in safety and security of transport in all modes of transport.</td>
</tr>
<tr>
<td>• Move towards full application of “user pays” and “polluter pays” principles and private sector engagement to eliminate distortions, including harmful subsidies, generate revenues and ensure financing for future transport investments.</td>
</tr>
</tbody>
</table>

---

Developing a better understanding of the secondary impacts, sensitivities for the decarbonisation of EU transport by 2050

The Transport White Paper goals are underpinned by 40 concrete initiatives, and the various actions and measures introduced within the Paper will be elaborated on over this decade through the preparation of appropriate legislative proposals with key initiatives to be put in place. The actions aim to increase the competitiveness of transport while contributing to delivering the 60% reduction in GHG emissions from transport required by 2050, using the ten goals as benchmarks.

Both the 2050 Roadmap and Transport White Paper set the context within which this EU Transport GHG: Routes to 2050 II project has been undertaken, although this work was commissioned prior to their completion.

The increasing political importance that is being attached to decarbonising transport reflects the fact that, of all the economy’s sectors, transport has made the least progress in terms of reducing its GHG emissions, despite significant potential at low cost. Since 1990, GHG emissions from transport, of which 98% are carbon dioxide (CO₂), had the highest percentage increase of all energy related sectors (even with non-CO₂ impacts of aviation excluded).

Figure 1.3 shows the updated baseline based on PRIMES-TREMOVE, as implemented in SULTAN. This is consistent with the range of results from other models and tools, although many of these only project to 2030. The previous baseline based on TREMOVE (total combined GHG emissions, 2010) is also indicated in the figure (showing WTW/fuel lifecycle emissions). Whereas the 2010 baseline anticipated continued growth in the EU-27’s GHG emissions from transport, the updated baseline sees a decline in GHG emissions over the period to 2050. This is mainly due to a range of existing and planned policies being included in the new baseline, including the 2020 regulatory CO₂ emissions targets for passenger cars and vans, the IMO Energy Efficiency Design Index (EEDI) based improvement targets for maritime shipping and estimated impacts of including aviation in the EU ETS. Another factor is that it also includes the impacts of the recession on transport sector GHG emissions, which affects mainly the 2010 starting point but also has some roll-on effects. Even a decrease in the order projected in Figure 1.3 for the updated baseline would leave transport’s WTW (fuel lifecycle) GHG emissions 17% higher in 2050 than they were in 1990 (when the sector’s emissions were nearly 1,200 MtCO₂e). This is a decline of 22% on 2010 GHG levels (which were around 32% above those in 1990).

Large increases in emissions between 2010 and 2050 are projected for aviation and maritime without additional policy instruments (by 42% and 22% respectively, even after recent policy developments). Under the previous baseline scenario, road freight volume was projected to increase significantly, however, due to significantly reduced levels of demand growth in the new PRIMES Reference Scenario (and some additional modal shift), it is now projected to have slightly decreased by 2050. Whilst GHG emissions from cars are still projected to contribute the most to the sector’s GHG emissions in absolute terms in 2050, their emissions are projected to have declined significantly from 2010 levels, due to the impacts of the 2020 regulatory CO₂ targets.

---

9 See Appendix 19 SULTAN: Development of an Illustrative Scenarios Tool for Assessing Potential Impacts of Measures on EU transport GHG for details of the assumptions used and approach taken in the SULTAN Illustrative Scenarios Tool to projecting business as usual GHG emissions; also see http://www.eutransportghg2050.eu
Developing a better understanding of the secondary impacts, sensitivities for the decarbonisation of EU transport by 2050

Figure 1.3: Business as usual projected growth in transport’s lifecycle GHG emissions by mode

Source: SULTAN Illustrative Scenarios Tool, updated for the EU Transport GHG: Routes to 2050 II project

Notes: Maritime shipping include estimates for the full emissions resulting from journeys to EU countries, rather than current international reporting which only include emissions from bunker fuels supplied at a country level (which are lower by around 18%). Previous SULTAN 2010 BAU included also international aviation on a similar basis. The new baseline has been developed to be consistent with the latest EC modelling reference scenarios and includes (a) the impact of the recession, (b) aviation based on bunkers, (c) includes additional policies and measures that were not in the previous baseline, including the 2020 Car CO\textsubscript{2} regulatory targets, the new Energy Efficiency Design Index (EEDI) targets for maritime shipping, and the estimated impacts of including aviation in the EU ETS.

The 'Total WP Targets' figure indicated includes both the goal of reducing maritime emissions by 40% by 2050, as well as the targets for the rest of transport in 2030 and 2050.

Despite the overall projected reduction in transport sector GHG emissions to 2050, this decline is not enough. If no action is taken to reduce these emissions, the EU will not meet the long-term GHG emission reduction targets that the European Council supports in 2030 and 2050.

Figure 1.4 demonstrates that on current trends, transport emissions could reach levels around 20% of economy-wide 1990 GHG emissions by 2050\textsuperscript{10} if unchecked. This would be equivalent to the total EU-wide GHG emissions budget for an 80% reduction target across all sectors. The figure also illustrates the 2050 Roadmap and White Paper targets for transport (54% to 67% reduction and 60% reduction in emissions compared to 1990 levels respectively for transport excluding maritime shipping, and the 40% GHG reduction goal for maritime transport from the White Paper). Whilst simplistic, in that it assumes linear reductions, the figure demonstrates that there is clearly a need for additional policy instruments to stimulate the take up of technical and non-technical options that could potentially reduce transport’s GHG emissions.

\textsuperscript{10} The emissions included in this figure – for both the economy-wide emissions and those of the transport sector – include emissions from international aviation and maritime transport, in addition to emissions from “domestic” EU transport.
1.2 Background to the project and its objectives

**EU Transport GHG: Routes to 2050 II** is a 15-month project funded by the European Commission's DG Climate Action and started in January 2011. The context of the project is the Commission's long-term objective for tackling climate change. The scope of the first project was ambitious, and the outputs from the project were detailed and of value to the European Commission and to industry, governmental and NGO stakeholders. However, there were a number of topic areas where it was not possible within the time and resources available for the team to research and analyse. In particular, as the project evolved, both the team and the Commission Services became aware that there were a number of themes and topic areas that would benefit from further, more detailed analysis. This current project is a direct follow-on to the previous EU Transport GHG: Routes to 2050? project, building on the

---


investigations and analysis carried out for that project and complementing other work carried out for the Transport White Paper. In particular, the outputs from this new project should be useful in prioritising and developing the future policy measures that will be critical in ensuring that GHG emissions from the transport sector are reduced significantly in future years.

The key objectives of the EU Transport GHG: Routes to 2050 II have been defined as to build on the work carried out in the previous project to:

- Develop an enhanced understanding of the wider potential impacts of transport GHG reduction policies, as well as their possible significance in a critical path to GHG reductions to 2050.
- Further develop the SULTAN illustrative scenarios tool to enhance its usefulness as a policy scoping tool and carry out further scenario analysis in support of the new project;
- Use the new information in the evaluation of a series of alternative pathways to transport GHG reduction for 2050, in the context of the 54-67% reduction target for transport from the European Commission’s Roadmap for moving to a competitive low carbon economy in 2050;  

As before, given the timescales being considered, the project has taken a quantitative approach to the analysis where possible, and a qualitative approach where this has not been feasible. The project has been structured against a number tasks, which are as follows, also summarised in earlier Figure 1.1:

- **Task 1:** Development of a better understanding of the scale of co-benefits associated with transport sector GHG reduction policies;
- **Task 2:** The role of GHG emissions from infrastructure construction, vehicle manufacturing, and ELVs in overall transport sector emissions;
- **Task 3:** Exploration of the knock-on consequences of relevant potential policies;
- **Task 4:** Exploration of the potential for less transport-intensive paths to societal goals;
- **Task 5:** Identification of the major risks/uncertainties associated with the achievability of the policies and measures considered in the illustrative scenarios;
- **Task 6:** Further development of the SULTAN tool and illustrative scenarios;
- **Task 7:** Exploration of the interaction between the policies that can be put in place prior to 2020 and those achievable later in the time period;
- **Task 8:** Development of a better understanding of the cost effectiveness of different policies and policy packages;
- **Task 9:** Stakeholder engagement: organisation of technical level meetings for experts and stakeholders;
- **Task 10:** Hosting the existing project website and its content;
- **Task 11:** Ad-hoc work requests to cover work beyond that covered in the rest of the work plan.

As in the previous project, stakeholder engagement has been an important element of the project. The following meetings have been held:

---

A large stakeholder meeting on 29th June 2011, at which the project was introduced to stakeholders, along with the presentation of interim results.

A series of four Technical Focus Group meetings. The first two were held on 4th May 2011 and the second two were held on 28th November 2011.

A second large stakeholder meeting on 23rd February 2012 at which the draft final findings of the project were presented and discussed.

As part of the project a number of papers have been produced, all of which have been made available on the project’s website in draft and then final form, as have all of the presentations from the project’s meetings.

1.3 Structure of the paper

Following this introduction this paper is structured according to the following further 6 chapters:

Chapter 2 General tasks and approach: This section provides a summary of the overall project methodology as well the activities carried out under Task 9 (stakeholder engagement), Task 10 (website) and Task 11 (ad-hoc tasks).

Chapter 3 Knock-on consequences of GHG reduction policies and measures: This section provides a summary of the project’s Task 3 work and findings.

Chapter 4 Risks and uncertainties of GHG reduction policies and measures: This section provides a summary of the project’s Task 5 work and findings.

Chapter 5 Co-benefits associated with GHG reduction policies and measures: This section provides a summary of the project’s Task 1 work and findings, and also the findings of the Task 11 ad-hoc paper 1 considering congestion.

Chapter 6 Cost effectiveness of different GHG reduction policies and measures: This section provides a summary of the project’s Task 8 work and findings.

Chapter 7 GHG emissions from infrastructure construction, vehicle manufacturing, and end of life vehicles (ELVs): This section provides a summary of the project’s Task 2 work and findings.

Chapter 8 The potential for less transport-intensive paths to societal goals: This section provides a summary of the project’s Task 4 work and findings.

Chapter 9 Considerations relating to the co-evolution of regulation and economic instruments: This section provides a summary of the project’s Task 11 ad-hoc paper 3 work and findings.

Chapter 10 SULTAN development and scenario analysis: This section provides a summary of the project’s Task 6 work and findings, and also the findings of the Task 11 ad-hoc paper 2 considering future road vehicle GHG emission targets.

Chapter 11 Potential impacts of policies that could be put in place by 2020: This section provides a summary of the project’s Task 7 work and findings.

Chapter 12 Overall Conclusions: This section provides overall summary and conclusions from the project work.

Appendices Full versions of individual Task papers: The complete versions of all the detailed task papers are included as Appendices to this final report.
2 General tasks and approach

Objectives:
The purpose of Tasks 9, 10 and 11 were to:

- Ensure expert and stakeholder involvement in the project, through the organisation of a series of technical level meetings (Task 9);
- Take over the hosting and maintenance of the existing project website, updating and adding materials to the website based on activities from this new project (Task 10);
- Carry out additional ad-hoc work beyond that covered in the rest of the work plan to be confirmed between the Commission and the contractor (Task 11).

Summary of Main Results

- **Stakeholder Engagement (Task 9):** A series of four focus group meetings and two large stakeholder conferences were held in order to facilitate discussion with stakeholders on the project’s key results and conclusions. The meetings helped to engage stakeholders, improve the work in the other tasks and reveal the key issues;

- **Project Website (Task 10):** The project website has been maintained and updated with new materials from the project. Provision has been made to ensure the website is available until 31st December 2015;

- **Ad-hoc Requests (Task 11):** Four pieces of work were commissioned under the ad-hoc budget, including three technical papers and some additional work carried out to further expand SULTAN functionality. Details on these elements are provided elsewhere in this report, together with the full papers as appendices (also available from the website).

2.1 General Approach

As indicated in the introductory section the purpose of this project was to develop further areas that could not be assessed in detail and new areas that were not covered at all in the previous project. The required output of this work was to produce a series of Task papers that would explore each of the subject areas in detail, plus a final overall report bringing together a summary of the work (this report).

The need to engage stakeholders was a fundamentally important element of this project. This engagement aimed in particular to:

1. Enable stakeholders to hear a summary presentation of draft findings at various key stages in the project.
2. Give stakeholders the opportunity to discuss and challenge the draft findings.
3. Reach consensus with stakeholders on what we know and what we do not know regarding the co-benefits and secondary impacts of options and policy instruments for reducing GHG emissions from all modes of transport.
4. Enable stakeholders to provide input to the project – either during the meeting or afterwards via the project’s website.
5. Stimulate further debate among EU stakeholders about future policy action that might be needed to reduce transport’s GHG emissions.
To achieve this objective a series of stakeholder meetings were organised, plus the further development and maintenance of the project’s website in order to facilitate engagement and access to outputs during and beyond the completion of the technical work. Finally, to allow for the coverage of topics not foreseen at the time of the work specification, an ad-hoc budget was provided. These elements are discussed in more detail in the next subsections.

2.2 Stakeholder Engagement

Stakeholder consultation was a key element of the project. It serves as a bridge between the project and stakeholders and two types of meetings were organised:

(1) Focus Group Meetings: These had much room for interaction, so stakeholders could share their visions and remarks. This required that the timings of the meetings were well aligned with the time schedule for the development of the various tasks.

(2) Large Stakeholder Conferences: These were aimed at informing stakeholders on the progress made and on the key results and conclusions.

Some of the tasks of this project particularly benefited from a focus group meeting, while for other tasks presenting their results at a large stakeholder conference was more appropriate. The stakeholder meetings that were planned as part of the project have all taken place:

- On 4 May 2011 the first two focus group meetings were held: meeting 1 on Task 2 and meeting 2 on Tasks 3 and 5. Both meetings provided useful feedback on the ongoing work and helped to improve the reports on the various tasks that were discussed. In addition, it helped more generally to strengthen the involvement of stakeholders to the project.
- On 29th June there was the first large stakeholder conference. At this conference, draft results of all ongoing tasks were presented (Task 1, 2, 3, 5). Furthermore the forthcoming work on the other tasks (Task 4, 6, 7 and 8) was presented so stakeholders had the opportunity to contribute at an early stage. Also a link was made to the White Paper on transport and the Roadmap 2050 by a presentation from DG CLIMA. The discussions at the conference were generally of good quality and useful for the project.
- On 28 November 2011 the second two focus group meetings were held: meeting 3 on Task 4 and meeting 4 on task 1 and 8.
- On 23 February the final conference took place. At this meeting the results of the scenario analysis (task 6 and 7) were presented and discussed, in the context of all other project results. A session with a panel discussion on the issue of decarbonisation of transport in relation to societal goods was held.

The number of participants at the focus group meetings and the stakeholder conference was somewhat lower than expected. At the focus group meetings around 20 to 30 people attended (including project partners); at the conference about 60. This is likely to have been due to the high number of meetings that were already organised in the previous project, in combination with the more specific types of subjects of the meetings in the new project.

Despite the lower number of participants the presentations and discussion at the various meetings were of good quality. The meetings supported in many cases the conclusions and results of the various tasks (e.g. on embedded emissions, knock-on effects, risks & uncertainties). At the same time the meetings also had some heated discussions, e.g. on subjects such as the relation between GHG and congestion and decoupling economic growth from transport. Overall, the meetings helped to engage stakeholders, improve the work in the other tasks and reveal the key areas of disagreement.
2.3 Project Website

The work under this task was on-going until the completion of the project (with the website hosting continuing beyond this until 31st December 2015). The existing website has been restructured and information on the new project added. It has been periodically updated with information on events and reports.

2.4 Ad-hoc Tasks

Table 2.1 summarises the ad-hoc work commissioned as part of this project. The process for agreeing individual ad-hoc items included:

1. Submission to Commission desk officer of initial idea for ad-hoc task;
2. Further work up idea into draft outline (e.g. including output paper structure), plus timing and indicative budget, and re-submit;
3. Finalise work specification, timing and budget in discussion with the Commission.

The following subsections provide a brief summary of the agreed work.

<table>
<thead>
<tr>
<th>Item</th>
<th>Budget</th>
<th>Responsible</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congestion and accessibility</td>
<td>10 days</td>
<td>CE Delft</td>
<td>Task 11 Paper 1</td>
</tr>
<tr>
<td>Additional SULTAN / illustrative</td>
<td>7 days</td>
<td>AEA</td>
<td>Additional SULTAN functionality, and traceability of baseline updates</td>
</tr>
<tr>
<td>scenario development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exploring road vehicle targets</td>
<td>20 days</td>
<td>AEA / TEPR</td>
<td>Task 11 Paper 2</td>
</tr>
<tr>
<td>Optimising regulation and</td>
<td>13 days</td>
<td>TEPR / TNO</td>
<td>Task 11 Paper 3</td>
</tr>
<tr>
<td>economic instruments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>50 days</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: The overall ad-hoc budget for Task 11 was set at a maximum of 50 days, depending on requirements.

Interaction of GHG policy for transport with congestion and accessibility policies

Ad-hoc paper 1 explored the potential interaction between congestion and climate policies and ways how the two could be combined effectively. A summary of the outputs of the work are presented alongside other co-benefits in Section 5.6.

Additional SULTAN / illustrative scenario development

There were limited resources available under Task 6 for the development of the SULTAN tool, substantiation of existing scenarios and development of new scenarios. A number of options were initially put forward for possible funding via the ad-hoc budget, with the following two items agreed to take forward using this budget:

1. **Co-benefits**: Build monetisation of GHG, NOx and PM impacts into the tool (3 days)
2. **Future baseline updates**: Annotated Excel workbooks used to update the SULTAN base data (4 days);

Both of these items were carried out in parallel with the other Task 6 development work.

Impact of different trajectories for road transport vehicle GHG standards

Ad-hoc paper 2 explored the interaction of the trajectories set for new road vehicle GHG emissions standards with other mitigation options necessary to achieve the 2050 transport GHG reduction targets. A summary of the task outputs is presented in Section 10.3.3 alongside the other scenario analysis carried out under Task 6.
Regulation and economic instruments working together/optimal future instruments

Ad-hoc paper 3 discusses the arguments against a focus on a “single instrument” solution to reducing GHG emissions from transport, and subsequently aims to explore the benefits and challenges of a co-evolving policy framework involving both regulation and economic instruments. A summary of the outputs of the work is presented in Section 9.
3 Knock-on consequences of GHG reduction policies and measures

Objectives:
The purpose of Task 3 of the project was to explore likely knock-on consequences, for the road vehicle fleet, of three relevant potential policies:

- Speed-related instruments
- Fiscal instruments
- Vehicle CO\textsubscript{2} legislation for passenger cars

Where possible, investigating the impact of these changes on the effectiveness of measures to mitigate GHG emissions from the transport sector.

Summary of Main Findings

Main Findings regarding speed limit related instruments:

⇒ Speed limits can have significant impacts on GHG emissions of transport.

⇒ The impact on transport demand and modal split is the most significant knock-on effect. It can be of the same order of magnitude as the direct impact on fuel efficiency of vehicles.

⇒ Other knock-on consequences for GHG emissions are poorly understood, but likely to be relatively small.

Main Findings regarding vehicle CO\textsubscript{2} legislation:

⇒ Given the relatively short payback time of required technical reduction measures, the 130 g/km target for 2015 is likely to generate small negative knock-on consequences or rebound effects, reducing its effect and very likely its cost-effectiveness.

⇒ Based on the main cost curves from a recent study in support of defining the modalities for the 2020 target\textsuperscript{14}, the payback time of the technical reduction measures required for going from 130 g/km to the 95 g/km target in 2020 is significantly longer. As a result the 95 g/km target is expected to lead to small but net positive knock-on consequences enhancing the effect and effectiveness of the legislation.

⇒ However, strong indications exist that the costs for meeting the 95 g/km target could be lower that estimated using the main cost curves from the above mentioned study. Scenarios exploring the consequences of these indications lead to payback times that are equal to or shorter than what was estimated for the 130 g/km target. Under these assumptions the 95 g/km should be expected to result in small negative knock-on consequences, i.e. a rebound that reduces the impact and effectiveness of the legislation.

⇒ Due to strongly non-linear cost curves for CO\textsubscript{2} reduction through technical measures on the vehicle, CO\textsubscript{2} legislation to be developed for the period beyond 2020 will likely not suffer from rebounds, while positive knock-on consequences may enhance its effect and effectiveness.

⇒ Note: These assessments assume that the application of efficiency improving technology does lead to a net increase in purchase price.

Main Findings regarding fiscal instruments:

⇒ As with first order effects, the second-order impacts from instruments targeting car purchasing are likely to be significantly greater than those targeting ownership.

\textsuperscript{14} [TNO/AEA/CE Delft/IHS/Ökopol/Ricardo/TML 2011], see Section 3.3.2.
Summary of Main Findings

⇒ The knock-on consequences would vary depending on whether an instrument has been designed to raise revenue or to be revenue neutral (or even to reduce revenue).
⇒ The net effect on CO₂ emissions of the knock-on consequences is likely to be negative (against the intended policy impact), or at best neutral for revenue raising instruments.
⇒ The net impact of first and second order impacts is unclear and will depend on the elasticities used.

3.1 Introduction

Task 3 looked at the knock-on consequences of three types of policy instruments for reduction of GHG from transport (speed limits, fiscal and vehicle CO₂ legislation). The main objective was to assess to which extent these second-order effects significantly contribute to or erode the intended, first-order GHG reduction impact of the policy instruments.

Knock-on consequences are defined as 2nd order impacts on the size, composition and usage of the fleet, as well as possible changes in vehicle design and other characteristics that may occur in response to an implemented policy in addition to the intended 1st order impacts of the policy. These knock-on consequences may either enhance or reduce the impact of the policy on reducing CO₂ emissions and in consequence may improve or deteriorate the policy's cost effectiveness.

Knock-on consequences that work against the 1st order impact and thus reduce the net impact of a policy are also called “rebound effects”. Besides rebound effects also positive knock-on consequences exist, which increase the net impact of a policy.

In the case of GHG reduction policies for transport 2nd order impacts are often related to the way in which changes in the costs of owning and using vehicles, resulting from e.g. applying efficiency improving technologies or behavioural changes, affect the ownership and usage of vehicles.

Likely knock-on consequences have been explored for three relevant examples of potential policies contributing to the realisation of a long term sustainable mobility system in Europe:

- Speed limitation
- Vehicle CO₂ legislation for passenger cars
- Fiscal instruments

Policies aimed at decreasing average vehicle speeds can potentially be an effective instrument to reduce the energy consumption of the existing fleet but may also induce consumers to buy less powerful cars. However, their implementation can be regarded as vehicle-independent in a first analysis. Therefore in the short term, the overall impact of such policies remains limited, in time and scale, by the relative inefficiency of many current vehicles (with dynamic performance far exceeding current, let alone decreased future requirements). Reducing the maximum speed, however, may in the longer term lead to changes in vehicle design. In this particular case, one could expect the industry to see an incentive towards vehicles which are not even capable of achieving high speeds, and which would then require less powerful engines and could probably have less rigid construction especially with respect to passive safety measures, with likely implications for their GHG footprint throughout their life cycle.

CO₂ legislation requiring manufacturers to produce and sell more efficient vehicles has first and second order impacts on the fleet. The first order impact is based on the existing sales
distribution over vehicle segments where vehicles in all segments become more efficient. Making vehicles more efficient results in lower vehicle operating costs; however it may increase manufacturing costs which can lead to higher vehicle prices. Depending on the net effect of the two, and on the cost impacts on vehicles in different segments and using different fuels (petrol/diesel), driving a car in a given segment may become more or less expensive, both in absolute terms as well as relative to cars in other segments. This will generally lead to changes in purchasing behaviour and thus to changes in fleet composition. Such second order effects are fairly adequately assessed in the TREMOVE calculations used to evaluate impacts of proposed EU legislation for vehicles and may be positive (enhancing the first order impact of the policy) or negative (rebound effect decreasing the overall impacts).

CO₂ reducing policies not directly aimed at manufacturers and the vehicle technology they produce generally impact CO₂ emissions through changes in mobility and transport behaviour or through changes in vehicle purchase behaviour. Generally these impacts can also be divided into first and second order effects, where the second order effects can be considered knock-on effects of the main desired impact.

A taxation policy, i.e. the introduction of fiscal instruments to stimulate the purchase of more energy efficient/low CO₂ emitting cars, may be expected to lead to second order behavioural effects with respect to driving style and speeds. The lower fuel costs, on the other hand, may lead to increased travel. Overall impacts on vehicle fleet and usage depend on whether the fiscal policy is revenue neutral or leads to a net increase or decrease of tax revenue.

The potential knock-on effects of the above-mentioned policy instruments have been explored and mapped based on literature review and expert judgement. The focus has been primarily on road transport. The analysis of CO₂ legislation is focussed specifically on passenger cars and vans with some discussion of impacts from upcoming CO₂ legislation for HD vehicles. The analysis of taxation policy is entirely focussed on passenger cars. Knock-on consequences in the transport (sub)sector(s) are explored in detail. The paper investigates qualitatively and quantitatively where possible on the basis of available data, the impact of these changes on the cost effectiveness of measures to mitigate GHG emissions from the transport sector.

3.2 Relevance of acknowledging knock-on consequences

Ignoring possible knock-on consequences is an important source of discrepancy between the actual impact of policy instruments and the ex-ante estimated effects. Engineering estimates made to assess policies in terms of their intended impacts on applied technologies or behaviour often ignores such 2nd order impacts. More complex models used for ex ante assessments include some of these 2nd order impacts, but generally with limited accuracy due to the complexity of modelling behavioural responses.

Proper accounting of knock-on consequences, or if that is not possible at least creating awareness of possible knock-on effects and the direction in which they may influence the net impact of a policy, is relevant for avoiding over-optimism in the stage of policy making as well as disappointments after implementation of the policy measure which may undermine the longer term sustainability of the policy strategy of which the instrument is a part. Alternatively evidence or awareness of possible positive knock-on consequences, which increase the net impact of the policy instrument and improve its cost-effectiveness, may help to increase political and societal acceptance of the measure. Awareness of knock-on consequences may also provide inspiration for the development of accompanying or flanking policies that may help to reduce societal responses that lead to undesired negative 2nd order impacts.
3.3 Conclusions

In general, it was concluded that knock-on consequences can have a significant and not always synergetic impact on the results obtained from GHG reduction policy instruments for the transport sector, which makes them a concern for the development of effective policy. They therefore deserve more systematic analysis. In particular, proper assessment of their implications on the cost-effectiveness of policy measures appears to require some methodological development.

The assessment of knock-on consequences is generally based on the concept of elasticities which describe the change in demand, e.g. of vehicles or of kilometres driven by car, in response to changes in supply characteristics such as prices or e.g. travel times / average speeds. These elasticities are derived from econometric analysis of observed behaviour, and will thus implicitly include possible dampening effects of the "law" of constant travel time budget. An increase in the distance driven by cars, in response to a reduction in the cost of driving resulting from CO₂ legislation or a change in taxation, will generally go at the expense of a smaller number of kilometres travelled by slower modes.

3.3.1 Speed related instruments

Policies have been assessed that lead to speed constraints. These policies usually primarily target accident rates, air pollution or traffic noise. However, they can also have significant impacts on GHG emissions. Instruments such as speed limits, strict speed limit enforcement or mandating speed limiters can considerably improve the fuel efficiency of vehicles because of lower or more constant speeds. This primary effect is taken into account in most studies that consider the GHG impacts of such policy instruments. However, there is a broad range of knock-on consequences that could also affect the net GHG impacts. Some of these effects can be very significant, but quantifications are very scarce.

The potential impact of speed-related policy on overall transport demand and modal split is likely to be quite significant, particularly in the long term. Estimates of the impacts of strictly enforced speed limits indicate that these effects can even be of the same order of magnitude as the direct effect.

Differentiated speed limits could lead to a shift between various vehicle categories of the same mode, in particular in the case of vans and small trucks. However, quantification of potential GHG impacts of this type knock-on effect is lacking.

Other knock-on effects are impacts on fleet size and composition, vehicle design, accident rates, congestion, highway avoidance and infrastructure. All these effects are poorly understood because of a lack of in-depth research. However, qualitative assessment makes clear that all these effects are likely to be relatively small, certainly considerably smaller than the demand and modal shift effects. Other than highway avoidance, these would all be likely to contribute to further improving the GHG benefit from the policy.

The impact of the knock-on effects of speed-related policy on cost effectiveness is very high. Speed-related policy can have net social benefits. Some studies estimated ‘optimal’ motorway speed limits of 90 to 110 km/h. However, other studies concluded that the net impact of lowering motorway speed limits would be an increase in net social cost. Comparison of these studies makes clear that the sign and magnitude of the net social cost of speed policy depends strongly on the size and valuation of co-benefits and of the travel time effects and may differ per country and traffic situation.
3.3.2 Vehicle CO₂ legislation

Instruments restricting vehicle CO₂ emissions per km will lead to a reduction in fuel costs per kilometre driven, which may induce additional travel demand or a shift to larger vehicles as a rebound effect. The net knock-on consequences of CO₂ legislation will strongly depend on the impact of applying efficiency reducing technologies on the net vehicle sales price. New technologies can add costs. If these translate into an increase of the sales price this may have 2nd order impacts that can (partly) counteract the effects of lower usage costs. The net production costs, however, can be kept constant by increased efforts in improving production efficiency or e.g. by postponing application of new performance or comfort enhancing features. Also manufacturers may (temporarily) decide not to entirely pass the additional costs through to the consumer. Without an increase in net purchase price, vehicle CO₂ legislation is more likely to lead to significant rebound effects. Under the assumption that the application of efficiency improving technology does lead to a net increase in purchase price the following conclusions can be drawn:

- Given the relatively short payback time of required technical reduction measures, the 130 g/km target for 2015 is likely to generate small negative knock-on consequences or rebound effects, reducing its effect and very likely its cost-effectiveness.

- Based on the main cost curves from TNO et al. (2011) the payback time of the technical reduction measures required for going from 130 g/km to the 95 g/km target in 2020 is significantly longer. As a result the 95 g/km target is expected to lead to small but net positive knock-on consequences enhancing the effect and effectiveness of the legislation.

- However, strong indications exist that the costs for meeting the 95 g/km target could be lower that estimated using the main cost curves from TNO et al. (2011). Scenarios exploring the consequences of these indications lead to payback times that are equal to or shorter than what was estimated for the 130 g/km target. Under these assumptions the 95 g/km should be expected to result in small negative knock-on consequences, i.e. a rebound that reduces the impact and effectiveness of the legislation.

- Due to strongly non-linear cost curves for CO₂ reduction through technical measures on the vehicle, CO₂ legislation to be developed for the period beyond 2020 will likely not suffer from rebounds, while positive knock-on consequences may enhance its effect and effectiveness.

Additional knock-on consequences have been identified which are associated with specific manufacturer responses to the CO₂ legislation, and with the increasing divergence between CO₂ reduction on the type approval test and in real-world driving. Their impacts on GHG emission reductions are generally negative, but probably small.

Knock-on consequences through marketing of vehicles with alternative propulsion systems and / or energy carriers depend on the WTW GHG emissions of the applied alternative energy carriers. If CO₂ legislation is based on a TTW metric, the marketing of electric or hydrogen-fuelled vehicles will result in a net WTW impact of the CO₂ legislation which is equal to or smaller than in case the target is met through efficiency improvement in conventional cars on petrol and diesel. Rebounds will be dampened if the production of the energy carriers takes place under the EU-ETS, but the extent to which this is the case depends on the water-tightness of EU-ETS in the short term and the development of the emission ceiling in the longer term.

The above conclusions are largely based on qualitative reasoning. A vast amount of literature exists on rebound effects from efficiency improvement in cars. In many of the studies econometric analysis of time series of various costs and fuel consumption is used to derive elasticities that describe the sensitivity of energy consumption and transport demand in passenger car transport to various price changes. However, the picture emerging from
these sources remains fairly inconclusive. At the same time the applicability of the reported
elasticities to the case of CO\textsubscript{2} legislation turns out not to be straightforward. Available
TREMOVE runs devoted to assessing overall impacts of CO\textsubscript{2} legislation indicate that the net
effect of knock-on consequences heavily depends on details of the modalities of the
legislation, while the estimated size of different effects appears to be inconsistent with what
is reported in literature.

The main conclusion is that knock-on consequences from vehicle CO\textsubscript{2} legislation can be
significant and are a concern for the development of effective CO\textsubscript{2} reduction policies in
transport because this is a key instrument. They therefore deserve more systematic analysis.
Proper assessment of their implications on the cost-effectiveness of policy measures
appears to require some methodological development.

Combining CO\textsubscript{2} legislation with a generic economic instrument, e.g. one that adjusts fuel
prices to such a level that the overall cost of driving remain constant compared to the
situation without CO\textsubscript{2} legislation, could provide an effective safeguard against rebound
effects.

### 3.3.3 Fiscal instruments

The introduction of fiscal instruments that aim, either directly or indirectly, to stimulate the
uptake of more fuel efficient or less CO\textsubscript{2} emitting vehicles potentially lead to a number of
knock-on consequences, i.e. second order impacts. These include knock-on consequences
on the size and composition of the fleet, the use of cars, the design of cars, on the second-
hand market and through that on different social groups, and on changes in the behaviour of
retailers and buyers.

Many of the consequences differ depending on whether the instrument aims to increase
revenues, be revenue neutral or reduce revenues, as well as on whether the instrument
targets car purchasing or car ownership. However some consequences are the same, at
least in direction if not in magnitude, for all of the instruments irrespective of the revenue
implications and behaviour targeted. Impacts from instruments targeting car purchasing are
likely to be significantly greater than those targeting ownership. All instruments are likely to
result in cars being used more, as they are more fuel efficient, which will in turn lead to
increased costs and an increased fleet size, and all will lead to increased proportions of more
fuel efficient cars in the second-hand market (and a reduction in the proportion of less fuel
efficient cars).

Where revenues increase, the size of the fleet will decline in the short-term and fleet turnover
will slow down (with the opposite effects arising from those instruments that reduce
revenues). The impact on the lifespan of vehicles depends on whether instruments target
purchasing or ownership, with lifespan increasing in the first case and decreasing in the latter
(again with the opposite effect when revenues decline). Additionally, for instruments that
increase the cost of car purchasing, retailers might take action to reduce pre-tax prices, while
purchasers might choose to buy a car in a neighbouring Member State in order to avoid any
tax increases.

For revenue-neutral instruments, there are often no consequences on average, but
consequences differ in their effects on smaller or more efficient cars and larger or more
inefficient cars. For instruments targeting purchasing, higher CO\textsubscript{2} cars will be retained for
longer, thus potentially leading to increased demand and prices for such cars on the second-
hand market, which in turn could have adverse effects on poorer, larger, families who rely on
the second hand market for their car purchasing. The opposite effect would happen for
smaller or more efficient cars, with those relying on the second hand market for their car
purchasing, e.g. poorer single people or couples. Revenue-neutral instruments focusing on
ownership will have opposite, and probably more significant, impacts. Such differing impacts
depending on car size or emissions might also been seen, but less obviously, for revenue-increasing and revenue-reducing instruments.

While the assessment focused on cars, it suggested that similar, but potentially larger, knock-on consequences might be seen from the application of such instruments to other modes of transport, both in the road transport sector and elsewhere.

The net effect on CO₂ emissions of the knock-on consequences is likely to be negative, or at best neutral for revenue raising instruments, of the instruments considered. As the impact on revenue declines, the effect increases, while the effect is less for instruments targeting purchasing than instruments targeting ownership. The net impact of first and second order impacts is unclear and will depend on the relevant elasticities.

However, the benefits of the first order effects can be increased by, for example, complementary instruments such as increases to fuel taxation or the introduction of road user charging, which could negate the rebound effect of increased use.
4 Risks and uncertainties of GHG reduction policies and measures

Objectives:
The purpose of Task 5 of the project was to:

- Explore and identify key risks and uncertainties associated with the achievability of relevant policies and measures, including lead times for policy implementation and time lags to the resulting impact on emissions.
- Assess the extent to which key factors outside the transport sector will affect decarbonisation of transport.
- Developing approaches to address those risks and uncertainties and optimize achievability.

Summary of Main Findings

Main Findings regarding biofuels:

⇒ There are significant risks and uncertainties related to the conditions that need to be met if the full potential of GHG reduction with biofuels is to be realised, in particular: the availability of low-carbon biomass and biofuels, the GHG reduction they actually achieve, their cost and market uptake, biomass demand from other sectors.
⇒ In the coming years, realistic policy strategies should be developed for biofuels use in transport. These strategies should be part of a broader strategy on the most effective use of biomass, assessing how to optimise the supply and use of non-food biomass for the various potential applications in a sustainable future: transport, electricity, heat, materials and chemicals.
⇒ Policy implementation should focus on effective implementation and improvement of the biofuels GHG emission reduction and other sustainability criteria. Prevention of negative impacts due to ILUC is key in this development. Research into new (2nd generation) biofuels production processes and a diverse and reliable supply of biomass that does not cause negative impacts should be promoted, to ensure a diverse biomass supply in the future, prevent competition with the food sector and reduce negative impacts from land use change.
⇒ Market response to policies and the outcome of technological developments may differ from what was envisaged. The effects and broader impacts of the policy strategy and measures should therefore be monitored critically, and policies should be adapted when necessary.
⇒ In parallel, efforts should also be put into global initiatives that can reduce land use change and biodiversity loss due to biomass cultivation for biofuels, for example within the IPCC and CBD framework.

Main Findings regarding electricity and hydrogen in transport:

⇒ The implementation of electricity and hydrogen as GHG reduction options for the transport sector is a transition that involves drastic and structural changes in both the transport and the energy sector and that will take several decades to start up, roll out and complete.
⇒ Governments and stakeholders in the market need endurance and a long term vision to manage this transition in an effective way. Mitigating risks and taking away uncertainties is an important and unavoidable part of that.
⇒ Proactive steps are required in the short term laying the ground work for longer term
Summary of Main Findings

Policy instruments, in early market formation and in setting up and managing a process that timely delivers the insights that are necessary to develop a suitable dominant design for the energy distribution infrastructure. For example, in the case of electric vehicles this dominant design relates to the roles of home charging, public slow charging, fast charging and battery swapping and the integration of this charging infrastructure in the future electricity grid, possible in combination with smart grids.

⇒ Important risk and uncertainties that require short term action relate to:
  
  o **Impact of zero-emission vehicles under the current LDV CO₂ legislation** in combination with the need for a methodology on how to account for GHG intensity of energy carriers. Determining appropriate metrics is essential to make sure that post 2020 targets provide the right incentives to manufacturers and energy suppliers.

  o **Uncertainty about the business case.** This issue is closely linked with development of costs of vehicles and infrastructure, consumer acceptance and the role of supply and demand oriented policy measures on the business case.

  o **Interaction with the energy system.** This issue partly concerns developing a more mature view on the dominant design of the charging infrastructure for electric vehicles in interaction with grid-related developments on the local and regional scale and among other things the development of the EV driving range. But it also concerns interaction on a (trans)national level regarding how electric and hydrogen-fuelled vehicles on the one hand require decarbonisation on the energy supply system and on the other hand influence investments in generation infrastructure that may or may not be consistent with the need for decarbonisation.

**Main Findings regarding economic instruments, particularly usage pricing:**

⇒ If road usage charging is to be introduced, it should take place in addition to, rather than instead of, fuel taxation.

⇒ At the strategic, or conceptual, level, the main risks relate to the acceptability by the public and business of the introduction of road user charging, and the associated political risk.

⇒ These strategic risks are linked to, and based on, a number of other economic, social and environmental risks. These include business concerns about the impact on trade or costs, and the social concerns relating to the impact on mobility, particularly for the poorer sections of society.

⇒ Some of the risks are perceived, but many are real, and could be addressed either in the design of the charging scheme, or by the introduction of complementary policy instruments (which could even be introduced in advance of the charging scheme itself).

4.1 Introduction

The goal of Task 5 of the project has been to identify in abstract the main risks and uncertainties that affect the likelihood that a policy strategy or instrument achieves the net GHG emission reductions it aims to achieve. This approach is then applied to 3 example policy areas. In general, risks and uncertainties with respect to the implementation and impact of GHG reduction policies and measures will pertain to the issues such as time, costs, quality, acceptance and impact.

Concerning risks and uncertainties with respect to policies and measures we discern the following processes:
Developing a better understanding of the secondary impacts, EU Transport GHG: Routes to 2050

Risks and uncertainties related to the process of developing and implementing policy instruments. Risks relate e.g. to validity of the assumptions underlying the policy strategy as well as to time and budget needed for development and implementation and the quality (and resulting effectiveness) of the outcome of the process or the political and societal acceptance of new policies. Quality issues can be particularly crucial where a policy is breaking new ground and the scientific and academic basis is limited. In the policy making process two steps can be discerned:
- setting out the general direction and approach;
- development and implementation of concrete policy instruments;

Risks and uncertainties related to the societal response to implemented policies. This societal response has several components which each have their own specific risks and uncertainties:
- technical responses, i.e. innovation and implementation of new technologies, which can be divided into incremental technologies and transitional technologies;
- behavioural responses, which can be divided into short term and long term, more structural, behavioural responses.

The societal responses in the end determine the net GHG emission reductions as a product of the amount of technical or behavioural changes implemented and the net sustainability of the new technologies or behaviour. Changes in technologies and behaviour may also have other foreseen or unforeseen impacts that may affect the acceptance of the policy and therefore impact on the net GHG emission reduction that is achieved.

In view of the above the net impact of a policy on GHG emissions is determined through the analysis of the 4 steps below:
1. Conception of the policy strategy
2. Implementation of the policy strategy by means of policy instruments
3. Implementation of technologies and behavioural changes in response to incentives provided by the policy instruments
4. Other impacts, related to the sustainability or other aspects of the implemented technologies and behavioural changes, that become apparent during implementation and affect the likelihood that a policy strategy or instrument in the end delivers the intended GHG emission reductions

Applying this to transport decarbonisation, in consultation with the European Commission the following policies and instruments have been selected for an in-depth assessment of risks and uncertainties in view of the fact that they could play a significant role:

- Biofuels
- Electricity and hydrogen in transport
- Economic instruments, particularly usage pricing, with the potential to directly affect demand for transport

**Biofuels** have been expected to play an important part in efforts to decarbonise the transport sector. Biofuels consumption was 4.7% of the transport fuels in 2010 based on energy content, and demand is growing. The main driver for the current developments in this sector in the EU is the EU Renewable Energy Directive, which sets a renewable energy target for the transport sector in 2020, of 10%. In addition, the Fuel Quality Directive defines a target for GHG emissions savings in the life cycle of the transport fuels, obliging fuel suppliers to reduce these emissions with at least 6% between 2010 and 2020.
Biofuels have been considered to be one of the key contributors to both these targets, as can be derived from the National Renewable Energy Action Plans that Member States submitted to the EC. Most Member States have implemented targets, policy incentives and obligations to promote their use. However, the GHG emission reductions that are achieved in practice have proven to be disappointing, according to various studies and reports, mainly because of indirect land use change (ILUC) effects. Net GHG impacts are found to differ significantly between biofuels, depending on many variables such as the feedstock type, energy use of conversion processes, etc. Some achieve significant GHG savings, while others do not achieve any savings, or cause more emissions than the fossil fuels that they replace.

The recent scientific and political debate about biofuels sustainability and ILUC effects illustrate the complexity of the topic, and the difficulties and risks that policy development in this area is faced with. Potential benefits, mainly GHG savings but also benefits regarding security of supply, economic development etc., may be large, but significant risks are also conceivable.

Vehicles running on electricity and/or hydrogen are important technical options for achieving a sustainable transport system in the medium and longer term. Electric vehicles in this context include battery-electric or full-electric vehicles as well as plug-in hybrid and range extender electric vehicles. Hydrogen vehicles may include vehicles with internal combustion engines, but for the longer term fuel cell powered vehicles are expected to prevail.

Both electricity and hydrogen offer the opportunity to use renewable energy from a wide range of source in the transport sector, and both enable driving with zero local emissions. Given their range limitations it is likely that EVs will be used more for short to medium distance trips in urbanised areas, while hydrogen could be more suited for applications where a larger range is required. One of the challenges in the promotion of these technologies is whether there is a need to make a priori choices for one technology or the other, or if both are applicable with respect to preferred applications. Another is the time frame over which any transition needs to occur. This choice is difficult to make at a time when neither is mature. This uncertainty creates a risk of wasted or duplicated investments. Other examples of risks and uncertainties e.g. pertain to the development of costs and market attractiveness of these technologies, the need GHG reduction potential depending on developments in the energy sector, and unknown knock-on GHG impacts through e.g. changed driving behaviour, the embedded emissions associated with battery manufacturing and recycling and oil price impacts.

User charging, as an economic instrument, clearly has a potential role to play in relation to reducing transport’s CO₂ emissions, but it has not yet been implemented that widely and its implementation still proves to be controversial. All Member States already have a crude form of road user charging in place in the form of fuel taxation. Existing fuel taxes bring in significant revenues for national administrations and were originally seen as a means of raising revenue, rather than as transport policy instrument. Fuel taxation has a number of benefits as a revenue-raising instrument as the level of income is relatively predictable and reliable; it is also generally considered to be progressive, as those on higher incomes generally drive more, and it is simple and easy to administer. However, in recent years fuel taxation has increasingly been used as an instrument of transport policy, either being raised above inflation to reduce CO₂ emissions or being differentiated to encourage cleaner fuels (although in general diesel remains under-taxed compared to petrol).

However, fuel taxation is a crude means of user charging (except for CO₂) as there are better ways of charging vehicles to reflect their wider impacts, e.g. air pollution and congestion, which would be fairer, make the transport system more efficient and could influence behaviour in particular locations. Introducing user charging by adopting a marginal damage cost pricing approach in which the external costs of the wider impacts of transport are internalised, i.e. included in the price of transport, is considered to be the first best and most
Developing a better understanding of the secondary impacts, EU Transport GHG: Routes to 2050 II sensitivities for the decarbonisation of EU transport by 2050

EU Transport GHG: Routes to 2050 II
Contract 070307/2010/579469/SER/C2

economically efficient approach, as was noted in the first EU GHG Transport 2050 project. User charging is also a more flexible instrument than fuel taxation, as it can be used to target particular modes, e.g. heavy goods vehicles, particular areas, e.g. city centres, or particular infrastructure, e.g. motorways, when a general increase in fuel taxation is not an option. Hence, for externalities other than CO₂ there is a rationale for introducing user charging as an alternative to fuel taxation, but it could also be introduced in addition to fuel taxation.

Possible risks and uncertainties relate e.g. to opposition from (local) business resulting from concerns over potential economic impact or from the public due to potential impacts on personal mobility, difficulties of agreeing taxation or charging policies at the European level (e.g. subsidiarity), the need to develop, potentially complex, technical and administrative systems to administer road user charging, or potential privacy issues resulting from the fact that charging according to time and location of travel requires knowledge of movements.

4.2 Risks and uncertainties in different steps of the policy process

The sections below provide a general description of the types of risks and uncertainties that have been identified and assessed in the different step of the policy process as indicated above.

4.2.1 Conception of the policy strategy

The policy strategy defines the overall target setting and the main routes through which the target should be reached. These routes are generally conceptions of the options (technologies or behavioural responses) that can be used to meet the target and the desired or required level of uptake of these options. Both the target and the routes are to a large extent decided on the basis of actual evidence, ex ante assessments (based on evidence, insights and expectations available at that time) and opinions or beliefs regarding the feasibility, costs and sustainability of technical and other solutions that can contribute to meeting the target. Misconceptions, lack of knowledge or ignored evidence may lead to targets that later on cannot be reached or routes that focus on the wrong solutions.

This step is essentially about whether the fundamental assumptions underlying a policy or concept are correct or not. If they are not, the policy should be altered, but that doesn't always happen. Ex-ante assessments should, but often do not, include foreseeable knock-on consequences, based on known and quantifiable mechanisms.

4.2.2 Implementation of the policy strategy by means of policy instruments

Given a choice of target and main means to achieve it, as laid down in the policy strategy, policy instruments need to be designed to promote the development and uptake of the desired technological solutions or the desired behavioural changes. This involves concrete target settings and detailed metrics to account for the extent to which various options contribute to meeting the target.

Possible risks and uncertainties with respect to policy development and implementation include:

- acceptance of policies by stakeholders, incl. industry, transport sector, NGOs and member states;
- time required for developing and implementing policies, including lead times for policy development and adoption and possibilities for delay tactics by various stakeholders
- Especially harmonised fiscal policies, requiring unanimous agreement in the Council, may take a long time to realise

- time required for developing associated test or assessment procedures or for changing codes and standards

- simplifications or political compromise leading to flaws, loopholes or other inconsistencies in the developed policy instrument

- imperfect implementation of policies, including lack of enforcement, resulting in undesired impacts

- changes in political landscape (e.g. elections leading to new parliaments and new Member State governments or appointment of new European Commissioners)

- lack of long term political consistency (e.g. with respect to subsequent tightening of emission standards or lowering emission ceilings under a cap & trade system)

Defining and implementing legislation inevitably involves simplification of complex issues. The specific design of the policy instrument may contain flaws or loopholes that later on lead to a reduced effectiveness or undesired societal responses. An example of how flaws in the metrics can affect the net GHG impact is the CO₂ legislation for cars. Part of the flaws there relate to a test procedure that is insufficiently precise. Another part relates to the fact that WTT GHG emissions are ignored so that implementation of zero CO₂ emission vehicles on the Type Approval test may lead to a net increase of WTW CO₂ emissions relative to what would be the case if the target was achieved without zero CO₂ emission vehicles. In this case the issue is about known flaws in metrics and the extent to which these are acknowledged (and possibly compensated for) in the design of the policy instrument. foreseeable knock-on consequences should be taken into account in specific target settings.

4.2.3 Implementation of technologies and behavioural changes in response to incentives provided by the policy instruments

Policy instruments may not have the desired effectiveness in the sense that they do not lead to the desired or required levels of implementation of technologies and behavioural changes. Also the implemented technologies and behavioural changes may be different from what was expected. Under this heading also knock-on consequences need to be included, specifically rebound effects insofar as they deviate from what was taken into account or foreseen in the design of the policy instrument. However, knock-on consequences are difficult to predict and specific elasticities are often not known. Further, consumer responses are to a large extent irrational.

This step is also about unforeseen ways in which the market may respond to, find and exploit the known flaws in the implemented measures or find and exploit unforeseen flaws. In the case of the CO₂ legislation for cars the apparently increasing gap between real-world and type approval CO₂ values and the increase of emissions in other parts of the life cycle of vehicles are examples of how implemented technologies may turn out to be less beneficial than had initially been believed.

Risks and uncertainties with respect to technological changes

Aspects of risks and uncertainties with respect to societal responses through adoption of new or improved technology in general include e.g. the time required for developing technical innovations and the uncertain outcome of R&D activities and product development, incl. compromises with respect to environmental performance. Another time-related risk is the time required for implementing innovations, including model development cycles, fleet renewal rates (which are different in different sectors). S-curves for increasing market shares may contain a so-called “valley of death” for innovations where innovations have difficulty to
Developing a better understanding of the secondary impacts, EU Transport GHG: Routes to 2050 sensitivities for the decarbonisation of EU transport by 2050

Ref. AEA/ED56293/Final Report – Issue No. 3

bridge the gap from early adopters and innovators to early majority. Cost development is a crucial but uncertain factor for new technologies, incl. the chicken and egg issue that costs only go down seriously when production volumes increase so that market formation is necessary to reduce costs. Incidents, leading to bad publicity for new technologies, also constitute a risk for successful implementation of e.g. electric or fuel cell vehicles.

Acceptance of new technologies by users and other stakeholders is crucial but new technologies may also encounter resistance by vested interests of existing market leaders and institutional and legal barriers. Innovations with respect to new energy carriers for transport can depend on developments in other sectors, specifically the energy sector for providing appropriate and sustainably produced energy carriers as well as the associated infrastructure. Cross-sector dependencies also involve uncertainties with respect to availability of resources (energy, materials, finance).

Risks and uncertainties with respect to behavioural changes

For behavioural responses possible risks and uncertainties include e.g. the actual possibilities for changing behaviour available to actors, e.g. the possibility to work from home or opportunities to move closer to the work location in order to reduce commuting distance in response to road pricing or increased fuel taxes. Even if the possibilities exist there is time required for actors to change behaviour, e.g. for development of new logistical concepts and new mobility concepts or in the longer term for structural changes in organisation of society.

Adoption of desired behavioural changes is furthermore affected by cultural aspects, the quality and valuation of attributes of alternatives to original behaviour, the acceptance of welfare impacts, and the economic situation allowing actors to deal with costs associated with behavioural changes.

4.2.4 Other impacts, related to the sustainability or other aspects of the implemented technologies and behaviours

This step is about sustainability impacts that are not directly related to GHG emissions. These impacts become apparent during implementation and may affect e.g. the acceptance of the policy and thereby the likelihood that a policy strategy or instrument will actually deliver the intended GHG emission reductions.

Even if the policy assumptions are valid, the implementation to achieve them is solid, the desired levels of uptake of technologies and behavioural changes are realized and there is little scope for market manipulation, it may turn out that a policy is socially or politically unacceptable or does not achieve the desired results for other reasons, even unrelated to GHG performance.

Considerations on other aspects than GHG reduction may thus undermine political acceptance of policies leading to discontinuation or weakening of the instrument. In terms of risks and uncertainties, also changes in political climate need to be mentioned here. In general the acceptance of policy strategies and instruments depends on a political weighting of various impacts. The desired GHG emission reductions may be considered to outweigh certain negative economic or social consequences at the time the policy is designed / implemented, but in a different political constellation later on the same facts may be weighted differently.
4.3 Conclusions

4.3.1 Biofuels

Biofuels have been expected to contribute significantly to future GHG emission reductions in the transport sector, as they can theoretically offer significant GHG savings and there is a large global potential (at least in theory) and they do not require a completely new infrastructure or engine technology. However, there are still quite a number of risks and uncertainties related to actually achieving this potential.

Firstly, a robust biofuels policy strategy should be developed. This should take the complexity of the issues into account and arrive at realistic estimates for biofuels supply and GHG emission reduction achieved in the future. This strategy should take into account land use and its impacts on GHG emissions and other sustainability issues and also consider alternative uses of the biomass. The latter is not only important for agricultural commodities, it is also important for waste and residues: these are often in use for other purposes. Shifting them towards the biofuels sector will cause a shift to other, perhaps less sustainable feedstocks in the other sectors. The biofuels strategy should thus not only be looking at transport, but it should be positioned in the larger context of increasing global food and feed demand, and take into account that other industries are also aiming to switch to low-carbon materials in the coming decades.

The strategy then requires policy instrument design and implementation that should address the issues mentioned above. Crucial to the success of the policies are those that have to ensure GHG emission reductions. To this end, ILUC effects are very important to include. Given the significance of ILUC emissions and the large volumes of biofuel foreseen, this means substantial expansion of productivity beyond that already foreseen, or sourcing biomass from otherwise unusable land. Furthermore, GHG assessments should also take into account indirect effects that may occur in other industries that may also use the feedstock. In parallel, efforts should be put into global initiatives that can reduce land use change and biodiversity loss due to biomass cultivation for biofuels, for example within the IPCC and CBD framework.

Research and development of new (2nd generation) biofuels production processes needs to be promoted and incentivised, to ensure a diverse biomass use in the future that does not compete with the food sector nor lead to significant negative impacts from land use change. Potential compatibility problems of the biofuels with existing vehicles or engines may need to be addressed. In addition, policies need to be developed for biofuels use in aviation and maritime shipping, two sectors that have to operate in a global context and thus may require implementation of global biofuels (or rather renewable energy) policies in the longer term.

Once the policies are implemented, the effects should be monitored critically, as the market may respond differently than expected.

Apart from GHG effects, there are a number of other impacts that should be addressed in the various steps of policy development. Examples are impacts on fuel and food costs, economic impacts on the transport sector but also on other sectors that either depend on transport or also use the biomass, and impacts of the biofuels policies on biodiversity and socio-economic developments.

4.3.2 Electricity and hydrogen in transport

The success of using electricity and hydrogen as a means to drastically reduce GHG emissions of the transport sector by 2050 depends on a multitude of factors. In as far as
these factors are exogenous to the transport sector, or endogenous but unpredictable or difficult to manage, they constitute risks or uncertainties or cause undesired long lead times.

Risks, uncertainties and lead times can be categorized as pertaining to three main conditions that must be fulfilled in order for electric and hydrogen fuelled vehicles to have the desired impact on GHG emissions:

1. Effective policies must be developed and implemented which promote the installation of the appropriate required energy infrastructure and the use of electric and hydrogen-fuelled vehicles;
2. Electric and hydrogen-fuelled vehicles need to reach significant market shares;
3. The environmental impact of the applied electric and hydrogen-fuelled vehicles must be such that it leads to a significant net reduction in GHG emissions. This relates to the WTW GHG emissions associated with energy use and probably to a lesser extent to the embedded GHG emissions associated with vehicle manufacturing and decommissioning.

An important part of the first risk / uncertainty relates to the choice between the two options either resulting in a risk to pick the wrong one, or a risk to invest in both unnecessarily.

Main identified uncertainties pertain to:

- Developments of costs for critical components of electric and hydrogen fuelled vehicles and the resulting possibilities for creating a favourable business case without subsidies or fiscal stimulation;
- Availability of critical materials, including the feasibility of scaling up mining and production activities fast enough to keep up the pace with developing demand;
- Development of the prices for fossil and low carbon energy;
- Timely availability of sufficient quantities of low carbon energy.

The following factors have been identified as significant risks:

- Unforeseen loopholes in policy instruments reducing the effectiveness of the policy or the net GHG impact;
- The possible occurrence of a "valley of death" in the market introduction when after serving the "innovators" and "early adopters" segments in the market the price and characteristics of electric or hydrogen fuelled vehicles have not yet developed to a level that is considered acceptable by the "early majority" segment of the market;
- High costs per vehicle in the early stage of market entry due to underutilisation of energy supply infrastructure;
- The (lack of) endurance of the current favourable attitude of governments, investors, consumers and other stakeholders towards electric vehicles.

Substantial lead times are caused by:

- the time to develop and implement required policy instruments at the European level;
- the finite rate of fleet renewal;
- the slow, iterative process of early market formation through subsequent niches.

All in all the implementation of electricity and hydrogen as GHG reduction options for the transport sector is a transition that involves drastic and structural changes in both the transport and the energy sector and that will take several decades to start up, roll out and complete. Governments and stakeholders in the market need endurance and a long term vision to manage this transition in an effective way. Mitigating risks and taking away uncertainties is an important part of that. Proactive steps are required in the short term in laying the ground work for longer term policy instruments, in early market formation and in setting up and managing a process that timely delivers the insights that are necessary to
develop a suitable dominant design for the energy distribution infrastructure. For example, in the case of electric vehicles this dominant design relates to the roles of home charging, public slow charging, fast charging and battery swapping and the integration of this charging infrastructure in the future electricity grid, possible in combination with smart grids.

4.3.3 Economic instruments, particularly usage pricing

This section has argued that, if road user charging is to be implemented to reduce transport’s CO₂ emissions, it should be introduced in addition to, rather than instead of, fuel taxation. At the European level, there is currently little in the way of barriers to implementing road user charging, as long as the schemes heavy-duty vehicles are consistent with the Eurovignette Directive. While the Commission has indicated that it intends to phase in mandatory charging (to cover at least some external costs) by 2016 for heavy goods vehicles and by 2020 for all road modes, in the meantime Member are still able to implement road user charging schemes. In Member States, there might be a need for additional national legislation before national and local authorities are able to implement road user charging. This could mean that there would be a lead time of perhaps a couple of years in some countries before the relevant legislation is in place. Once permitted, it could take the relevant authorities a number of years, perhaps up to three, to design the scheme, engage the public, business and other stakeholders and make the scheme operational. When (or if) a mandatory charging framework is put in place at the European level, all national, regional and local schemes would potentially have to be redesigned in order to be consistent with the respective EU framework. However, EU legislation usually gives Member States a number of years to make national policies consistent with EU legislation.

However, a number of economic, social, environmental and political risks and uncertainties exist. Many of these are linked. For example, the two main risks of relevance to road user charging are public acceptability and the associated political risks. Unless these can be overcome, road user charging schemes will not be implemented. However, the political and acceptability risks are often based on the other economic, social and environmental risks that relate to the potential behavioural responses from road transport users, to the introduction of road user charging. These include the potential adverse impacts on local businesses and poorer road users in the charging area and the potentially adverse environmental impacts on those just outside the charged area. Some of these risks and uncertainties are more perceived than real, whereas others are genuine.

Hence, taking steps to improve the acceptability of any proposed user charging scheme is fundamentally important, and should be the number one priority of policy makers, so as to reduce the risks associated with a lack of acceptability amongst the public and business. In this respect, perceived and real risks need to be identified and addressed in the implementation of the policy, particularly in its rationale, design and communication. In order to reduce the risks of acceptability, it is important that complementary policy instruments (which could even be introduced in advance of the charging scheme itself) are implemented in order to address concerns or demonstrate benefits. This could include, for example, the recycling of revenues to improve conditions for the poorer parts of society, or by investing in modes, such as buses, that these sectors of society are more likely to use.
5 Co-benefits associated with GHG reduction policies and measures

Objectives:
The purpose of Task 1 of the project was to develop a better understanding of the air quality, energy security, environmental noise, and health co-benefits associated with possible transport sector GHG reduction policies. Additional investigations on the interaction of GHG policy for transport with congestion and accessibility policies was also included under the Task 11 ad-hoc budget.

Summary of Main Findings

Air quality
⇒ GHG reduction options can have varying effects on emissions of air pollutants
⇒ GHG reduction options likely to have a positive impact on reducing air pollutant emissions include hydrogen (when produced from natural gas reforming and coal gasification); electric vehicles where renewable energy is used; hybrid electric and PHEVs when used in urban environments; measures affecting driving style (e.g. eco-driving, speed limits); non-technical measure (e.g. economic instruments and spatial policy – affecting transport activity and modal split); and technologies such as regenerative braking that can reduce non-exhaust air pollutant emissions.
⇒ GHG reduction options which are likely to have a negative effects on reducing air pollutant emissions include hydrogen (produced by water electrolysis, although predicted to decrease in future); electric vehicles using electricity generated using average European grid mix; hybrid and PHEVs when used in non-urban locations; and biofuels (tend to emit same or higher air quality pollutant emissions over fuel lifecycle)

Noise
⇒ GHG policies aimed at reducing emissions in urban areas by access restriction have potentially large traffic noise reductions and take immediate effect both for road and rail.
⇒ Introduction of electric, fuel cell and hybrid powertrains will generally reduce environmental noise, but take 12 years to reach full impact on average road traffic noise levels, mostly in urban areas. For railways the effect is smaller due to the predominance of rolling noise. The effect will mainly be for lower speeds and in acceleration and stationary idling conditions.

Energy security
⇒ The results suggest that energy demand reduction is consistently the best option for energy security.
⇒ In the short-term, conventional fuels score well because a high proportion of the vehicle fleet is able to use them and prices are currently low. Costs are projected to increase over time, and indicators for surplus capacity show that over time oil-derived fuels become less secure as global resources are depleted.
⇒ In the longer term, oil-derived liquid fuels also become more susceptible to supply disruptions. Biofuels also show a reduction in energy security due to increasing resource concentration, poorer supply resilience and a lack of surplus capacity.
⇒ Electricity and hydrogen are the only fuels that become more secure, due to increased contributions from renewable technology production.
⇒ Modelling results suggest that GHG policies could lead to significant benefits for transport energy security. Under the core reduction scenario (broadly consistent with
Summary of Main Findings

the Transport White Paper targets), the energy security rating shows only a small decrease of 3% between 2010 and 2050, vs BAU which shows a decrease of 40%.

Health – Accidents
⇒ Reduction in speed levels (speed limits), introduction of road charging, reduction in average vehicle mass (vehicle standards), and a shift from car to public transport are likely to have positive effects on accidents (number and/or severity)

Health – Physical Activity
⇒ Where more active modes are stimulated, more people will cycle and walk.
⇒ Per km health benefits from increased physical activity from cycling varies from €0.30 to around €1.20.
⇒ In terms of potential benefits in the EU, if 10% inactive people become active through increased cycling and walking, the health benefit could be in the range of €9 to €37 billion. This could increase to €31 to €122 billion if one third of the inactive population became active.

Congestion
⇒ Win-neutral policies: Many instruments to tackle GHG only have a small impact on congestion (e.g. technology options that are not tied to location or time);
⇒ Win-lose policies: Instruments aimed at reducing congestion often have potential for increasing GHG (mostly related to capacity expansion). Therefore it is important to consider both short-term (flow) and long-term impacts (induced demand);
⇒ Win-win policies: These include taxes and charges that make car travel less attractive and shifts to more footprint efficient modes (e.g. bus) or non-road modes.
⇒ Policy implications: It is important to take into account the risk of adverse effects in the decision making process. There should be a focus on policy instruments related to the reduction of congestion, since congestion instruments might significantly increase GHG. Where infrastructure expansion is considered, there is a general need to investigate whether the same congestion reductions can be achieved without GHG increase.

Relative values of different co-benefits and conclusions
⇒ Currently the aggregate costs of congestion and accidents are estimated to be highest, although by 2050 the combined cost impacts of GHG, air quality pollutants and energy security are likely to be a similar size under business as usual conditions;
⇒ Monetised co-benefits for different scenarios show combined co-benefits of GHG policy actions could be very significant – up to €243 billion per annum by 2050 under the core GHG reduction scenario (R1-a) and total monetised benefits are potentially as high as €384 billion per annum by 2050 if all modelled mitigation options were implemented.
⇒ Non-technical measures can have the largest co-benefits per tonne GHG abated - particularly for those leading to increases in walking and cycling (due to health benefits).

5.1 Introduction

The objective of Task 1 was to develop a better understand the scale of co-benefits associated with transport sector GHG reduction policies, including air quality, environmental noise, energy security and health.

Analysis of the co-benefits of GHG reduction policies is an increasingly important area of research as it is becoming clear that co-benefits can be very important in helping to make the
economic case for GHG abatement measures. During the previous project, our team carried out initial exploration of some of the key co-benefits, but there was not the time available within the study to carry out detailed quantitative analysis of all of the issues.

The majority of the co-benefits associated with GHG reduction policies for the transport are directly related to health\textsuperscript{15}, including:

- Improved \textit{air quality} due to reduced emissions of air pollutants from transport;
- Reduced \textit{ambient noise} levels due to quieter low-carbon vehicles (e.g. electric vehicles);
- Reductions in the number and/or severity of traffic \textit{accidents} (e.g. through speed reduction policies);
- Increases in the amount of \textit{physical exercise} carried out by the population in general due to a shift to non-motorised transport modes (cycling and walking); and
- Indirect pollutant emissions impacts related to the \textit{life cycle effects} of vehicles, energy carriers or infrastructure.

Task 1 examined the co-benefits through initially reviewing the available literature. The relative values indicative of each of the co-benefits were then considered. An additional paper was also commissioned under the Task 11 ad-hoc budget to explore the significance of congestion. The following sections summarise the key findings in relation to each of the co-benefits.

\section*{5.2 Air Quality}

Transport-related air pollutant emissions are a major cause of health and environmental problems. A range of GHG reduction options were considered in terms of potential air pollutant co-benefits, with a particular focus on road transport measures as the impacts of air pollution are greatest (due to the proximity of road networks to populations). The main findings are as follows:

- Use of low-carbon vehicles may involve a trade-off between lower emissions during vehicle use against higher emissions in the upstream phase. It is found that the production process used to make alternative energy sources significantly influences the overall level of emissions.
- Currently, hydrogen is mainly produced from natural gas reformation and coal gasification, which were both found to reduce levels of NO\textsubscript{x}, SO\textsubscript{x} and PM from hydrogen fuel cell vehicles on a well-to-wheels basis compared to conventional petrol/diesel vehicles. Using hydrogen produced by water electrolysis could increase emissions overall given the current power mix, but it is anticipated that emissions will decrease as more renewable or nuclear generation comes online.
- Electric vehicles may produce higher levels of NO\textsubscript{x}, SO\textsubscript{x} and PM overall if the electricity is generated using the average European grid mix, due to the high contribution of coal power plants. Future emissions will decline with the introduction of newer and cleaner plants and greater contributions from renewable generation. Emissions of air pollutants are virtually eliminated if electricity generation switches to renewable energy sources or nuclear.
- The \textit{air quality benefits} of hybrid electric vehicles and plug-in hybrid vehicles depend on the drive cycle. They are most beneficial when used in urban environments.
- Biofuels can cause increases or decreases in WTW emissions depending on the fuel specifications and particular fuel production pathway. In general, biofuels are thought to emit similar or higher levels of air pollutants over the fuel lifecycle, whereas the effects on tailpipe emissions are uncertain.

\textsuperscript{15} Reduced climate change itself can also have various health benefits. However, since these are related to the primary aim of climate policy, these should not be labelled as co-benefits.
• Measures affecting driving profiles are known to have an impact on emissions, for example, driving style training and traffic management. It is found that eco-driving techniques and speed limits can have beneficial impacts on air pollutant emissions.
• Non-technical measures such as economic instruments and spatial policy may also affect air quality through impacts on transport activity and modal split.
• Non-exhaust emissions relating to tyre and brake wear can be reduced through uptake of vehicles that incorporate regenerative braking, such as electric and hybrid vehicles.

Introduction of higher Euro standards will substantially reduce vehicle pollutant emissions. Therefore, the local air quality co-benefits of many GHG reduction policies are likely to diminish as conventional cars become cleaner. However, new technologies take many years to penetrate the fleet. Results from the analysis of different indicative scenarios suggest that uptake of all GHG reduction policies could reduce total air quality pollutant costs out to 2050 by up to 50% (~€60,000m), see Figure 5.1.

Figure 5.1: Comparison of potential air quality pollutant emission costs for different individual measures and policy/scenario packages in 2050

5.3 Noise

Transport is the major source of environmental noise pollution in the EU. Noise generation from both road and railway traffic is influenced by vehicle type, speed, traffic intensity, road and track type, road and rail surface conditions, maintenance and usage. Also, the time and route of operation is a factor that determines the average exposure levels, in particular night time freight haulage is a critical issue for both road and rail. Key findings from the review of literature regarding noise co-benefits of GHG emission reduction policies include the following:
• All GHG policies that reduce vehicle speeds, engine speeds and traffic intensity can substantially reduce road and railway traffic noise and the exposed population.
• GHG policies aimed at reducing emissions in urban areas by access restriction have potentially large traffic noise reductions and take immediate effect both for road and rail.
- Introduction of electric, fuel cell and hybrid powertrains will generally reduce environmental noise, but take 12 years to reach full impact on average road traffic noise levels, mostly in urban areas. For railways the effect is smaller to the predominance of rolling noise. The effect will mainly be for lower speeds and in acceleration and stationary idling conditions.

5.4 Energy Security

Energy security in the transport sector is becoming an increasingly important issue, particularly given the current heavy reliance on oil-based fuels. Energy security is defined as the availability of sufficient, affordable and sustainable energy supplies. The performance of various fuels, including conventional oil-based fuels and alternative energy sources, is assessed against different energy security factors. These factors are: linkage to oil price, proportion of vehicle fleet able to use the fuel; cost of the fuel; surplus supply capacity; resilience of supply chain to disruption and resource concentration. This study developed quantitative rankings (MCA framework) to assess the energy security implications of different policy options.

The results suggest that energy demand reduction is consistently the best option for energy security. However, it is clearly not feasible to rely on energy demand reduction as the only means of improving energy security without severely impacting the economy. In the short-term, conventional fuels score well because a high proportion of the vehicle fleet is able to use them and prices are currently low. Costs are projected to increase over time, and indicators for surplus capacity show that oil-derived fuels become less secure as global stocks are depleted. In the longer term, oil-derived fuels also become more susceptible to supply disruptions. Biofuels also show a reduction in energy security due to increasing resource concentration, poorer supply resilience and a lack of surplus capacity. Electricity and hydrogen are the only fuels that become more secure, due to increased contributions from renewable technology production. Electricity is currently less secure than petrol/diesel, but becomes more secure after around 2025. Hydrogen becomes more secure than petrol/diesel after 2040.

The results suggest that GHG policies could lead to significant benefits for transport energy security, as illustrated in Figure 5.2 where a higher score for a factor shows a larger contribution to energy security. In the business-as-usual scenario, the energy security rating falls by 40% between 2010 and 2050. Under the core reduction scenario (broadly consistent with the Transport White Paper targets), the energy security rating is much better protected, and shows only a small decrease of 3% between 2010 and 2050.

A comparison is also provided with the previous project’s scenarios. Using all technical/non-technical options (C5-a) increases the energy security rating by 14% and using only non-technical options (C6-a) the rating is similar to R1-a, mainly due to significant energy demand/activity reduction.
5.5 Health

GHG reduction policies for the transport sector can have various health co-benefits in different areas (i.e. air quality, noise, accidents and physical exercise). This subtask focused on the health impacts from accidents and physical exercise:

- Reductions in the number and/or severity of traffic accidents (e.g. through speed reduction policies); and
- Increases in the amount of physical exercise carried out by the population in general due to a shift to non-motorised transport modes (cycling and walking).

5.5.1 Health - Accidents

It was identified that GHG emission reduction policies may affect the number and severity of traffic accidents via various channels; including changes in speed levels, traffic levels, vehicle characteristics, etc. The Task 1 paper considered the impacts of such policies on accidents. The results are summarised as follows:

---

16 Reduced climate change itself can also have various health benefits. However, since these are related to the primary aim of climate policy, these should not be labelled as co-benefits.
Developing a better understanding of the secondary impacts, EU Transport GHG: Routes to 2050

5.5.2 Health - Physical activity

GHG reduction policies can lead to an increased use of non-motorised transport modes, in particular cycling and walking. Besides various other co-benefits such as reduced pollutant and noise emissions, this can also result in personal health benefits from increased physical activity. Higher use of cycling and walking can increase the percentage of the population that meets the minimal physical activity level which is regarded to be required for a good health. Cycling and walking can easily be integrated in daily life and can ensure that a healthy level of physical activity is sustained over time. Also increased use of public transportation can indirectly contribute to more physical activity, as it generally results in more cycling and walking to and from public transport stations.

GHG policies can contribute to reducing the level of physical inactivity. In situations where more active transport modes are stimulated, more people will cycle and walk. The health benefits gained by reducing physical inactivity can be quantified and monetized. The per km health benefits from increased physical activity from cycling vary from €0.30 to around €1.20. Based on these numbers, indicative estimates were made for the total potential benefits in the EU. They range from €9 to 37 billion in the case that 10% of the inactive people would become active because of increased use of cycling and walking. In the case that a third of the inactive population would become active, the benefits would even be in the range of 31 to 122 billion Euro per year. The ranges in these estimates reflect uncertainties in quantification of the benefits. Overall, it can be concluded that the health effects of increased physical activity represent significant financial benefits and therefore should also be taken into account when assessing the cost-effectiveness of transport and climate policies.

5.6 Congestion

The interactions between GHG policy and congestion policy were assessed in a specific ad-hoc task. The main objective was to explore the potential interaction between road congestion and climate policies and ways that the two could be combined effectively.
5.6.1 Understanding the GHG impacts of congestion

Congestion progressively slows down traffic where the number of vehicles increases towards the maximum capacity. Due to this slowing down process, congestion results in lower average speeds and often also higher speed dynamics (e.g. stop-and-go-traffic). Because of this, congestion influences both the total amount of vehicle kilometres as well as the GHG emissions per kilometre.

The sum of both effects of congestion depends on local circumstances. On motorways, although the emissions per kilometre during congestion can in some cases be higher than without congestion, this is never the case for the emissions per minute travelled. Therefore, when the rule of constant travel time budget applies, the reduction of congestion on motorways generally leads to an increase in transport emissions. The effect of the increase in demand is apparently much stronger than the potentially saved emissions from the fuel efficiency improvements at vehicle level.

This means that congestion reduction can only lead to lower emissions when there is a shift to travel types with lower emissions per minute travelled, e.g. a shift to non-motorized transport or rail transport.

In the case of freight transport, the relationship between transport speed and transport demand may be different than for passenger transport. However, also for freight transport an increase in travel speed will lead to a decrease in travel times and overall costs and so to an increase in transport demand.

5.6.2 Impacts of policy instruments

The effects on congestion as well as the effects on GHG reduction were assessed for the main policy instruments that are aimed at reducing GHG emissions and/or road congestion. The assessment makes clear that some policies clearly contribute to both objectives, while a broad range of others have a positive impact on GHG emissions but a zero or unclear effect on congestion. A few policies result in less congestion but a clear increase in GHG emissions. There were no policies found with a strong GHG reduction potential but a clear adverse effect on road congestion.

In general it can be concluded that GHG reduction policy instruments have some co-benefits in terms of congestion reduction or have a more or less neutral effect on congestion. Particularly economic instruments (e.g. road pricing, fuel taxes, congestion charges, etc.) contribute generally to the reduction of both GHG emissions and road congestion. Pricing instruments can be used as an alternative for other policy instruments, but can also be complementary to them and increase the effectiveness of other policy instruments.

Vehicle CO₂ regulation is very effective in reducing in reducing GHG emissions, but any effect this may have on congestion is unknown, but expected to be small.

Investments in non-road infrastructure can result in some reduction of road congestion, the GHG effect depends strongly on the specific case. When a true shift from road is achieved, GHG emission reduction can be significant, but when most of the traffic on the new infrastructure comes from other (non-road or aviation) modes, the GHG impact can be neutral or sometimes even negative.

As opposed to all these instruments that contribute more or less to both policy objectives, many instruments focused on the reduction of congestion can increase GHG emission significantly, especially in the case of expanding infrastructure capacity. Although expanding capacity can result in GHG reduction in the short term, this instrument will induce traffic in the long term when no additional policies, like road pricing, are applied.
5.6.3 Policy recommendations

Overall, it can be concluded that the risk of adverse effects from congestion reducing policies should be taken into account in the decision making process. Because, congestion reduction policy instruments might significantly increase GHG emissions, their GHG impacts should be considered carefully. Particularly in case infrastructure expansion is considered as an option, it should be investigated to what extent the same congestion reduction can be reached without an increase in GHG emissions. Pricing instruments can be an alternative from this perspective and therefore could often be applied first.

5.7 Relative values of different co-benefits

For road passenger transport, congestion and accidents currently have the highest costs; hence any GHG policies that have significant co-benefits in these areas are likely to be particularly important. In particular, policies such as speed limits and road user charging would be able to differentiate according to the location, time of day and type of vehicle that are most affected. However, by 2050 estimated GHG costs for passenger transport could reach similar levels to those of noise and congestion in the baseline scenario assuming no further abatement.

For road freight transport, the highest costs are attributed to accidents, noise and air pollution in 2010. Costs are anticipated to remain high for accidents and noise in 2050. Therefore, GHG policies that have co-benefits relating to noise and accidents would be particularly beneficial. All GHG policies that reduce speed, reduce traffic intensity or stimulate uptake of electric, hybrid or fuel cell powertrains can contribute to noise reduction. It is expected that policies such as speed limits and road user charging could result in lower accident risks. Costs for air pollution from road freight are anticipated to decrease significantly in 2050 due to the introduction of increasingly higher Euro standard vehicles, which if effective would mean that air quality co-benefits would become less important over time.

Overall it appears that the costs of accidents are the most pervasive in both passenger and freight transport. Congestion also has a large impact on passenger transport, whilst noise is an important cost factor for freight vehicles. It appears that GHG policies that help to control traffic flow (such as speed limits and/or road user charging) could result in a “quadruple benefit” for climate change, safety, noise pollution and the economy (through reduced time wasted in traffic). Such policies also help to alleviate air pollution; however, it is expected that air pollution would continue to be effectively dealt with by Euro standards and fuel quality regulations. Although there could be benefits in the short- and medium-term (particularly since existing standards have failed to deliver the expected levels of improvements in real-world conditions), the importance of co-benefits in this area will diminish over time.

Estimates for the combined monetised co-benefits of different scenarios and scenario packages for different policy actions are summarised in Figure 5.3. These show that the combined co-benefits of GHG policy actions could be very significant – up to €243 billion per annum by 2050 under the core GHG reduction scenario (R1-a) and total benefits are potentially as high as €384 billion per annum by 2050 if all modelled mitigation options were implemented. The figure also illustrates that per tonne GHG abated, non-technical measures can have the largest co-benefits (particularly for those leading to increases in walking and cycling, which are comparable in size to total average road transport running costs in €/pkm).
5.8 Conclusions

Task 1 has explored a wide variety of co-benefits associated with GHG reduction policies, including air quality, noise, energy security and health (accidents and physical exercise). Impacts vary depending on the GHG reduction policy, and they can be both negative and positive. In the majority of cases, co-benefit impacts can be monetised, enabling comparisons between them. Comparing the relative values of co-benefits revealed that the negative impacts of accidents are the most pervasive in both passenger and freight transport. GHG reduction policies aimed at controlling traffic (e.g. speed limits, road user charging etc.) are anticipated to have positive benefits on climate change, safety, noise and the economy, in addition to alleviating air pollution problems (although these will continue to be effectively dealt with by Euro standards and fuel quality regulations in the short to medium term). In the future the monetised co-benefits of GHG reduction policies have the potential to be substantial (in the order €243 billion per annum by 2050 under the core GHG reduction scenario, consistent with the White Paper GHG target), in particular those that result in significant increases in walking and cycling (due to associated health benefits).
6 Cost effectiveness of different GHG reduction policies and measures

Objectives:
The purpose of this task was to develop a better understanding of the cost effectiveness of different technical and behavioural measures and policy instruments.

Summary of Main Findings

⇒ In the short term, several technical measures for passenger cars and heavy good vehicles with negative abatement costs are available.
⇒ With respect to behavioural measures, fuel efficient driving and probably also teleworking result in negative abatement costs. The purchase of an electric or smaller car (instead of a regular car), on the other hand, probably results in positive abatement costs.
⇒ For some of the GHG policies (e.g. vehicle standards, fuel taxes, road user charges) it was found that they could be implemented in a cost effective way. However, the cost effectiveness of these policies is strongly case dependent due to the large dependency on local/national characteristics and the design of the instrument.

6.1 Introduction

In the previous EU Transport GHG: Routes to 2050 project a large range of technical and behavioural reduction options as well as policy instruments are identified and assessed. In the current project we gained more in-depth knowledge on these measures and policies, among other things by assessing co-benefits and knock-on consequences of some of the policies. Additionally, we also assessed the empirical evidence on the cost effectiveness of these measures and policies. The main results of this assessment are presented in this chapter.

The assessment of cost effectiveness of (technical and behavioural) measures and policy instruments was based on a review of the literature. It should be noted that past studies assessing the cost effectiveness of policies and measures addressing the climate impact of transport have yielded widely different results. An important reason for these varying results are differences with respect to methodological issues, like the perspective applied (end-user or social perspective), the way direct expenditures are calculated (choice of baseline scenario, discount rate, depreciation period, etc.) and whether or not broad welfare impacts are taken into account. Due to these methodological differences between studies it is hard to come up with general cost effectiveness figures for particular measures or policies. However, by comparing different studies (and particularly the key methodological choices and assumptions made in the various studies) we were able to establish the strength and direction of evidence on cost effectiveness of some of the measures/policies. Additionally, for some of the measures we were also able to come up with best estimates of (ranges of) cost effectiveness figures.

For the best estimates we assumed a social perspective taking broad welfare impacts into account. This also implies that the co-benefits of the various policies and measures (see also section 5) and knock-on consequences (see also section 3) are taken into account as much as possible (particularly with respect to policy instruments).
6.2 Technical measures

In this section we discuss the main results of the assessment on the cost effectiveness of technical and behavioural measures. Based on a review of recent literature we provided some best estimates of the cost effectiveness of technical measures for passenger cars and heavy good vehicles (HGVs). In Figure 6.1 the main results of this assessment are shown. The cost effectiveness figures refer to packages of technical measures necessary to realise the chosen CO₂ reduction target. The ranges in the figures are mainly due to variances in fuel prices and discount rates applied.

Figure 6.1: Indicative ranges of short term (2020) abatement costs of various technical and behavioural GHG reduction options for passenger cars and HGVs

-25% Petrol Cars¹  
- 25% Diesel Cars¹  
-9% Medium Duty Truck¹  
-15% Medium Duty Truck¹  
-30% Heavy Duty Truck¹  
-40% Heavy Duty Truck¹  
Fuel Efficient Driving

Notes:
¹ The abatement cost estimates for passenger cars and HGVs refer to the costs associated to packages of technical measures with certain abatement potentials. For example, ‘-25% petrol cars’ refers to the abatement costs of a package of technical measures for petrol passenger cars that result in 25% lower CO₂ emissions.

² Due to the very high uncertainty in the estimation of abatement costs for biofuels, electric vehicles (EVs) and fuel cell electric vehicles (FCEVs) it is not possible to provide reliable ranges for the abatement costs for these technologies/fuels. However, the very rough estimates for specific assumptions provided in this paper shows that the abatement costs for these technologies are probably very high (at least on the short term) and (largely) beyond the scale of this figure.

On the short term (up to 2020) various fuel saving measures are notable in passenger cars:
- **Engine options:** further refinement of existing ICE technology including: gas-wall heat transfer reduction, lower internal friction, cam phasing, direct injection, thermodynamic cycle improvements
- **Transmission options:** including optimisation of gear box ratios (downspeeding), automatic manual gearboxes, dual clutch gearboxes and CVT’s
Developing a better understanding of the secondary impacts, EU Transport GHG: Routes to 2050

- Hybridisation, from start-stop systems to full hybrids
- Driving resistance reduction: weight reduction, aerodynamic improvements, lowering of rolling resistance and minimisation of driveline loss
- Various others, such as efficiency improvement in auxiliary systems and thermal management

The various individual fuel saving measures can also be combined to increase the technical reduction potential. The cost effectiveness of one specific package of technical measures (reducing CO$_2$ emissions from 130 g/km in 2015 to 95 g/km in 2020) is shown in Figure 6.1. It is clear that significant CO$_2$ reduction could be realised until 2020 with negative or relatively low abatement costs. Although the effectiveness of reduction measures is in general higher for petrol cars than for diesel cars, the cost effectiveness figures show an opposite picture. The higher cost effectiveness of technical measures for diesel cars can be explained by the higher number of lifetime kilometres of diesel cars, as a consequence of which the amount of CO$_2$ emissions reduced over the lifetime of a diesel car by installing a reduction measures is much higher than for petrol cars. Figure 6.1 shows that the cost effectiveness figures strongly depend on the fuel prices and discount rates assumed. For example, doubling the fuel price assumed result in abatement costs for petrol cars of - €100 per tonne CO$_2$ (instead of € -10 per tonne).

Also for heavy good vehicles (HGVs) various fuel saving measures are available up to 2020, including hybridisation start-stop, variable pumps/compressors, automated transmission, various engine options, etc. Again, these measures could be combined to realize larger reduction potentials. Both for medium and heavy duty HGVs various packages with negative abatement costs are available. For example, the cost effectiveness of a package of reduction measures for medium heavy HGVs (~12 tonne) resulting in ca. 16% lower CO$_2$ emissions is ca. -€5. For heavy duty HGVs (~40 tonne) even a larger CO$_2$ reduction could be realised at negative abatement costs (see Figure 6.1).

The abatement costs of alternative fuels are significantly higher than for technical reduction options. Both CNG and LPG results in rather high abatement costs, which is due to its relatively small CO$_2$ reduction potential combined with significant vehicle and infrastructure costs. The abatement costs of biofuels are not presented in Figure 6.1; recent studies on the abatement potential of biofuels show that due to indirect land use change (ILUC) effects most of the biofuels will result in a net increase of GHG emissions. Therefore, it is not possible (and useful) to determine cost effectiveness figures for these biofuels. The evidence on the cost effectiveness of the biofuels which do result in net GHG emission savings is rather scarce. However, the rare studies carried out show that these biofuels have very high abatement costs (for at least the short to medium term).

On the longer term (up to 2050) more fuel saving measures will become available for both light-duty and heavy-duty vehicles. For light-duty vehicles particularly the electric drivetrains and fuel cells are promising technologies. For heavy-duty vehicles hybrid drivetrains using biofuels appears to be a good opportunity to reduce their climate impact. However, current knowledge on both the reduction potential as the costs associated to these technologies is too limited to provide reliable cost effectiveness figures. Based on some rough estimates using specific assumptions provided in this study it was concluded that these will probably very high on the short term. Due to scale and learning effects these costs could be reduced on the longer term, although they are expected to be high on the medium term too (to 2030).

### 6.3 Behavioural measures

Next to technical CO$_2$ reduction options also the cost effectiveness of some behavioural reduction measures are assessed. Only for fuel efficient driving quantitative cost
effectiveness figures were available from the literature: -€100 to -€10 per tonne CO₂ (see Figure 6.1). Based on a qualitative assessment positive cost effectiveness figures are expected for the purchase of electric/plug-in hybrid cars and smaller cars, while for teleworking negative abatement costs are expected. For the behavioural options ‘modal shift’ and ‘applying virtual meetings’ it was not possible to determine the sign or size of their cost effectiveness.

6.4 Policy instruments

Next to the cost effectiveness of technical and behavioural measures we also assessed the cost effectiveness of some GHG policy instruments. However, the empirical evidence on the cost effectiveness of policy instruments is rather limited. Moreover, the figures available depend heavily on the design of the instrument and the national or local context and hence figures could not be transferred to a more aggregate, European level. Therefore, the quantitative results on cost effectiveness of policy instruments should be considered as illustrative figures. Without further study, these figures could not be applied in other cases.

In Table 6.1 some cost effectiveness figures of various policy instruments for specific cases are shown. These results show that several of the policy instruments (vehicle standards, fuel taxes, road user charges, certain fiscal measures for commuter and business travel) could be implemented in a cost effective way. The cost effectiveness figures for lowering speed limits, as presented in Table 6.1, suggest that this measure is cost ineffective. However, some other studies, not presenting quantitative cost effectiveness figures, suggest that lowering of speed limits could be cost effective. Differences in local characteristics (initial speed limits, intensity/capacity ratios of roads, initial congestion levels) and design of the instrument (e.g. level of enforcement applied) seems to be an important explanation of these opposing conclusions. Finally, the empirical evidence on cost effectiveness of vehicle taxes is too limited to come up with some general conclusions.

As illustrated by the discussion on lowering speed limits, the cost effectiveness of policy instruments depends heavily on the design of the instruments and national/local characteristics. For example, European Commission (2007b) present cost effectiveness figures ranging from €24 to €134 per tonne CO₂ for three variants of vehicle standards. An example of the dependency of cost effectiveness figures on the national context is shown by AGPC (2011) which shows that a fuel tax is more cost effective in European countries (i.e. UK and Germany) than in, for example, the US. According to the authors this could probably be explained by the fact that the initial fuel prices in the European countries were higher than in the US, suggesting that the marginal costs of reducing emissions become higher as more emissions are abated.
Developing a better understanding of the secondary impacts, sensitivities for the decarbonisation of EU transport by 2050

EU Transport GHG: Routes to 2050

Table 6.1: Example estimates of the cost effectiveness figures of certain policy instruments based on some specific case studies

<table>
<thead>
<tr>
<th>Measure</th>
<th>Source</th>
<th>Cost elements included</th>
<th>Methodological assumptions</th>
<th>Cost effectiveness (€/tonne CO₂)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle standards: 130 g/km</td>
<td>EC (2007a)</td>
<td>Consumer surplus, producer surplus, marginal cost of public funding and external costs</td>
<td>Discount rate: 4% Oil price: varies between $50/bbl and $75/bbl</td>
<td>6 to 54</td>
<td>Range depends on design of standards.</td>
</tr>
<tr>
<td>Fuel taxes</td>
<td>CE (2010b), MNP (2007)</td>
<td>Consumer surplus, external costs</td>
<td>Discount rate: 4% Oil price: ca. $65/bbl</td>
<td>-592 to -150</td>
<td>Range depends on differences in estimated benefits due to lower congestion and air pollution levels.</td>
</tr>
<tr>
<td>Road user charges for passenger cars</td>
<td>CE (2010b)</td>
<td>Consumer surplus, external costs, investment and operational costs</td>
<td>Discount rate: 4% Oil price: $65/bbl</td>
<td>-99 to -38</td>
<td>Range depends heavily on design of the scheme and local characteristics.</td>
</tr>
<tr>
<td>Lowering speed limits motorways: 120 km/h → 100 km/h</td>
<td>CE (2010b)</td>
<td>Consumer surplus, external costs, infrastructure costs</td>
<td>Discount rate: 4% Oil price: $65/bbl</td>
<td>250</td>
<td>Range depends heavily on local characteristics and initial situation. Some other studies suggest (without providing actual cost effectiveness figures) that specific reductions of speed limits could be cost effective in some cases.</td>
</tr>
<tr>
<td>Lowering speed limits motorway: 120 km/h → 100 km/h and 100 km/h → 80 km/h</td>
<td>CE (2010b)</td>
<td>Consumer surplus, external costs, infrastructure costs</td>
<td>Discount rate: 4% Oil price: $65/bbl</td>
<td>420</td>
<td></td>
</tr>
<tr>
<td>Reduction of tax-free compensation for commuter and business travel</td>
<td>CE (2010b)</td>
<td>Consumer surplus, change in travel cost, external costs</td>
<td>Discount rate: 4% Oil price: $65/bbl</td>
<td>-84 to -338</td>
<td>Range depends on the extent employers provide a taxable compensation for commuter and business travel to employees.</td>
</tr>
</tbody>
</table>

a All cost effectiveness figures presented in this table are best estimates from a social perspective.
b Also AGCP (2011) present cost effectiveness figures of fuel tax increases for some European countries. However, in contrast to CE (2010b) and MNP (2007) no reduction in other external costs are taken into account in this project. The results of this project are not comparable to the figures presented by CE (2010b) and MNP (2007) and are therefore not included in this table.

6.5 Conclusions

This assessment has focussed on current estimates of cost effectiveness of GHG reducing policies and options. The assessment shows that both for passenger cars and heavy duty vehicles several technical options are available with negative costs. With respect to biofuels it was not possible/useful to come up with cost effectiveness figures. This is due to the fact that recent studies show that many biofuels result in net GHG emission increases due to indirect land use change (ILUC) effects. Next to the technical measures, also the cost effectiveness of behavioural measures was assessed. For fuel efficient driving negative abatement costs were found in the literature, while probably also teleworking will have negative abatement costs. The purchase of electric or small cars, on the other hand, will probably result in positive abatement costs. For the behavioural options 'modal shift' and 'applying virtual meetings' it was not possible to determine the sign or size of their cost effectiveness.

The empirical evidence on the cost effectiveness of policy instruments was rather scarce. Based on the evidence available we could conclude that some of the policies (vehicle standards, fuel taxes, road user charges and some of the fiscal measures for commuter and business travel) could be applied in a way that leads to low or negative cost. However, the cost effectiveness of these instruments depends heavily on design of the instrument and the local or national context.
7 GHG emissions from infrastructure construction, vehicle manufacturing, and end of life vehicles (ELVs)

Objectives:
The purpose of Task 2 of the project was to develop a better understanding of the role and significance of GHG emissions resulting from infrastructure construction and use, vehicle manufacturing, and end of life vehicles (ELVs). In particular, a key objective was to ascertain if consideration of these aspects might influence the optimal pathway to transport sector GHG reduction by 2050.

Summary of Main Findings

General
⇒ The key materials and components influencing the overall GHG footprint for the construction of new transport infrastructure and vehicles (and factoring in recycling benefits) include: iron/steel, aluminium, plastics, cement/concrete and batteries.
⇒ The potential GHG intensity of European production of these key materials is anticipated to reduce by between 30% and 55% from 2010 to 2050, depending on the material. However, these materials will be sourced globally (particularly where vehicle construction occurs outside of the EU) where the improvement rate may not be as great.

Infrastructure construction and use
⇒ There is relatively little information in the literature that provides significant detail on the GHG footprint of infrastructure in relation to overall GHG emissions, except for rail transport. However, there are a range of studies that explore specific aspects in more detail for both road and rail infrastructure.
⇒ The contribution of GHG emissions from the development and use of transport infrastructure varies significantly between different transport modes (though typically 15-30% over the overall GHG footprint). Where comparisons have been made between road and rail modes, the relative magnitudes of infrastructure emissions are similar, with some studies showing higher emissions for road and others for rail. Comparisons are highly dependant on a range of factors, such as: (i) how intensively specific infrastructure is used, (ii) the lifetime activity of the vehicles using them, and (iii) the GHG intensity of the energy used to power the infrastructure and vehicles. This all makes it difficult to assess the impacts of future infrastructure development at an EU level without specific local context.
⇒ A scoping analysis of the potential contribution of GHG emissions resulting from land use change (LUC) on rail and road infrastructure impacts concluded that these LUC were unlikely to contribute significantly to total infrastructure emissions.
⇒ Considering the available information for different modes, it appears unlikely that factoring in GHG emissions from infrastructure development and use will significantly influence the selection of optimal pathways to GHG reduction at the EU level. However, such considerations are likely to have an important effect on specific development projects at a local level, so should ideally be factored into their impact assessments.

Vehicle manufacturing and end of life vehicles
⇒ For road and rail, GHG emissions vehicle manufacturing and disposal is predominantly due to the use of materials (around 60% for current technologies, and larger for battery
Summary of Main Findings

Electric and fuel cell vehicles. For aviation, most of the GHG emissions are due to energy consumption resulting from the manufacturing process (including electricity, as well as diesel for vehicles transporting components). Very little information is available in the literature for ship production and disposal, preventing a more detailed assessment.

For vehicle production and disposal, some future technologies have significantly higher GHG emissions (e.g. for battery electric and hydrogen fuel cell cars). However, indicative analysis carried out under Task 2 of this project suggests their net benefits in terms of GHG savings over conventional technologies are still anticipated to be significant factoring in the operational energy use of vehicles.

Overall conclusions

- GHG emissions due to transport infrastructure and vehicle manufacturing and disposal are significant components of the current overall transport GHG footprint that are likely to significantly increase in their importance in the long term.
- Policy action should therefore be taken to minimise the degree to which future GHG emissions from infrastructure development and use, vehicle production and disposal erode the GHG savings benefits due to the improved operational energy use of vehicles.

7.1 Introduction

The objective of Task 2 was to better understand the significance of GHG emissions from infrastructure construction, vehicle manufacturing, and end of life vehicles (ELVs) and their possible influence on designing optimal routes to long-term GHG reductions from transport.

To date, transport sector emissions have been dominated by direct emissions associated with the operational use of vehicles. Previous research in the last ten years has shown that for passenger cars, GHG emissions from vehicle use account for approximately 80% of total life-cycle emissions. Many previous studies have indicated that the usage phase dominates even further for other modes of transport such as trains, aircraft, and ships, all of which have much longer vehicle lifetimes than road transport vehicles. However, a need was identified to understand this in more detail and expand the scope of the analysis. This is because it is possible that some policy options could have unintended impacts on total GHG emissions that may not be immediately obvious if the emissions analysis solely focuses on in-use emissions. In the following sections, we set out our findings on the role of GHG emissions from infrastructure development and use, vehicle production and disposal (end of life vehicles) in the context of this project.

7.2 General considerations

As part of this Task general information relevant to the analysis was collated and developed or estimated, including:

- Current and likely future development of the GHG intensity of fuels and energy carriers used in the construction and recycling or disposal of infrastructure and vehicles;
- Current emission factors for the production of key materials (components) used in infrastructure and vehicle construction and indications of potential future changes.

Life cycle estimates for different activities and components in the LCA literature invariably use different assumptions on the GHG intensity of energy consumed as a result of different activities or processes. Where possible it is desirable to normalise literature estimates, or utilise consistent assumptions in the development of new estimates for activities. As far as
possible analysis for this Task used a unified set of assumptions for calculations. In addition, a consistent dataset of GHG emission factors for material production (and recycling) was also utilised in the analysis where this was feasible. Furthermore, estimates were also developed on the likely trajectory for improvement in the GHG intensity of key materials/components (plastics, steel, cement, aluminium and batteries) to 2050 for use in the analysis. Estimates for global material sourcing were also considered through comparison with the current EU production levels. These are both summarised in the following Figure 7.1.

Figure 7.1: Estimates of future GHG intensity of key materials and current production of key materials in Europe compared to the rest of the world
7.3 Transport infrastructure

Road

Road infrastructure typically consists of the roads themselves, but also includes other elements such as bridges and lighting. Although the GHG emissions attributed to the road infrastructure itself are currently not the main contributor to the total GHG emissions from the total system of road transport they are not negligible. The evidence shows that emissions related to road construction, maintenance, operation and end-of-life may range from just a few per cent to typically 10%-15% of total road lifecycle GHG emissions. However, there are also sources that state that 35% to over 40% of the GHG emissions for the full road infrastructure system including vehicle production and use can be attributed to the road construction, maintenance and operation. Unless low GHG electricity is used, the operational emissions due to lighting can be a significant proportion of the overall impact for roads where lighting is provided (i.e. particularly in urban areas). It is likely that in the future the indirect GHG emissions associated with road infrastructure will become increasingly important and significant as direct GHG emissions from road transport decrease as a result of advances in technology, fuel and vehicle manufacturing.

There are a number of methods and processes that could be employed in the road transport sector to reduce the GHG emissions at the road construction stage, including the use of alternative materials and low carbon energy. In addition the condition of the road surface can also directly influence traffic safety, noise generation and vehicle fuel consumption. Road surface maintenance can therefore be optimised to fulfil GHG emission reductions and other sustainable transport and safety objectives. As lighting also contributes greatly to the GHG emissions related to the operation of the road, energy-efficient lighting scenarios may be a key option for reducing these emissions with reductions in energy demand of up to 70% possible using a combination of optimised lighting and LED illumination. Future reductions in electricity GHG intensity will also provide significant benefits in this area.

Rail

Rail-related infrastructure is typically made up of a number of elements, including stations, ballast, track, tunnels, bridges, Overhead Line Equipment (OLE), signalling and telecommunications, electrified third rail, and road crossings and culverts.

The construction of rail infrastructure has different requirements in urban and rural environments, which can have large effects on both cost and greenhouse gas emissions. Retained cut or trench cutting often accompanies urban routing, and involves building a walled trench for trains to pass through beneath street level. The extent to which it is required depends on the topography of the route. It is also important to consider the demand for new rail infrastructure, since lines with high use will have lower associated net GHG emissions per passenger-km. These elements, together with the GHG intensity for powering rail rolling stock, are the main basis for a very wide range of figures quoted in the literature for the proportion of overall lifecycle GHG emissions due to rail infrastructure development and operation (e.g. from 5% to 80% in a sensitivity analysis of high-speed rail options by UIC, 2009). In terms of the components of rail infrastructure’s GHG footprint, the most significant elements for electrified tracks are from material use: steel (50%), concrete (~11%), aluminium (~10%) and copper (~8%). For non-electrified tracks the contribution of metals to the overall footprint is significantly reduced and the energy used in construction and transport of materials becomes more significant.

The greenhouse gas intensity of both the energy used in the construction of new infrastructure (e.g. electricity for tunnel boring machines) and in the production and transport of materials used in construction, is expected to reduce in the future (as will operational emissions including maintenance and energy consumption). However, it seems likely they will constitute a much larger proportion of the overall rail footprint in the longer-term.
Therefore focusing on reducing emissions from the construction phase will be important to minimise erosion of the anticipated future benefits of greater use of rail for both passenger and freight transport.

Shipping

The main functions of a port are to supply services to freight (for example, storage or transhipment) and to vessels (refuelling, repairs etc). The main elements required of a port include the docking areas for ships (which can be quite substantial in size) and refuelling infrastructure. Ships powered using alternative fuels such as nuclear power or hydrogen require ports that are able to store and handle these fuels. Shore-side power for ships while at dock, also known as cold-ironing, allows ships to turn off their diesel-powered auxiliary engines (ships can be docked for times ranging from one hour to three days). Port facilities are also determined by the type of cargo they must handle, for example:

- Liquid bulk cargoes, such as crude oil, are moved using pumps and pipelines; they require only limited handling equipment but may need significant storage capacity.
- Dry bulk products are unpackaged goods such as ore, cereals and coal. Handling these materials requires more sophisticated equipment such as cranes, specialized grabs and conveyor belts. Some terminals have specialized storage structures such as grain silos and refrigerated warehouses.
- General cargo requires a lot of labour to handle where dimensions and weights are not uniform. Containerisation of cargo has allowed handling to become mechanized and it is progressively more common for bulk products to be containerised.
- Container terminals have minimal labour requirements, but generally require large amounts of space for moving and stacking containers.

Whilst the range of infrastructure that makes up ports can be quite extensive, little literature currently exists that considers the embedded CO₂ emissions associated with its production. A study by Walnum (2011) considers both the direct and indirect emissions from ships. The indirect emissions ideally considered would include the energy used and emissions produced during the construction, maintenance and operation of the ship infrastructure, the harbours and the ship itself. The transoceanic tanker’s life cycle CO₂ emissions are be broken down as illustrated in Figure 7.2 from the study. However, other studies (e.g. Simonsen, 2010) found that port infrastructure and the building of ships played a minor role in total lifecycle CO₂ emissions. There is insufficient information available in the available literature to ascertain the reasons for this differential. However, port GHG footprinting studies have shown that the impacts of port operation are split roughly 40%:40%:20% for direct emissions due to fuel consumption of port vessels and equipment, electricity consumption of port equipment and offices, and emissions due to travel (commuting and business) by port staff. Anticipated future improvements in all these areas would also be expected to be high in the long-term, so it seems unlikely that their overall contribution to shipping emissions will change significantly.

Figure 7.2: Transoceanic lifecycle emissions of CO₂ (adapted from Walnum 2011)
Aviation

Aviation infrastructure consists primarily of airport terminals, runways/tarmacs and ground support equipment (GSE). These aspects of aviation infrastructure are found at airport sites but their use depends on both the size and function of the airport. Aviation infrastructures are complex and different infrastructure systems are generally owned or operated by different organisations or companies, resulting in different impacts on energy and GHG emissions.

When looking at the GHG emissions from infrastructure in the context of aircraft lifecycle emissions there are few estimates available in the public domain. In Simonsen (2011) the total emissions from infrastructure construction and operation are estimated to account for ~3.2% of lifecycle emissions from aviation – see Figure 7.3. This is very small compared to the 92.7% of GHG emissions due to the operation of aircraft (i.e. jet fuel lifecycle emissions).

**Figure 7.3: Life-cycle emissions in aviation (Simonsen, 2011)**

![Diagram showing life-cycle emissions in aviation]

Energy carrier infrastructure

Energy carrier infrastructure was also considered as part of the review for this task, focusing on infrastructure for: (i) hydrogen fuelled vehicles; (ii) electric vehicles; (c) biofuels. There is quite a lot of information available in the literature on the types of additional infrastructure that might be needed for each of the relevant energy carriers, and in some cases also potential costs. However, we were unable to identify any information that would allow a meaningful comparison of their likely impact in terms of GHG emissions, either in total or relative to other parts of the transport GHG footprint. The exception was an older study by (Nansai, 2001) for Japan, where electric recharging infrastructure GHG for electric cars were estimated to be around 5% compared to the equivalent gasoline car’s total GHG footprint.

**Scoping the potential contribution of land use change emissions**

Estimates of potential Land use change (LUC) emissions as a result of transport infrastructure were developed using IPCC guidance on the carbon content of the biomass on typical European land classes in order to assess their potential significance. The results of the scoping analysis showed that LUC emissions are unlikely to contribute a significant amount to the overall footprint of transport - between 0.06% and 6.56% of transport infrastructure emissions (= 0.01%-0.83% total lifecycle transport emissions).
7.4 Vehicle manufacturing and ELVs

Road

A range of different factors influence the amount of emissions related to the production of a road vehicle, including the relationship between mass and production related emissions and the contribution of different materials, and impacts of technical options aiming to reduce GHG. Light weighting, hybrid and electric-powered vehicles and fuel cell cars also reduce emissions during the usage phase but can lead to increased production emissions related to those new technologies, which have been estimated to be as high as double those of conventional vehicles for fuel cell technology. For current conventional ICE passenger cars (i.e. ~2010), production, maintenance and disposal/recycling emissions are estimated to typically account for around 16% of total GHG emissions including those from vehicle operational energy use (see Figure 7.6). The proportion for heavy trucks is around half that of cars due to their significantly higher lifetime activity. Figure 7.5 provides a summary of the breakdown in GHG emissions from cars and trucks due to different materials. For conventional vehicles, the embedded GHG emissions in materials used in the vehicle account for around 60% of all manufacturing emissions, with a larger proportion due to materials for alternative technologies like hybrid and electric vehicles (mostly due to their batteries). It is anticipated that the proportion of total GHG emissions due to vehicle production and disposal will increase significantly by 2050, since vehicle efficiency and energy GHG intensity is anticipated to reduce at a faster rate than the embedded emissions of materials used in the vehicle. Therefore it is advisable to take steps to ensure embedded emissions are minimised as far as possible to ensure they do not erode the GHG savings in road vehicle operation.

Rail

A number of studies are available in the literature that assess lifecycle emissions from rail rolling stock production, operation and disposal. The breakdown of embedded GHG emissions due to the materials used to construct rail vehicles is dominated by the use of steel and aluminium in both heavy and light rail vehicles – see Figure 7.5. Similarly to road vehicles, the embedded GHG emissions in materials used in rail rolling stock have been estimated to account for around 60% of all manufacturing emissions. Due to their long lifetimes and high activity, GHG emissions from manufacturing, maintenance and disposal of current new rail rolling stock only accounts for up to 5% of all emissions including vehicle operational energy use (even factoring in likely future reduction in electricity GHG intensity). Unlike road transport, technological developments are unlikely to very significantly increase the importance of embedded emissions. However, as for road transport the proportion in the total climate impact is likely to increase in the period to 2050 due to an anticipated shift to predominantly electric rail using highly decarbonised electricity.

Shipping

The GHG emissions associated with manufacturing of vessels for international and inland shipping mainly results from the production and processing of steel and energy consumption at shipyards. The direct energy associated with the construction of ships can be attributed to handling and transport, (e.g. raw materials, fabricated sections and blocks etc); fabrication processes (e.g. cutting processes, forming, welding); assembly of steel plates and sections; construction of 2D and 2D blocks; erection and assembly of blocks on berth or in dock; outfitting operations; tests and trials (Sharma, 2005). Very little information is available in the literature on ship production and disposal, with estimates on the proportion of total lifecycle GHG emissions for ships ranging from 1.3% to 12.5% depending on the vessel type and annual activity, with a central/typical value estimated around 3.2% (see Figure 7.6). It is unclear as to the specific impacts of technological improvements on future production and disposal emissions, although they are unlikely to result in very significant increases in this
component. However, as for road and rail, new vessel efficiency is likely to increase at a higher rate than the GHG intensity of materials used in construction so in the long term this aspect is likely to become a larger component in the overall GHG emissions accounting.

Aviation

According to the information available in the literature, the primary GHG emissions and energy factors in the manufacturing of aircraft are related to the electricity used at the manufacturing facilities and the diesel fuel consumed in truck transportation moving parts for assembly (EIOLCA, 2007). The GHG effects of vehicle manufacturing have been estimated to account for between 5-11% of aircraft life-cycle GHG emissions, despite high lifetime activity. The component of GHG emissions from aircraft production and disposal due to materials use has been estimated to be much smaller (only a few percent) compared to other modes. Therefore it is anticipated that the embedded emissions are unlikely to grow very significantly in comparison to operational GHG emissions in the longer term, since the GHG intensity of energy used in the manufacturing process (including component transport fuel consumption) is also anticipated to reduce significantly.

7.5 Overall comparisons, scenario analysis and conclusions

7.5.1 Infrastructure

Figure 7.4 provides a summary of the range of estimates from the literature and typical values for the contribution of the GHG emissions resulting from the development and operation of transport infrastructure for different modes as a proportion of overall GHG emissions. The GHG impacts of infrastructure can be quite significant per passenger-km or tonne-km, particularly for lower activity intensity areas and are likely to significantly increase versus GHG from vehicle energy use in the future since infrastructures have a long lifetime and material GHG intensity is not anticipated to reduce as fast as vehicle efficiency. The range of values for rail is particularly large due to a combination of two principal effects (i) passenger numbers/frequency of services (i.e. how intensively the infrastructure is used), (ii) the GHG intensity of electricity used to power the trains (i.e. for very low GHG electricity, the proportion of total GHG due to infrastructure is much higher).

The scoping analysis of the potential contribution of GHG emissions resulting from land use change (LUC) on rail and road infrastructure impacts concluded that these LUC were likely to only contribute between 0.06% and 6.56% of total infrastructure emissions (= 0.01%-0.83% total lifecycle transport emissions).

It is very difficult to predict specific impacts on infrastructure construction between different scenarios without quite sophisticated network modelling to work out the effects of changes in demand on the need to develop new infrastructure for different modes. Therefore quantification of these effects was not possible for this project. However, accounting for differences in GHG emissions per passenger-km for vehicle energy use, the infrastructure emissions of road and rail appear to be of a similar size (in GHG/pkm) for infrastructure meeting equivalent transport demands and therefore unlikely to significantly influence optimal pathways to GHG reduction at the EU level. However, such considerations are likely to have an important effect on specific development projects at a local level, so should ideally be factored into the overall impact assessment of such projects.
Figure 7.4: Comparison of the relative significance of GHG emissions from infrastructure development and operation as a proportion of overall lifecycle GHG emissions (including vehicle energy consumption and vehicle production and disposal) for different modes of transport

Notes: The figures in the chart represent the range of values identified in the literature for different modes of transport.

7.5.2 Vehicle production and disposal

The following Figure 7.5 and Figure 7.6 provide a summary comparison of the GHG due to different materials and the breakdown of the vehicle lifecycle emissions between production/disposal, maintenance and operational energy use for different transport modes.

Figure 7.5: Comparison of the GHG emissions breakdown from vehicle manufacture and disposal by material for different modes of transport

Notes: CFRP = carbon fibre reinforced plastic; GFRP = glass fibre reinforced plastic
According to analysis carried out under Task 2, GHG emissions from the production and disposal of new vehicles are anticipated to become an increasing component of a vehicle lifetime emissions in the future. The analysis, illustrated in Figure 7.7 and Figure 7.8 show their proportion could double, or triple for some modes in relation to total in-year transport energy consumption emissions. This is mainly because improvements in the carbon intensity of vehicle production (of which the largest component is materials use) is not anticipated to reduce as fast as vehicle energy use GHG emissions – being offset by (a) higher emissions from vehicle production outside the EU or from materials sourced from outside the EU; (b) higher GHG production emissions for the most efficient technologies (e.g. electric, fuel cell vehicles), particularly in road transport.

Nevertheless the study analysis has indicated that, although offset to a degree, the benefits of more efficient vehicle technologies in reducing emissions from energy consumption far outweigh possible disbenefits from higher production and disposal emissions. However, there are significant uncertainties in this aspect which mean that it will be important to take action to minimise the likelihood of this component significantly eroding future benefits of alternative technologies in terms of GHG emissions from energy consumption.

These effects are illustrated in Figure 7.7 and Figure 7.8, which respectively provide a time-series summary of the results for the R1-a scenario and a comparison of this scenario with the other primary sensitivity scenarios explored in the project (detailed in Section 10.3.2).
Figure 7.7: Potential impacts on total annual lifecycle GHG emissions of factoring in emissions from the production and disposal of new vehicles – comparison of cars versus all modes of transport for the core GHG reduction scenario (R1-a)
Developing a better understanding of the secondary impacts, EU Transport GHG: Routes to 2050

Figure 7.8: Comparison of the total annual GHG emissions including vehicle production and disposal in 2050 for passenger cars for the different project Routes to 2050 scenarios

![Comparison of total annual GHG emissions including vehicle production and disposal in 2050 for passenger cars for different project Routes to 2050 scenarios](chart)

Notes: The ‘a’ and ‘c’ variants for scenarios R2-R5 have not been adjusted back in line with the 2050 GHG reduction targets. The ‘b’ and ‘d’ variants have had their GHG emission trajectories adjusted back to the 2050 reduction targets by adding/strengthening or removing/relaxing GHG reduction measures.

7.5.3 General Conclusions

The GHG emissions due to transport infrastructure and vehicle manufacturing and disposal are significant components of the current overall transport GHG footprint that are likely to significantly increase in their importance in the long term. Therefore policy action should be taken to minimise the degree to which future GHG emissions from these elements erode the GHG savings due to reductions in the operational energy use (and its GHG intensity) of vehicles.

It appears unlikely that factoring in GHG emissions from infrastructure development and use will significantly influence the selection of the optimal pathways to GHG reduction at the EU level. However, such considerations are likely to have an important effect on specific development projects at a local level, so should ideally be factored into the overall impact assessment of such projects.

For vehicle production and disposal, although some future technologies have significantly higher GHG emissions (e.g. for battery electric and hydrogen fuel cell cars), their net benefits in terms of GHG savings over conventional technologies are still anticipated to be significant.
8 The potential for less transport-intensive paths to societal goals

**Objectives:**
The purpose of Task 4 of the project was to:
- Provide an overview of alternative development paths that could be less transport intensive, but still deliver increasing levels of prosperity
- Discuss preconditions for such development paths and in particular reconsider implications of redefining societal goals (e.g. ‘Green GDP’).

**Summary of Main Findings**

⇒ Over the last decades no clear indication of a decoupling of freight transport from economic growth in the EU has been found. For passenger transport the evidence is less clear; there has been a decoupling of land-based transport from GDP growth, but this decoupling is (at least partly) reduced by a coupling of air passenger transport and GDP growth. For the (near) future no significant decoupling is expected.

⇒ Important potential drivers of decoupling freight transport are a reduction of spatial concentration of the production of goods (although it should be considered to what extent reductions in transport volumes are undone by reductions in GDP growth) and a shift to less transport intensive economic sectors (although leakage effects should be considered). Important drivers of decoupling passenger transport are a change in consumption patterns (less consumption of transport) and urban re-densification.

⇒ As regards redefining societal goals, the aim of both alternative welfare indicators and a more fundamental transition towards a more sustainable economy is to change the relative balance of environmental and social considerations compared to economic considerations.

⇒ Both have similar implications for transport’s GHG emissions, as the impact will depend on the net effect of the likely benefit from the greater consideration of environmental impacts and the change in emissions due to an improved consideration of social issues.

⇒ An important consideration is that a more fundamental change to a sustainable economy implies meeting economic and social objectives within environmental boundaries.

8.1 Introduction

The previous EU Transport GHG: Routes to 2050? project shows that it is challenging to reach substantial GHG reduction objectives for transport using only technical measures. Therefore, it was concluded that in addition to technical measures, non-technical options should also form part of a long term climate policy for transport. This includes policies that on the long term could curb the expected growth of transport. However, the argument is often made that a lower growth of transport volume slows down economic growth.

In this chapter we explore this statement by discussing potential routes to less transport-intensive prosperity growth. These routes are in line with the Europe 2020 Strategy, which was published in 2010. In this document the European Commission sets the economic and wider framework for EU policy-making in the next 10 years; one of the objectives mentioned in this strategy is to realise a smart, sustainable and inclusive growth, which would facilitate
the transition to a green economy in the longer term. Realizing less transport-intensive paths to prosperity could contribute to this ambition.

In this project we explored the issue of less transport intensive growth paths from two perspectives. The first perspective is seen from within the currently dominant paradigm of economic growth. The focus would be on reducing the transport-intensity of growth as it is currently measured, i.e. decoupling transport growth from GDP growth – discussed in section 11.2. A second, wider perspective starts from redefining the way in which we measure prosperity. For example, by using an alternative indicator of welfare greater consideration could be given to social and environmental considerations. However, some researchers argue that even these adapted growth indicators would not, on their own, be sufficient to deliver a sustainable economy in the long run. These aspects are discussed in section 11.3.

8.2 Decoupling of transport and GDP growth

By decoupling transport growth from GDP growth, less transport-intensive economic growth could be realised. Theoretically there is a large potential for decoupling transport and economic growth, particularly in the case of passenger transport; since most passenger transport is consumption instead of production transport\(^{17}\), reducing the amount of passenger transport will not directly harm GDP growth. The decoupling potential for freight transport is smaller, particularly because freight transport is an important driver of economic growth as it facilitates regional specialisation. Reducing the amount of freight transport could therefore in some cases result in less efficient production processes and hence less GDP growth.

Although there is significant potential for decoupling transport and GDP growth from (at least) at theoretical perspective, this potential has hardly been realised over the last few decades. The European Environment Agency (EEA, 2011) shows comparable growth paths for freight transport and GDP for the period 1995-2003, while in the period afterwards particularly ‘coupling’ instead of decoupling has taken place. Comparable results are found for the US and Japan. For passenger transport the EEA (2010) shows decoupling of land-based transport from GDP growth for the period 1995-2007. However, this decoupling trend is (at least partly) reduced by the coupling of air passenger transport and GDP growth. For the (near) future, the same patterns of transport growth and GDP growth may be expected, suggesting no significant decoupling of transport demand from economic growth.

These findings on realised and expected decoupling show that the objective of achieving a decoupling of transport and GDP growth is challenging. Therefore, understanding the drivers of (de)coupling is very important. With respect to freight transport, reduction of spatial concentration (and hence more regional production) and changes in the composition of GDP (shift to less transport intensive economic structures) are identified in the literature as effective ways to realise decoupling. However, with regard to the first option it should be considered whether the reduction in transport volumes is not undone by reductions in GDP growth, while for the latter option the possible existence of leakage effects should be carefully considered. Also some transport efficiency improvements (improved vehicle routing) may contribute to the decoupling of transport and GDP growth. For passenger transport, changing consumption patterns (less ‘consumption’ of transport) and urban redensification are identified as potentially powerful drivers of decoupling. However, autonomous reductions in the demand for transport are quite uncertain, while adapting urban structures will only be effective on the long term. Digitisation and improving transport efficiency, on the other hand, are drivers that could be effective on the short term, but their maximum impact on decoupling is limited. Finally, future demographic developments, like an ageing population and individualization, may even have a negative impact on decoupling figures.

---

\(^{17}\) Production transport “involves activity related to the production of goods and services and essential household sector activities”. It covers the transport of intermediate and final goods to production locations and customers, as well as essential household operations such as the commute to work. Consumption transport on the other hand includes all transport for non-essential purposes (i.e. leisure).
8.3 Alternative welfare measures and their implications for transport

The discussion in section 8.2 relates to the decoupling of transport activity from GDP. However there may be better measures of prosperity or welfare than GDP. This section explores the implications that such alternative measures might have in terms of transport intensity. In the literature, a number of 'alternative indicators' to GDP have been developed, which can be classified as either:

- **Adjusting GDP**, in which more activities are converted to monetary values in a way that is compatible with the activities already included in GDP.
- **Replacing GDP**, where GDP is replaced by another indicator, which takes economic and/or environmental and/or social considerations into account.
- **Supplementing GDP**, where other indicators that add an environmental or social dimension are used alongside GDP in order to put it into an “appropriate socio-ecological context”.

If these indicators were used as a guide for government policies, they may have different impacts on transport volumes and GHG emissions. The impacts of the indicators adjusting GDP and supplementing GDP are probably comparable, as environmental and usually social considerations are given equal prominence to economic considerations in the decision-making process. With many of these indicators, the impact on transport’s GHG emissions would depend on the net impact of any improvement on the environmental performance of transport resulting from a greater consideration of environmental impacts and the net change in emissions resulting from any change in travel due to the consideration of social concerns. The sign and size of the latter depends on the type of social concerns taken into account by the indicator; if they are related to improved access or reduced inequalities, the indicator could stimulate transport policies that enable transport. On the other hand, if the social concerns are addressing health and improvement of local cohesion, a shift to more local, active transport, will probably occur.

The impact of those indicators that would replace GDP is more variable as the indicators themselves tend to vary more in their design and focus. Where these focus purely on the environment, there is a likelihood that these would place more prominence on environmental considerations with a possible dampening effect on the economy and of society (and of transport) if these indicators replaced GDP. Other indicators could even increase the amount of transport, depending on the manner in which they balance different social considerations like improved accessibility, reduction of social inequalities with health and local cohesion.

The use of the alternative welfare indicators mentioned above may result in decoupling transport growth from prosperity growth if it results in a reduction of unproductive\(^{18}\) transport. However, the increased consideration of environmental issues will often also lead to a decrease in productive transport and hence lower GDP growth rates\(^{19}\), while the increased consideration of social issues may result in an increase in consumptive transport and hence a coupling of transport and GDP growth.

A more fundamental approach to achieving less transport-intensive prosperity would be to introduce a more fundamental change to the macro-economic framework of society by not only using another welfare indicator, but also making more fundamental changes to the rules and principles that guide policy decisions. In the Task-specific paper on this topic we

---

\(^{18}\) Productive transport refers to all transport related to the production of goods and services. In other words, transport directly contributing to GDP growth. Unproductive transport, on the other hand, doesn’t contribute directly to GDP growth (e.g. leisure traffic).

\(^{19}\) However, notice that from a welfare economic point of view internalising environmental costs of transport will result in a more efficient allocation of transport. Despite the possible decline in GDP growth levels, internalising external costs of transport has still to be preferred from a welfare economic perspective.
discussed several diverse views on such fundamental changes in the macro-economic framework and their impact on transport volumes and GHG emissions. The framework proposed by Jackson was judged to be most useful. It focuses on providing capabilities for people within ecological limits. Compared to the other routes it provides stricter constraints to human actions and hence transport, challenging the consumer sovereignty which is one of the key elements of the current macro-economic framework. However, it also provides the best protection for societal and environmental resources, which will, among other things, be indicated by lower GHG emission levels of transport.

8.4 Policy implications

The various routes to less transport-intensive growth paths may require different transport policy strategies. Implementing economic instruments (road charges, fuel taxes) to internalise the external and infrastructure costs of transport are proven ways to reduce transport demand without harming both social welfare and economic growth. Other interesting policy strategies to stimulate the decoupling of transport from GDP growth are the implementation of an integrated long term policy strategy for spatial planning, transport (infrastructure) and GHG reduction, and lowering speed limits. To improve the effectiveness of these instruments (in terms of realising decoupling) they may be mainly targeted on passenger transport, since the potential for decoupling is larger for passenger transport than for freight transport.

The policy implications of using alternative welfare indicators depend heavily on the type of indicator that is considered. Indicators particularly focusing on environmental considerations require policies stimulating the purchase and use of more fuel efficient vehicles, as well as policies that affect transport demand. The policies may (partly) be the same as the ones stimulating decoupling transport from GDP growth (although they may be more ambitious, resulting in higher tax levels, lower speed limits, etc.), but also instruments meant to increase the fuel efficiency of vehicles (e.g. vehicle regulation, purchase taxes) should be considered. If social considerations are also taken into account by alternative welfare indicators, policy instruments that increase accessibility (e.g. investments in public transport, road or cycling and walking infrastructure, car sharing investments) may also be relevant.

A more fundamental transition to a sustainable economy would require probably the most far-reaching policy intervention in the transport sector. Many of the policy instruments mentioned above could be considered (and hence are explicitly mentioned in Jackson’s vision on a sustainable economy). But in addition to these instruments, policy instruments guaranteeing that transport demand acts within environmental boundaries are required (e.g. budgets for CO₂, air pollutant emissions, noise, etc).
9 Considerations relating to the co-evolution of regulation and economic instruments

Objectives:
The purpose of this additional ad-hoc (Task 11) work was to:

- Review the arguments against a focus on a "single instrument" solution to reducing GHG emissions from transport; and
- Set out the benefits and challenges of a co-evolving policy framework involving both regulation and economic instruments.

Summary of Main Findings

⇒ There are a number of benefits of using regulation and economic instruments together to deliver GHG reductions from transport.

⇒ The uncertainty associated with specific instruments and the benefits of using regulation and economic instruments together suggests that using a range of instruments is important to reduce transport's GHG emissions.

⇒ Additionally, it might be wise, from the perspective of increasing the chances that transport delivers significant reductions in CO₂ emissions, to make sure that policy is able to cater for a pessimistic longer-term scenario in which alternative technologies do not become competitive. Such policy instruments require time to be prepared and implemented, which argues for early action.

⇒ The most appropriate combination of regulation and economic instruments depends on the evolution of the total costs of ownership and the longer-term behavioural responses to policies, which are as yet unknown.

9.1 Introduction

The aim of Task 11 ad-hoc paper 3 was to explore how regulation and economic instruments might work together in order to reduce GHG emissions from transport. Given that regulation to improve the efficiency, and to reduce the CO₂ emissions, of cars and vans is already in place at the EU level, the assessment relates to this existing situation, where appropriate, in order to provide a more practical illustration of the issues being discussed. However, identifying the most appropriate combination of regulation and economic instruments is challenging, and depends on, for example, the evolution of the total costs of ownership (TCO) of both future conventional (i.e. those using internal combustion engines, including non plug-in hybrids) and future alternative vehicles (e.g. plug-in hybrids, electric vehicles, hydrogen vehicles) relative to each other, but also relative to current conventional vehicles. The paper provides some insights into the combination of regulation and economic instruments that might be most appropriate under different future scenarios for the development of the TCO.

The paper also built on indications that emerged in 2011/12 that the costs of meeting the 95 gCO₂/km target under the passenger car CO₂ Regulation might not be as high as had been expected on the basis of previous work. This is supported by work in support of the US car CO₂ legislation that suggests that the costs might be lower still. In this context, the aim of this paper was to explore how economic instruments might work together with regulation to deliver the 95 g/km target in 2020 and, possibly, more ambitious targets for beyond 2020.
The paper focuses on a selection of economic and regulatory instruments that could be introduced in order to contribute to reducing transport’s GHG emissions. In this respect, it covered the use of regulation targeting road transport vehicles, particularly cars, and energy carriers, as well as economic instruments targeting the use of vehicles.

9.2 Exploration of the impacts of potential single instrument solutions

The potential impacts of the instruments were identified by reviewing the impacts on the main stakeholders involved – i.e. manufacturers, fuel and energy suppliers and vehicle users. Of the instruments covered, each category of stakeholder is targeted directly by at least one of the types of instrument considered. In addition to the direct effects of specific instruments, each stakeholder is often also indirectly affected by other instruments through, for example, changes in relative costs, or the potential behavioural responses of other stakeholders.

The review also explored the potential impacts of the instruments from the perspective of policy makers. While it might be possible to identify first order impacts of the policies considered on the basis of existing knowledge, there are many other elements that cause uncertainty for policy makers with respect to the design and stringency of instruments. Of particular relevance in this respect are the potential future evolution of TCO and longer-term behavioural responses. Different combinations of regulation and economic instruments might be more appropriate for different future situations, depending on the evolution of the total cost of ownership (TCO) of conventional and more sustainable vehicles.

9.3 The benefits of using different instruments in an evolving policy framework

In addition to the uncertainty with respect to the impact of instruments, and even which instruments to use, there are a number of other arguments in favour of using different types of instruments. Regulation is an important instrument in overcoming the first mover and prisoner dilemma problems by effectively requiring the necessary equivalent action. Both of these problems potentially prevent actors, in this case manufacturers, from taking forward actions that might be beneficial for the industry and for society more generally if the industry acted together, but which might have adverse impacts if unilateral action was taken. Additionally, at the European level, it has proved more feasible politically to deliver strong regulation rather than strong economic instruments often as a result of objections from Member States.

Regulation can also be used to complement economic instruments in cases where market imperfections mean that economic instruments alone would not deliver the anticipated GHG reductions. The existence of such market failures is reasonably common, as, for example, actors rarely have full information and rarely act purely rationally. Potential adverse knock-on consequences from regulation, such as rebound effects, could also be addressed by the application of economic instruments, particularly user charging. However, as rebound effects only occur when the costs of use of future vehicles are lower than the cost of use of existing conventional vehicles, whether these effects occur depends on the evolution of the TCO. Regulation and economic instruments can also be used together to address the issue of split incentives. However, the indications that the costs of meeting the 95gCO₂/km target for 2020 might be less than anticipated, and might deliver benefits to consumers and society, suggest that this issue may not be as relevant as had been thought, at least in the short-term. However, in the longer-term it may become an issue if more expensive technical options need to be taken up (and if they are still more expensive) to meet longer-term targets.
Using different instruments that target different actors is also important as these can ensure that all stakeholders act in a consistent direction to deliver the ultimate objectives of policy. From the policy context, this is important as individual actors often rely on other actors to meet objectives required by various policy instruments. Finally, the scale of the GHG reduction challenge facing the transport sector suggests that it will be necessary to use regulation and economic instruments, as well as other types of instrument to deliver the necessary GHG reductions.

9.4 Conclusions on the co-evolution of regulation and economic instruments

The most appropriate combination of regulation and economic instrument to deliver CO₂ emissions reductions from road transport depends on the evolution of the costs of conventional and alternative vehicle technologies. At present, it is not possible to say whether the costs of alternative technologies will decline in the future and, if they do, whether they will decline sufficiently for such technologies to become competitive with future conventional technologies. It is anticipated that, at least in the longer-term, the costs of future conventional technologies will increase as increasing levels of CO₂ reduction technology need to be applied.

The scenarios developed in the paper suggest that, if it is anticipated that the costs of alternative technologies continue to remain higher than those of future conventional vehicles, strong, generic instruments would be needed. In this respect, strong regulation would need to be complemented by incentives for the purchase of such alternative vehicles.

If, on the other hand, the costs of alternative technologies are expected to decline sufficiently fast at some point reaching levels comparable to those of future conventional vehicles, then more focused, as well as more temporary, interventions would be more appropriate. This could include regulation and/or temporary fiscal incentives in order to overcome any remaining barriers, e.g. on-going market imperfections, and/or temporary subsidies or fiscal incentives to promote early market formation.

At any point in time, if alternative technologies are needed to meet a CO₂ reduction target and if these have not become sufficiently competitive with future conventional technologies, then economic instruments in the form of incentives or differentiated taxes would be very helpful to improve the business case for alternative vehicles. When the total cost of ownership of both future conventional and future alternative technologies is lower than the total cost of ownership of current conventional vehicles, road pricing would need to be used to counter any rebounds. In the event that the total costs of future conventional technology are lower than current conventional technology, but alternative technology costs are higher, then road pricing might still be appropriate, but alternative technologies would need to benefit from additional tax reductions on their energy use if they are needed to meet the future targets.

Given that future costs remain uncertain, it might be wise, from the perspective of increasing the chances that transport delivers significant reductions in CO₂ emissions, to make sure that policy is able to cater for a pessimistic longer-term scenario in which the costs of reaching further reduction increases and in which the required sustainable alternatives do not become competitive with future conventional technology by themselves. As the appropriate policy measures for such a scenario require time to be prepared and implemented, early action is needed to make sure the instruments are effectively available by the time that they are needed.
10 SULTAN development and scenario analysis

Objectives:
The purpose of Task 6 of the project was to:

- Further develop the SULTAN Illustrative Scenarios Tool to further improve its usefulness for scoping possible impacts of policies on transport GHG emissions and to facilitate analysis to feed into other project tasks.
- Update the baseline scenario to be consistent with Commission modelling and develop additional policy scenarios and packages to feed into other project tasks.

Additional analysis on the interaction of GHG options for transport with different trajectories for new road vehicle GHG standards was also included under the Task 11 ad-hoc budget.

Summary of Main Findings

SULTAN Development (Task 6):
⇒ The SULTAN tool and its results viewer have been updated to provide a new baseline (business as usual) scenario, consistent with the latest Commission modelling, and with additional functionality to assist with scenario definition and impact analysis (including tables on biofuel use, energy security indicators, monetisation of emission impacts, etc).

Scenario Analysis (Task 6):
⇒ In general the analysis illustrates the need for a balanced mix of well integrated policy actions to reduce the risk of failure to reach targets (maybe with an extra safety margin);
⇒ There are significant uncertainties around GHG savings from biofuel and electricity which pose a risk of leaving very large gaps versus GHG targets if there is over reliance on these options or action is not taken to mitigate or minimise these risk and uncertainties. Alternative options require a lead time for sufficient deployment by 2050, so need to be factored in early.
⇒ The exploration of sensitivities in demand showed the implication of higher demand was that additional or stronger actions may be needed to build contingency, e.g. in setting trajectories for new vehicle GHG standards, applying non-technical measures;
⇒ There is the potential for air quality, energy security and health co-benefits generating savings of up to €177bn annually by 2050 versus business as usual for scenario R3-b in the case of low biofuel and electricity GHG savings (the total benefit rising to up to €323bn, when including GHG savings). The greatest co-benefits per tonne GHG are achieved for actions that reduce vkm or shift to more efficient modes (particularly walking/cycling - comparable to total average road transport running costs in €/pkm);

New road vehicle GHG standard trajectories (Task 11 Ad-hoc Paper 3):
⇒ Sensitivity tests on LDV and HDV standards showed an impact range of +/- 50MtCO₂e variation in GHG emissions (+/- 10% target for 2050) through varying end point targets, and +/- 100 MtCO₂e (+/- 20%) for estimated maximum and minimum trajectories. More stringent vehicle GHG emission standards also offer the additional benefit of reducing biofuel volumes required;
⇒ Since GHG savings in all areas may not be as large as hoped for due to a variety of knock-on consequences it may be desirable to err on the side of caution in setting reduction trajectories. The application of more stringent new vehicle GHG standards may be useful in this regard in that are also likely to provide air quality pollutant and energy security co-benefits.
Summary of Main Findings

⇒ GHG emissions from vehicle production and disposal are significant (particularly for LDVs) and their share is likely to grow compared to vehicle use emissions. Action should therefore be taken to minimise erosion of the benefits of vehicle GHG reduction policies. Providing such action is taken it is unlikely factoring in this aspect would alter the preferred or optimal pathway to total GHG reduction.

10.1 Introduction

The purpose of the task is to further develop and update the SULTAN Illustrative Scenario Tool developed in the previous project and carry out a range of additional scenario analysis. The ultimate objective of this task was to utilise the scenario analysis factoring findings from other project tasks to provide an effectively integrated and linked overall assessment.

There were a wide number of possibilities for the development of SULTAN, and it was only possible to develop a selection of these within the available resource for this work. In addition, there were many potential linkages with other project tasks – at the very least SULTAN and the policy scenarios were to be developed further and utilised for Task 7 (see Section 11). In discussion with the Commission at the project inception stage, the specific scope of the SULTAN and scenario development work to be covered as part of the Task 6 budget was agreed, as well as additional work to be carried out using some of the ad-hoc budget (Task 11). The following sub-tasks were carried out in accordance with the work agreed under Task 6 in order to meet the overall project’s objectives:

1) SULTAN Development:
   a) Baseline update;
   b) New functionality;

2) Scenario Analysis:
   a) Simple scenarios;
   b) Routes to 2050 sensitivity analysis;
   c) Co-benefits and embedded GHG;
   d) New road vehicle GHG emission standard trajectories (Task 11 Paper 2).

The following sections summarise the work carried out under each of these sub-task areas.

10.2 SULTAN Development

10.2.1 Update of baseline and original scenarios

Before any scenario analysis work could be completed it was necessary to update the SULTAN baseline dataset for the business as usual scenario (BAU-a) to be consistent with the most recent European Commission analysis. The previous baseline (SULTAN 2010 BAU-a) was developed based on the TREMOVE model version 2.7 baseline scenario, which excluded the effects of a range of elements including the impacts of the recent recession, as well as the impacts of a range of policies that have been implemented in the EU.

In order to maintain consistency as far as possible with other Commission modelling work, the update of SULTAN carried out was based primarily on datasets provided directly by the Commission in the following way:

- PRIMES-TREMOVE reference scenario was used as the primary source for the 2010-2050 projections of the following data types by mode of transport:
- Activity (passenger-km and tonne-km);
- Stock (i.e. numbers of vehicles, trains, inland ships and aircraft);
- Powertrain technology penetration (e.g. % hybrid and electric cars);
- Energy carrier GHG intensity (in direct/indirect kgCO$_2$e/MJ), etc.

**TREMOVE v3.3.2** alternative baseline scenario was used where data was not available/calculable from the PRIMES-TREMOVE dataset provided by the Commission, and includes the following data types by mode of transport:
- Vehicle lifetimes;
- Vehicle-km and corresponding vehicle occupancy/load factors;
- Urban/Non-urban/Motorway road split of activity;
- NOx/PM emission factors; etc

- Maritime shipping is currently not included in the PRIMES-TREMOVE or TREMOVE models, so updates to the SULTAN baseline were largely based on previous assumptions, with the exception of estimates of the impact of the IMO’s energy efficiency design index (EEDI) targets.

Complications in the update process included inconsistencies between the respective baselines from the TREMOVE and PRIMES-TREMOVE modelling, which required some adjustment and calibrations. Overall the updated baseline was calibrated to be consistent with the PRIMES-TREMOVE reference scenario as closely as possible in terms of GHG emissions (as the top priority) and energy consumption (as a secondary priority) from 2010 to 2050. The resulting 2012 BAU-a scenario is compared to the old SULTAN 2010 BAU in the following Figure 10.1.

**Figure 10.1: Comparison of the SULTAN business as usual scenarios from current and previous projects**

Notes: The ‘Total WP Targets’ figure indicated includes both the goal of reducing maritime emissions by 40% by 2050, as well as the targets for the rest of transport in 2030 and 2050. The error bars on these points represent the range of values for these targets that were indicated in the 2050 Roadmap.
The primary differences between the SULTAN 2012 and SULTAN 2010 baselines illustrated in Figure 10.1 can be summarised as follows:

a) A lower 2010 starting point, reflecting the impacts of the recession (not included in the previous Commission modelling baseline);
b) Inclusion of 2020 regulatory CO₂ targets for new cars (95 gCO₂/km) and vans (147 gCO₂/km) - only the 2015/17 targets were included in the baseline previously;
c) Significant activity modal shifts in passenger and freight transport and a 13% reduction in non-shipping tonne-km by 2050 (versus the previous baseline).
d) Maritime shipping GHG emissions now factor in the IMO’s new Energy Efficiency Design Index (EEDI) targets for new vessel efficiency (balancing demand growth);
e) Aviation activity and energy consumption is lower as this is now scaled to international bunkers, rather than full flight distance to/from EU countries (previously);
f) A reduction in the average road vehicle lifetimes used in the modelling, particularly for commercial vehicles where previously they were quite high vs European statistics.

10.2.2 New Functionality

In addition to the updating of the SULTAN baseline dataset, there were a number of other additional elements that have been developed in terms of new functionality for SULTAN, which include the following elements in the calculation tool and results viewer:

- **SULTAN Tool (scenario definition and calculations):**
  - Assistance in editing energy carrier GHG emission factor assumptions;
  - Assistance in making estimates on the impacts of speed changes on road transport efficiency and on responses to changes in fuel prices (pending);
  - Calculations feeding the results viewer with regards to biofuels use, external costs of GHG/NOx/PM emissions, and energy security indicators;

- **SULTAN Results Viewer:**
  - Indicators for targets for transport GHG reduction from WP2011 and 2050 Roadmap;
  - Monetised costs of GHG/NOx/PM emissions;
  - Biofuel use and GHG abatement;
  - New vehicle average MJ per km by mode;
  - Energy security results.

10.3 Scenario Development and Analysis

10.3.1 New simple scenarios

As part of the specification and agreement of the scenario analysis with the Commission the following simple scenarios were developed to explore key sensitivities, to complement the existing suite of 13 simple scenarios (plus BAU) developed under the previous project:

i. **Scenario BAU-b:** A low demand growth scenario, where demand intensity per head of population stabilises post-2030;

ii. **Scenario BAU-c:** A high demand growth scenario, where demand grows at a rate in-between BAU (~150% by 2050) and GDP (200% by 2050);

iii. **Scenario BAU-d:** Scenario assumptions allowing the exploration of the impacts of alternative energy carrier GHG intensities in kgCO₂e/MJ. These included central and
Developing a better understanding of the secondary impacts, EU Transport GHG: Routes to 2050 II
sensitivities for the decarbonisation of EU transport by 2050

low biofuel GHG savings (55%, 20% reduction respectively), marginal/higher GHG electricity, marginal natural gas and the use of unconventional oil (15% by 2050);

iv. **Scenario 14-a**: A scenario exploring additional maritime fleet efficiency measures, other than simple improvements to new vessel efficiency (which were modelled within the previous project’s simple scenario variants 2-a and 2-b).

The following Figure 10.2 provides a summary of the output results from the analysis. The alternative demand growth scenarios result in a -15% (~200MtCO₂e) and +13% (~175MtCO₂e) change in GHG emissions by 2050 respectively for low (BAU-b) and high (BAU-c) demand versus the base case (BAU-a). The alternative (pessimistic) assumptions on the future trajectories of energy carrier GHG intensity (BAU-d) lead to an increase of 10% (~125MtCO₂e) in lifecycle GHG emissions by 2050 versus the base case. The most significant component of this increase is due to pessimistic assumptions on biofuel savings (in line with the no-action ILUC case from draft Commission impact assessment analysis available in the public domain). In possible alternative scenarios where more significant proportions of transport’s energy demand is met with electricity or hydrogen, the alternative assumptions for these energy carriers would be expected to have a greater effect. Additional maritime fleet efficiency measures (scenario 14-a) may be able to reduce lifecycle GHG emissions by 4% (~60MtCO₂e) by 2050.

**Figure 10.2:** Comparisons of the overall time series trajectories of GHG emissions for the different simple scenarios developed under Task 6 of the project

![Graph](image)

10.3.2 Central ‘Routes to 2050’ scenarios

As part of the project’s central scenario analysis a series of 5 core scenario packages and sensitivities were agreed with the Commission to explore key risks and uncertainties identified in other project tasks (i.e. Task 3, 4 and 5) in relation to meeting the EU’s overall target for GHG reduction by 2050 in the transport sector.
A central Core GHG Reduction Scenario (R1) was developed as the basis for the sensitivity analyses carried out for Task 6, as well as that carried out for Task 7 and the Task 11 ad-hoc analysis. This core scenario was developed according to the following general principals:

1) It was designed to achieve the White Paper’s 60% GHG reduction target (on 1990 levels) for transport excluding maritime shipping by 2050, and goal of a 40% reduction in maritime shipping GHG (on 2005 levels) (R1-a = lifecycle GHG basis; R1-b = direct GHG basis);

2) Lower conventional fuel prices were used versus the baseline (BAU-a) scenario, consistent with the White Paper’s Impact Assessment Global Decarbonisation Scenario (provided by the Commission). A degree of rebound (in activity and increased vehicle energy consumption) resulting from these lower prices was factored into the calculations;

3) 2050 targets were assumed to be achieved through predominantly technical measures, plus additional measures broadly consistent with other White Paper Goals (e.g. internalising of external costs, additional shift of road freight transport to rail and IWW);

The methodology employed in carrying out the analysis was to take the core R1-a scenario as a basis and explore sensitivities in relation to this scenario:

a) Energy Carrier Sensitivities: The potential impacts of key energy carrier and technology risks and uncertainties identified in Task 5 were explored with scenarios R2 and R3 - potential impacts of low biofuel GHG savings and low biofuel AND low electricity GHG savings, respectively;

b) Demand Sensitivities: The potential impacts of variances in the growth of activity demand identified in Task 4 were explored with scenarios R4 and R5 (low and high demand scenarios respectively);

For the analysis a two-stage process was utilised for exploring potential implications:

(1) First amend the R1-a scenario assumptions for the area being explored to discover the resulting gap to reach the 2050 GHG emission targets;

(2) Re-adjust the scenario to again meet 2050 GHG targets by adding and strengthening or removing and relaxing GHG mitigation options as appropriate.

General Results

The following Figure 10.3 provides a comparison of the different Routes to 2050 scenarios before adjustment has been made to the trajectories to bring them back in line with the 2050 targets.
Figure 10.3: Comparisons of the overall timeseries trajectories of GHG emissions for the different Routes to 2050 sensitivity scenarios developed under Task 6 of the project (unadjusted*)

The analysis shows that under the pessimistic biofuel savings assumptions (R2-a) there is a very substantial gap opened compared to the White Paper Target – a 43% increase in GHG (~230 MtCO₂e), which further widens to 54% (~300 MtCO₂e) if electricity GHG savings are also low (R3-a scenario). To close this latter gap in the second stage of the scenario analysis it was necessary to apply essentially all identified mitigation options to their maximum levels (as defined in the previous project). This results in very significant increases in technical efficiency, operational efficiency, and the application of measures to shift and ultimately reduce net transport activity further versus the core scenario (R1-a) – see Figure 10.4. The corresponding reduction in GHG emissions needed to bring them back into line with 2050 targets is also significantly greater in some transport modes than for others – see Figure 10.5.

The corresponding variance to the 2050 GHG target for the low and high demand scenarios are lower at -15%/+11% (-80/+60 MtCO₂e) respectively, requiring fewer (but still significant) changes to the application of GHG mitigation measure in order to re-adjust back to target. For the low demand scenario (R4-b) the gap to 2050 GHG targets could be closed mainly through relaxed harmonisation of fuel taxes (air/ship demand increase, efficiency decrease), and small reductions in biofuel % deployment. Conversely for the high demand scenario (R5-b) the gap to 2050 GHG targets may be closed through the application of a range of non-technical measures (e.g. eco-driving, speed reduction, spatial planning, etc).
Figure 10.4: Comparison of the decomposition of impacts by scenario versus the baseline (BAU-a)
Figure 10.5: Comparison of differences in annual lifecycle GHG emissions and demand for different *Routes to 2050* scenarios relative to the core reduction scenario (R1a) for 2050

The following Figure 10.6 also provides a summary on the levels of biofuel use in different scenarios. This illustrates that when additional action is taken to reduce GHG emissions, very significant reductions occur in the volumes of biofuels needed to meet 2050 targets, e.g. as applied in scenario R2 (and R3 to an even greater degree) through a combination of:

- Vehicle efficiency improvements;
- Substantial further shift to electrification;
- Modal shift and activity reduction;
- Reduced deployment of biofuel (R2-d) but with that used having higher average GHG savings;
**Co-benefits and Embedded GHG Emissions**

The following Figure 10.7 provides a summary of the potential implications in terms of the direct and indirect air quality pollutant emissions from different scenarios. As shown in figure 9.9 substantial monetised benefits - in the order of €45 billion per annum - are achieved relative to the baseline for the core scenario (R1-a) by 2050. Further benefits are achieved from the energy carrier sensitivity scenarios (R2-R3), mainly due to reductions in overall demand and energy consumption needed to achieve 2050 GHG targets. The majority of air quality pollutant emissions are due to aviation and shipping by 2050 in all scenarios.

In terms of energy security, the following Figure 10.8 provides a summary of the likely implications for different scenarios using the methodology developed under Task 1 (discussed in section 5.4). The figure shows that there are anticipated to be very significant energy security benefits form actions aimed at reducing GHG to meet the 2050 targets versus business as usual. The significantly increased benefits for R2-b and R3-b illustrated in the figure are mainly due to a reduction in overall energy consumption, which provides the highest energy security benefits.

In terms of the overall monetisation of co-benefits, Figure 10.9 provides a summary of the potential overall benefits per annum by 2050 (versus BAU-a), which could be as high as €250 billion for R1-a or even reach €325 billion for R3-b. These are high-case estimates for those co-benefits that could be quantified for this project. However, additional noise, health and congestion co-benefits would likely further significantly add to these. The figure also provides an illustration of the importance of the benefits of walking and cycling which provide health co-benefits far higher than their relative contribution to GHG reduction, making policies that promote greater activity in this area particularly compelling.
Developing a better understanding of the secondary impacts, sensitivities for the decarbonisation of EU transport by 2050

Figure 10.7: Summary of the impacts of the Routes to 2050 sensitivity scenarios with respect to total air quality pollutant emissions from transport versus the BAU scenario

Notes: The ‘a’ and ‘c’ variants for scenarios R2-R5 have not been adjusted back in line with the 2050 GHG reduction targets. The ‘b’ and ‘d’ variants have had their GHG emission trajectories adjusted back to the 2050 reduction targets by adding/strengthening or removing/relaxing GHG reduction measures.

Figure 10.8: Comparison of the estimated impacts on energy security of the adjusted Routes to 2050 sensitivity scenarios with the baseline (BAU-a) scenario

Notes: The ‘b’ variants of scenarios R2-R5 have had their GHG emission trajectories adjusted back to the 2050 GHG reduction targets by adding/strengthening or removing/relaxing GHG reduction measures.
10.3.3 Sensitivity analysis on alternate new road vehicle GHG trajectories

The methodology employed in carrying out the analysis was similar to that used in the core Routes to 2050 scenario analysis – i.e. to take the core R1-a scenario as a basis and explore sensitivities in relation to this scenario:

a) GHG Standard Sensitivities: Scenarios V1 to V5 explored sensitivities around high and low trajectories for LDV and HDV new vehicle GHG standards;

b) MIN/MAX Feasible Trajectories: Scenarios V6 and V7 explored the possible minimum and maximum feasible trajectories for LDV and HDV new vehicle GHG standards.

The main sensitivity analysis explored the impacts of Low/Central/High GHG reduction standards, relative to 2010 levels (on a lifecycle GHG basis, excluding biofuel effects):

- For LDVs (cars and vans) this equated to 2050 reduction targets of 70% / 80% / 90%;
- For HDVs this equated to targets of 65% / 75% / 85% for medium trucks; 50% / 60% / 70% for heavy trucks; and 70% / 80% / 90% for buses;
- Where in R1-a the Central GHG standards are the ones already applied.

The minimum trajectories for GHG Standards were estimated based on a starting point of R1-a and the application of all other available measures identified in the previous and this project up to their maximum levels (with the exception of fuel tax harmonisation and biofuels – kept at R1-a levels). In addition it was assumed the LDV trajectories should be higher than HDVs. To determine the maximum trajectories for GHG standards, the process was again to start with R1-a and build up as believable as possible a transition from ICE through to essentially (in most cases) electricity and hydrogen fuelled transport system by 2050 and as fast as ‘possible’.
Developing a better understanding of the secondary impacts, EU Transport GHG: Routes to 2050

The general results of the sensitivity analysis are summarised in Figure 10.10 for lifecycle GHG emissions, which show up to approx +/- 50MtCO₂e (+/- 10% GHG) variation in GHG emissions through varying the end point targets for LDVs and HDVs by +/- 10% points (in the Low and High trajectories). For the LDV and HDV trajectory low case (V2) closing the resulting gap is likely to require significant uptake of additional non-technical measures (e.g. eco-driving, speed measures and special planning). However, in the LDV and HDV trajectory high case (V5) closing the gap could allow relaxation of modal shift and reduced use of biofuel, or alternatively this gap could be kept as a contingency to safeguard the possible under-achievement of other GHG mitigation actions taken.

The impact of applying the minimum or maximum GHG standard trajectories without other changes results in a gap versus the 2050 GHG reduction target of +/- 100MtCO₂e (+/- 20% GHG).

Figure 10.10: Comparison of the lifecycle GHG impacts of different scenarios on LDV and HDV GHG standard trajectories versus the core GHG reduction scenario (R1-a) / 2050 target

As discussed in earlier Section 10.3.2, the application of higher GHG standards for road vehicles would also have benefits in significantly reducing the volumes of biofuel needed – e.g. as illustrated in Figure 10.11. Opting for the minimum or maximum feasible GHG standard trajectories also has a very marked impact on the necessary uptake of different road vehicle technologies. These differences are illustrated for cars and heavy trucks in Figure 10.12. The corresponding trajectories for total lifecycle GHG emissions for each scenario and direct/lifecycle GHG emissions for passenger cars are provided in Figure 10.13 for comparison. Somewhat coincidentally the maximum direct CO₂ reduction for new cars by 2025 has been estimated at ~70 gCO₂/km (test-cycle basis excluding biofuel), which is similar to the figure that has been recently proposed by the European Parliament.
The potential impact of GHG emissions from production and disposal of new vehicles was also considered in the analysis, building on the estimates developed under Task 2 (Section 7). A summary of the results for passenger cars is provided in Figure 10.14, which shows the proportion of total annual lifecycle GHG emissions due to vehicle production and disposal could rise from around 15% in 2010 to between 35% (minimum trajectory) and 69% (maximum trajectory) by 2050. The corresponding figures across all transport modes are a rise from around 11% in 2010 to between 21% and 25% in 2050. However, although the GHG benefits of electrified transport are eroded somewhat due to higher vehicle production and disposal emissions, the overall net GHG reductions are still quite significant. This analysis does, however, underline the importance of taking suitable action in this area to minimise the level of erosion of the GHG benefits from tighter new vehicle GHG standards.

Figure 10.11: Comparison of the relative volumes of biofuels needed to achieve low and high new vehicle GHG standard trajectories

Figure 10.12: Comparison of technology deployment rates needed to achieve low and high new vehicle GHG standard trajectories (V6-a and V7-a respectively)
Developing a better understanding of the secondary impacts, sensitivities for the decarbonisation of EU transport by 2050

Figure 10.13: Comparison of the lifecycle GHG trajectories for the MIN (V6-a) and MAX (V7-a) GHG standard trajectories versus BAU and R1-a, and the corresponding direct and indirect vehicle emissions per km for passenger cars.

Figure 10.14: Comparison of the total annual GHG emissions including vehicle production and disposal in 2050 for passenger cars for the adjusted* new vehicle GHG standard scenarios versus R1-a.
10.4 Summary and Conclusions

The following provides a general summary of the main conclusions from the Task 6 work:

SULTAN Development:
The SULTAN tool and its results viewer have been updated to provide a new baseline (business as usual) scenario, consistent with the latest Commission modelling, and with additional functionality to assist with scenario definition and impact analysis (including tables on biofuel use, energy security indicators, monetisation of emission impacts, etc).

Scenario Analysis:
- General:
  - The analysis illustrates the need for a balanced mix of well integrated policy actions to reduce the risk of failure to reach targets (maybe also with an extra safety margin);
- Co-benefits (Task 1):
  - There is the potential for air quality, energy security and health co-benefits generating savings of up to €177bn annually by 2050 versus BAU for scenario R3-b (low biofuel / electricity GHG savings) (total benefits rising up to €323bn, including GHG savings);
  - The greatest co-benefits per tonne GHG are achieved for actions that reduce overall vkm or shift to more efficient modes (particularly for increasing walking and cycling);
- Embedded GHG emissions (Task 2):
  - Vehicle production and disposal related GHG emissions are currently a significant component of the vehicle lifecycle GHG footprint (particularly for LDVs) – accounting for an estimated 11% of all in-year transport GHG emissions. It is expected this proportion will increase significantly versus vehicle use GHG emissions in the future (potentially doubling on average, and more than tripling for some modes).
  - It is therefore important to take action to ensure potential erosion of the GHG reduction benefits of policy actions is minimised as far as possible;
  - However, it appears that this aspect is unlikely to alter the preferred or optimal pathway to total GHG reduction (there are still significant net GHG benefits from increasingly electrified road transport).
- Knock-on consequences (Task 3):
  - GHG savings in all areas may not be as large as hoped for due to a variety of knock-on consequences.
  - Therefore it may be desirable to err on the side of caution in setting reduction trajectories, for example through the application of more stringent new road vehicle GHG standards
  - Stronger road vehicle GHG standards would also provide additional air quality pollutant and energy security co-benefits, plus reduce the biofuel volumes required to meet targets.
- Decoupling of transport demand and GDP (Task 4):
  - One of the conclusions of Task 4 was that decoupling seems unlikely without a limited number of specific policies (speed, pricing, land use), which could mean that the baseline assumptions of decoupling are over-optimistic.
  - The exploration of demand sensitivities shows that the implication of higher demand was that additional or stronger actions may be needed to build contingency, e.g. in setting trajectories for vehicle GHG standards and applying non-technical measures;
- Risks & Uncertainties (Task 5):
  - Significant uncertainties around GHG savings from biofuel and electricity were identified in Task 5 and assessed in the core sensitivity analysis.
  - These pose a risk of leading to very large gaps versus GHG targets if there is over reliance on these options or action is not taken to mitigate them.
  - Alternative options require a lead time for sufficient deployment by 2050, so need to be factored in early.
11 Potential impacts of policies that could be put in place by 2020

**Objectives:**
The purpose of Task 7 of the project was to:

- Examine the long-term emissions impacts of policies that could be introduced prior to 2020 through SULTAN scenario analyses
- Identify additional policy measures that may need to be implemented prior to 2020 to achieve long term emissions reductions
- Investigate the impacts of these policies on cumulative GHG emissions out to 2050
- Explore the emissions trajectories and emissions budgets that may be required.

**Summary of Main Findings**

⇒ Lower than hoped biofuel GHG performance could result in significantly increased GHG emissions, and unless compensated for could lead to missing the 2050 target by as much as 100 MtCO$_2$e (scenario P4-b).

⇒ Action on external costs and shipping and aviation has been shown to be very important. If less action than anticipated is taken in these areas (scenarios P2-b and P6-b), then the 2050 60% GHG reduction target could be missed by 35 / 60 MtCO$_2$e respectively.

⇒ Should existing policies fail to deliver or be weakened, additional actions would have to be implemented in order to make up for the shortfall in GHG emissions reductions. Necessary actions that could be necessary include:
  - Additionally tightened CO$_2$ emission standards for road vehicles;
  - Strong levels of speed enforcement and motorway speed reductions;
  - Eco-driver training; and
  - Measures that significantly improve vehicle loading and reduce demand vs BAU.

⇒ Both policy design and timing are important. Policies may result in higher transport costs, less perceived freedom and infringement of obtained rights – a reserved attitude from politicians, industry and public may result. Therefore early action and well developed communication is required. Delay of policy implementation can also lead to the need to take stronger actions to catch up in later years (resulting in increased cost, reduced feasibility);

⇒ Potential emissions budgets to achieve the 2030 and 2050 GHG emission reduction targets may be developed through identifying the cumulative emissions over 5-year periods in the emissions trajectory to 2050.

⇒ Potential emissions budgets for R1-a and 2050 Roadmap (low) ensure that WP 2050 targets are met (ahead for 2030). Both scenarios have an increased rate of emissions reduction after 2030, which is necessary in order to meet the 2050 60% reduction target. It is also increased in later years due to the reliance on applying low carbon technologies to significant portions of the vehicle fleet - initially limited by the fleet turnover rates.

⇒ The average annual rate of GHG reduction for the BAU scenario is just 0.31%. The R1-a scenario has an average annual rate of reduction of 2.55%, compared to 3.01% and 2.26% for the low and high 2050 Roadmap scenarios respectively (all are lower than the current UK carbon budgets, at 3.3% annual reduction).

⇒ In setting carbon budgets, it is generally recognised that it is desirable to set more stringent budgets in earlier periods to help ensure actions required to meet long-term targets start happening as soon as possible. However, following straight-line trajectories to the 2030 and 2050 GHG reduction targets from the 2050 roadmap and White Paper would result in steeper trajectories in later periods, which may be undesirable. However, the trajectories across all sectors of the European economy would ideally be factored in.
11.1 Introduction

There is a clear need to understand the longer term emissions impacts associated with policies that can be introduced prior to 2020. This is because policy measures that induce a more rapid reduction in emissions may be preferable to those that take more time to achieve their effects. However as pointed out in the stakeholder consultation, it is likely that too rapid reduction will impose excessive and unnecessary costs as *inter alia* they disregard technological developments. Therefore the sole point cannot simply be to minimise cumulative emissions of greenhouse gases. Some policy measures may lead to very large reductions in annual emissions in later time periods, because, in some cases, they rely on applying low carbon technologies to significant portions of the vehicle fleet, however the rate at which GHG emissions decline is limited by the natural fleet turnover rate\(^*\). Therefore the potential impacts of existing and already planned GHG reduction policies on emissions were initially identified as a starting point.

Secondly, the types of additional policy measures that could be implemented prior to 2020 that would help to achieve longer term emissions reduction targets were identified. Whilst there are already a number of EU-level policies in place (or planned for introduction prior to 2020) for controlling transport sector GHG emissions, there are many additional measures that could be introduced prior to 2020 that could play a significant role in reducing emissions in the longer term. The focus of this task has been on those measures that would be practical to introduce prior to 2020, and to investigate the likely scale of emissions reductions achievable through the introduction of these measures in the periods between 2020 and 2050. Existing policy scenarios were used, along with combinations of scenarios, and the general scenario framework developed for the previous ‘EU Transport GHG: Routes to 2050?’ project. Where required, scenarios have been refined based on the policy measures identified. Scenarios were developed based on selected measures (those which were identified as being particularly significant in transport GHG reductions):

- **Internalisation of transport external costs** (focussing on GHG and pollutant emissions);
- **Biofuel deployment and sustainability** amendments to the Fuel Quality Directive (FQD) in relation to lifecycle GHG reduction of supplied fuels; and
- **Action taken on international aviation and maritime shipping**.

Six scenarios were developed (plus variants) covering optimistic and pessimistic versions of the measures identified above, which included the following:

**Internalisation of transport external costs**:
- **P1**: More rapid internalisation of certain external costs via additional fuel tax (vs R1-a);
- **P2**: Limited internalisation of external costs via additional fuel tax (50% of R1-a by 2050);

**Biofuel deployment and sustainability in relation to lifecycle GHG emissions reduction**:
- **P3**: Biofuel GHG sustainability strengthened (as included in the central R1-a scenario);
- **P4**: Biofuel GHG sustainability action delayed (substitution in road/rail/IWW reduced to 40% vs 50% in R1-a; biofuel GHG savings on conventional fuels only 65% by 2050, compared to 85% savings in R1-a and 20% savings in R2-a – see earlier Section 10.3);

**Action taken on international aviation and maritime shipping**:
- **P5**: Strengthening of fleet and new aircraft/ship efficiency improvements to 2030 vs R1-a;
- **P6**: Weakening of new aircraft/ship efficiency improvements to 2030 vs R1-a.

The three-part scenario analysis approach applied to each of these scenarios consisted of:
- Direct impacts of policy action and roll-on effect (‘a’ variant);
- Impact of policy action on R1-a scenario (‘b’ variant); and
- Adjust to bring GHG savings in line with 2050 targets (‘c’ variant).

\(^*\) Unless vehicles are prematurely scrapped and replaced with low carbon vehicles.
Developing a better understanding of the secondary impacts, sensitivities for the decarbonisation of EU transport by 2050

EU Transport GHG: Routes to 2050

For each of the possible policy measures and combinations, the SULTAN tool was used to analyse their impacts on emissions trajectories out to 2050. The focus has been on identifying the packages of policy measures that minimise cumulative transport sector GHG emissions between now and 2050.

The concept of emissions budgeting has, in recent years, become an important element in climate change policy. Emissions budgets can be used to set limits on the total volume of greenhouse gases that can be emitted in a particular time period. Emissions budgets are useful in the context of trying to ensure that policies are introduced that help to reduce GHGs sooner rather than later, thereby potentially reducing cumulative emissions releases, and minimising the need for very drastic (and very expensive) emissions reductions in later time periods to meet 2050 targets.

Potential EU transport emissions budgets have been investigated using the SULTAN illustrative scenario tool. This work has been carried out to focus on developing emissions budgets that correlate with achieving a 60% reduction in transport sector emissions by 2050, as set out in the Transport White Paper. While SULTAN was not designed to provide outputs in the form of periodic emissions budgets, the tool already has the structure and datasets available to provide this type of output. Primarily, the core GHG reduction scenario (R1-a) has been considered, but we have also looked at the potential carbon budgets consistent with the likely range of GHG emissions reductions necessary from the transport sector in the 2050 Roadmap (low and high targets for 2030 and 2050) 21.

11.2 Results of the scenario analysis

The potential of the ‘single measures’ is significant as shown in Figure 11.1 (cumulative emissions) and Figure 11.2 (emissions in 2050), but the design of policies is of upmost importance. P2-a and P1-a (50% and 100% internalisation of certain external costs respectively) demonstrate the extent to which internalisation of certain external costs is very sensitive to overall emissions reduction achieved (reduction roughly twice as high in P1-a than P2-a). In the P3-a scenario, life cycle emissions of biofuels are further reduced by reducing the impacts of indirect land use change (ILUC). In contrast to the P3-a scenario, the GHG performance for biofuels are delayed in the P4-a scenario. As can be seen, this can have a significant impact on the total emissions (an increase in emissions by up to 100 MtCO₂e annually by 2050 compared to the central R1-a scenario).

Compared to the BAU-a, the P5-a scenario assumes a 5-10% biofuel use, up to 6% improvement of the maritime load factor, and up to 8% efficiency improvement for aviation. The P6-a scenario results in an increase of the GHG emissions due to a reduction in the fuel efficiency of aviation and shipping, by the absence of fuel consumption standards. The cumulative emissions of P3-a are lower than P2-a, although for in-year emissions for 2050 the opposite is true – lower cumulative emissions of P3-a have been achieved over the period to 2050 due to early implementation of measure. This demonstrates that the timing of measures is important and can impact significantly on cumulative emissions.

The weakening of biofuel GHG performance results in increased emissions, and may lead to missing the 2050 target by 100 MtCO₂e (P4-b). Early action on internalising certain external costs and shipping/aviation was also shown to be very important. If less action than anticipated is taken in these areas (P2-b and P6-b), then the 2050 emission reduction targets could be missed by 35 MtCO₂e and 60 MtCO₂e (respectively). Additional actions would therefore have to be implemented in order to make up for the shortfall in emissions reductions.

21 2050 Roadmap targets for transport GHG emission reductions are +20% to -9% for 2030 and -54% to -67% for 2050.
The analysis shows that cumulative transport GHG emissions over a long period of time strongly depend on the effectiveness and timing of policies. A delay in the development and
implementation of policies to internalise certain external costs, is likely to require further increases in the use or improved GHG performance of biofuels, whereas a delay in improving the GHG efficiency of air and maritime transport may result in an increase of 195 MtCO$_2$e in 2050. This corresponds to 36% of the total emissions in 2050 in the core scenario.

The importance of timing is demonstrated again through a number of examples. For the P1-b scenario there is a large difference between 2050 emissions and cumulative emissions (see Figure 11.2 for emissions in 2050). This is due to the early timing of internalising external costs, which leads to a reduction in cumulative emissions compared to the core scenario. When comparing cumulative emission profiles for scenarios, those that have similar emissions in 2050 do not necessarily have same cumulative emissions due to timing of measure implementation: the difference in cumulative emissions between R1-a and P1-b is 2,500 MtCO$_2$e (P1-b lower cumulative emissions), four times the annual emissions in 2050 of R1-a.

To compensate for the delay in emissions reduction as a result of weakening policies in the area of internalisation of external costs, biofuel GHG performance, or aviation and maritime shipping emissions, the following additional policy measures are likely to have to be undertaken:

- Additional tightened fuel efficiency targets for road vehicles;
- Strong levels of speed enforcement and motorway speed reduction;
- Eco-driver training; and
- Measures that significantly improve vehicle loading and reduce demand vs BAU.

### 11.3 Exploration of potential EU-level transport GHG emission budgets

Five-year budget periods have been suggested by this study. Such a period is thought to be long enough to provide a benchmark to measure the EU's transport GHG emissions against, whilst being able to absorb any short-term fluctuations in emissions (e.g. due to weather extremes or fluctuations in business cycle). Longer budget periods (e.g. 10-years or more) would not offer any flexibility with regards to mid-term corrections.

GHG emission budgets could be developed based on the cumulative emissions of each 5-year period to 2050. The budgets for both the R1-a and 2050 Roadmap (low) scenarios contribute towards successfully meeting (and exceeding) the White Paper 2030 and 2050 emissions reduction targets. Compared to the BAU scenario, both have an increased rate of emissions reductions after 2030.

It is important to ensure that changes in budget allowances from one period to the next are not too steep. If this is the case, it is likely that budgets will become increasingly unattainable as time goes on, reducing the ability to meet the end target. The average annual percentage reduction for the BAU is just 0.31%, the R1-a scenario has a reduction of 2.55%, compared to 3.01% and 2.26% for the low and high 2050 Roadmap scenarios respectively (each one lower than UK carbon budgets, at 3.3%).

The BAU scenario sees relatively high annual reductions until 2030 (-0.42% per year) which slow substantially in the subsequent period to 2050 (-0.20%). Conversely the other scenarios see a relatively low level of emissions reductions up to 2030 compared with the level of reductions required annually after this point to 2050. In order to meet the White Paper 2030 target, average annual percentage reductions of 0.69% are required (2011 to 2030). The R1-a scenario exceeds this requirement with an average annual reduction rate of 1.05%, meeting the 2030 targets sooner. The rate of emissions reductions then needs to increase substantially to 4.07% (annual average) in the subsequent period to 2050 for the R1-a scenario.
For greater certainty of meeting the long term targets, it is desirable to set more stringent budgets in earlier periods to help ensure that actions required start happening as soon as possible. This approach is also likely to have positive effects on minimising total cumulative emissions and abatement costs over the period. Of course this has to be balanced with what can be feasibly achieved in the budget periods. Following straight-line trajectories to the 2030 and 2050 GHG reduction targets from the 2050 roadmap and White Paper would result in steeper trajectories in later periods, which may be undesirable. However, the trajectories across all sectors of the European economy should also be factored into consideration.

11.4 Conclusions

The policy scenarios were compared to the core scenario (R1-a) and BAU scenario to identify any differences. When considering the emissions trajectories to 2050, emission reductions can be significant. However, it is not possible to achieve the WP 60% reduction target with just any one of the single measures in addition to the BAU.

The weakening of biofuel GHG performance requirements results in increased emissions, and may lead to missing the 2050 target by 100 Mt CO$_2$e (P4-b). Action on external costs and shipping/aviation was shown to be very important. If less action than anticipated is taken in these areas (P2-b and P6-b), then the 2050 60% reduction target could be missed by 35 Mt CO$_2$e and 60 Mt CO$_2$e (respectively). Additional actions would therefore have to be implemented in order to make up for the shortfall in emissions reductions. These actions are likely to include:

- Additional tightening of GHG emission targets for road vehicles;
- Strong levels of speed enforcement and motorway speed reduction;
- Eco-driving training; and
- Measures that significantly improve vehicle loading and reduce demand.

Policy design is an important consideration. Scenario P1-a (further internalisation of certain external costs) has significantly lower emissions of GHGs in the period to 2030, which can be explained by 100% internalisation of certain external costs in 2020. The importance of timing of measures is again demonstrated when the cumulative emissions for two scenarios which provide equal emissions in 2050 but have different time profiles are compared (R1-a core scenario and P1-b further internalisation of external costs). The cumulative emissions for the P1-b scenario are around 2,500 Mt CO$_2$e less over the 2010-2050 period compared to the R1-a scenario because in P 1-b there are larger savings earlier. This illustrates the benefit of early action and how this may avoid more difficult and costly actions later.

Policies may result in higher transport costs, less perceived freedom and reductions in perceived rights – resulting in a reserved attitude from politicians, industry and public. In addition, the perceived costs and uncertainty for industry groups and customers of necessary policy interventions may also reduce support. In view of these concerns, early action and well-developed explanatory communication is required.

Long lead times provide the ability to first introduce a legislative framework, and subsequently tighten its application in the light of improved knowledge and experience. An example of this is early introduction of external cost internalisation with, over time, an increased amount of modes and cost categories covered. The same principle applies to CO$_2$ legislation for road transport, aviation and maritime shipping. The earlier a policy framework is available, the longer is the lead time until 2050, which can increase the acceptability and ease of planning for industry. Delay in implementing necessary policies should be avoided, as it can lead to the need to catch up with the needed emission reductions in later years, and result in increased cost and reduced feasibility of achieving targets.
12 Overall Conclusions

A number of important conclusions were reached at the end of the previous project with regards to decarbonising the EU transport sector, as summarised in the final project report under three key headings, which were:

i. The need to stimulate a broad range of technical and non-technical options;
ii. The need for a wide range of complementary policy instruments;
iii. The urgent need for action.

It would be beneficial to revisit each of the key headline messages in turn to assess how the findings of this project have supported or detracted from them. However, there was also a range of further work previously identified to help further enhance the overall picture that has formed the basis of many of the tasks carried out under this new project. It is useful first therefore to recap on the some of the key findings from this project. In particular the sensitivity analyses carried out with SULTAN have reinforced the previous messages and clearly show that there is a need for a balanced mix of well integrated policy actions to reduce the risk of failure to reach EU transport GHG reduction targets. In addition the following key findings and conclusions were drawn from this analysis, which are summarised as follows, with their link to other project tasks indicated:

- **Co-benefits (Task 1):**
  - There is the potential for air quality, energy security and health co-benefits generating savings of up to €177bn annually by 2050 versus business as usual for scenario R3-b in the case of low biofuel and electricity GHG savings (total benefits rising to up to €323bn per year, including GHG savings);
  - The greatest co-benefits per tonne GHG are achieved for actions that reduce overall vkm or shift to more efficient modes (particularly for increasing walking and cycling);

- **Embedded GHG emissions (Task 2):**
  - Vehicle production and disposal related GHG emissions are currently a significant component of the vehicle lifecycle GHG footprint (particularly for LDVs) – accounting for an estimated 11% of all in-year transport GHG emissions. It is expected this proportion will increase significantly versus vehicle use GHG emissions in the future (potentially doubling on average, and more than tripling for some modes);
  - It is therefore important to take action to ensure potential erosion of the GHG reduction benefits of policy actions is minimised as far as possible;
  - However, it appears that this aspect is unlikely to alter the preferred or optimal pathway to total GHG reduction (e.g. there are still significant net GHG benefits for increasingly electrified road transport);

- **Knock-on consequences (Task 3):**
  - The net GHG savings in all areas may not be as large as hoped for due to a variety of knock-on consequences;
  - Therefore it may be desirable err on the side of caution in setting paths, for example through the application of more stringent new road vehicle GHG standards;
  - Stronger GHG standards would also provide additional air quality and energy security co-benefits, plus reduce the biofuel volumes needed to meet targets;

- **Decoupling of transport demand and GDP (Task 4):**
  - One of the conclusions of Task 4 was that decoupling seems unlikely without a limited number of specific policies (speed, pricing, land use), which could mean that the baseline assumptions of decoupling are over-optimistic;

---

The exploration of sensitivities in demand showed the implication for higher demand was that additional/stronger actions may be needed to build contingency, e.g. in setting trajectories for new vehicle GHG standards, applying non-technical measures.

- **Risks & Uncertainties (Task 5):**
  - Significant uncertainties around GHG savings from biofuel and electricity were identified in Task 5 and assessed in the core sensitivity analysis;
  - These pose a risk that very large gaps versus GHG targets may arise if we overly rely on these options and do not act to mitigate the problems;
  - Alternative options require a lead time for sufficient deployment by 2050, so need to be factored in early.

- **Impact of policy actions by 2020 (Task 7):**
  - Early action and well-developed communication required to ensure policies can be implemented as soon as possible;
  - For some instruments that quickly achieve GHG savings the cumulative GHG savings can be substantial. This is desirable since minimising overall atmospheric GHG concentrations is the ultimate objective, not simply specific annual emissions;
  - The implementation of 5-year GHG budgets for the EU transport sector could be an effective way to encourage timely action and minimise cumulative GHG emissions;
  - Delay of key policy actions should be avoided as this is likely to lead to the need to further accelerate action in later years to catch up, with higher risk, increased costs and reduced feasibility of achieving targets.

- **Co-evolution of regulation and economic instruments (Task 11 Paper 3):**
  - The most appropriate combination of regulation and economic instruments depends on the evolution of the total costs of ownership and the longer-term behavioural responses to policies, which are as yet unknown.
  - There are a number of benefits of using regulation and economic instruments together to deliver GHG reductions from transport.
  - The uncertainty associated with specific instruments and the benefits of using regulation and economic instruments together suggests that using a range of instruments is important to reduce transport’s GHG emissions.
  - Additionally, it might be wise, from the perspective of increasing the chances that transport delivers significant reductions in CO₂ emissions, to make sure that policy is able to cater for a pessimistic longer-term scenario in which alternative technologies do not become competitive. Such policy instruments require time to be prepared and implemented, which argues for early action.

The implications of this analysis and the wider work carried out in this project on each of the key headline messages from the previous work are as follows:

**I. There is a need to stimulate a broad range of options**

This message is still valid for a range of reasons, including:

⇒ The scale of the challenge is significant, so it would be very challenging to deliver required GHG reductions by stimulating technical options alone;
⇒ There are significant risks and uncertainties associated with GHG reductions from biofuels and electricity, which could lead to 2050 target levels being missed significantly;
⇒ If less is achieved from fuels or vehicle efficiency, essentially all of the other options quantified in this and the previous project would be needed to meet the current targets;
⇒ Broad action decreases the risks associated with putting confidence in too few options;
⇒ Action on vehicle efficiency means that lower levels of GHG reductions would be needed from energy carriers (e.g. through biofuel deployment), thus reducing the associated risks there.
II. A wide range of policy instruments are needed to stimulate the uptake of the necessary options

This message is also still valid, because the work carried out for this project has shown that:

⇒ There are potential rebound effects from uptake of technological options which underline the importance of user charging (Task 3);

⇒ Using different instruments better:
  - Stimulates different options and targets different actors;
  - Addresses problems such as split incentives, first mover, etc

⇒ Decoupling of transport from GDP growth could be achieved by charging, speed and land use policies (Task 4 and also explored in SULTAN sensitivity analysis);

⇒ When dealing with reducing GHG emissions and delivering co-benefits (Task 1, Task 3), different instruments are useful:
  - To reduce GHG and relieve congestion: Speed policy and user charging;
  - To reduce GHG and air pollutants: Eco-driving, speed limits, economic instruments and spatial policies
  - To deliver additional health benefits: options delivering increased walking and cycling;

III. Early action is needed to introduce a set of complementary policy instruments as soon as possible

The aspect of the timing of policy instruments has been particularly explored in Task 7, which has considered the impacts of policy in the 2020 timeframe. However, such considerations were also important in the other scenario analysis carried out for this project. Again the results are supportive of the previous conclusion for a range of reasons, including:

⇒ There are significant risks and uncertainties that mean that options need testing early;

⇒ In the event of an option not delivering sufficient emission reductions, early action will leave time to take alternative (or more stringent) action to ensure 2050 GHG reduction targets are achieved;

⇒ Different policy instruments will have different political considerations and barriers that need to be overcome, and starting early with a measured and gradual approach will facilitate this;

⇒ A wide range of stakeholders need to be engaged and involved in the solutions;

⇒ Therefore, a further important conclusion is that uncertainty about GHG impacts of options should not lead to inaction for the above reasons.

Overall the analysis carried out for this project clearly shows that there is a need for a balanced mix of well integrated policy actions to reduce the risk of failure to reach EU GHG reduction targets. It may also be beneficial to build in a level of contingency or safety margin due to the risks and uncertainties associated with the delivery of key options. The likely increasing future significance of GHG emissions from development and use of transport infrastructure and the production and disposal of vehicles mean it will also be important to take action to ensure these do not significantly erode the benefits of GHG reductions in vehicle operational energy use. Finally, setting 5-year cumulative GHG budgets for the EU transport sector could be an effective way to encourage timely action and minimise total cumulative GHG emissions in the long term.
Appendices

A full list of the full references for all of the papers and reports produced in this project, along with the respective Appendix in which the document can be found, is given in the contents table below. All of the papers and reports can be found on the project’s website (www.eutransportghg2050.eu).

Contents

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Contents</th>
<th>Report Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Task 3 Paper:</td>
<td>Smokers, R. (TNO), Skinner, I. (TEPR) and van Essen, H. (CE Delft) (2012), Exploration of the knock-on consequences of relevant potential policies</td>
</tr>
<tr>
<td>5</td>
<td>Task 5 Paper:</td>
<td>Smokers, R. (TNO), Skinner, I. (TEPR) and Kampman, B. (CE Delft) (2012), Identification of the major risks/uncertainties associated with the achievability of the policies and measures considered in the illustrative scenarios</td>
</tr>
<tr>
<td>6</td>
<td>Task 6 Paper:</td>
<td>Hill, N. and Morris, M. (AEA) (2012), Further development of the SULTAN tool and scenarios for EU transport sector GHG reduction pathways to 2050</td>
</tr>
<tr>
<td>7</td>
<td>Task 7 Paper:</td>
<td>Brannigan, C., Hill, N. (AEA); Smokers, R. (TNO), Skinner, I. (TEPR), den Boer, E. and van Essen, H. (CE Delft) (2012), Exploration of the interaction between the policies that can be put in place prior to 2020 and those achievable later in the time period</td>
</tr>
<tr>
<td>10</td>
<td>Task 11 Paper 2:</td>
<td>Hill, N. (AEA) and Skinner, I. (TEPR) (2012), The relationship of road vehicle GHG regulations with the necessity for application of wider transport mitigation options to meet 2050 reduction targets</td>
</tr>
</tbody>
</table>