



EU Transport GHG: Routes to 2050 II

Exploration of the likely knock-on consequences of relevant potential policies

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Executive Summary

Objectives:

The purpose of this Task was to:

- Explore likely knock-on consequences, for the vehicle fleet, of three relevant potential policies
 - Speed
 - Fiscal matters
 - Vehicle CO₂ legislation for passenger cars
- Obtain order of magnitude estimates with respect to the impacts at fleet level for the relevant knock-on consequences
- Where possible, obtain order of magnitude estimates with respect to the impact of various knock-on consequences on cost effectiveness of GHG mitigation instruments

Objective of discussion at Stakeholder Meeting

- ⇒ Challenge the analysis
- ⇒ Identify possible gaps, especially regarding 2nd order effects that have been quantified
- ⇒ Discuss the policy implications of 2nd order effects which are considered to be relevant for the assessment of overall policy impacts

Task 3 looked at the knock-on consequences of three types of policy instruments for reduction of GHG from transport (speed-related, 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.

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. Combining CO₂ legislation with a generic economic instrument, one which gives CO₂ a price, could provide an effective safeguard against rebound effects.

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 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 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

Main Findings regarding vehicle CO₂ legislation:

- ⇒ The 130 g/km target for 2015 is likely to generate negative knock-on consequences or rebound effects, reducing its intended effect and very likely its cost-effectiveness
- ⇒ Most likely the 95 g/km target will lead to small but net positive knock-on consequences enhancing the effect and effectiveness of the legislation
- ⇒ 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

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

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Glossary¹

BAU	Business as usual, i.e. the projected baseline of a trend assuming that there are no interventions to influence the trend.
BEV	Battery electric vehicle, also referred to as a pure electric vehicle, or simply a pure EV .
Biofuels	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.
Biogas	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 .
Biomethane	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 .
CNG	Compressed Natural Gas. Natural gas can be compressed for use as a transport fuel (typically at 200bar pressure).
CO ₂	Carbon dioxide, the principal GHG emitted by transport.
CO ₂ e	Carbon dioxide equivalent. There are a range of GHGs whose relative strength is compared in terms of their equivalent impact to one tonne of CO₂ . When the total of a range of GHGs is presented, this is done in terms of CO ₂ equivalent or CO ₂ e.
DG TREN	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.
Diesel	The most common fossil 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.
EEA	European Environment Agency.
EV	Electric vehicle. A vehicle powered solely by electricity stored in on-board batteries, which are charged from the electricity grid.
FCEV	Fuel cell electric vehicle. A vehicle powered by a fuel cell, which uses hydrogen as an energy carrier.
GHGs	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 .
HEV	Hybrid electric vehicle. A vehicle powered by both a conventional engine and an electric battery, which is charged when the engine is used.
ICE	Internal combustion engine, as used in conventional vehicles powered by petrol, diesel, LPG and CNG .
Kerosene	The principal fossil fuel used by aviation, also referred to as jet fuel or aviation turbine fuel in this context.

¹ Terms highlighted in bold have a separate entry.

Lifecycle emissions	In relation to fuels, these are the total emissions generated in all of the various stages of the lifecycle of the fuel, including extraction, production, distribution and combustion. Also known as WTW emissions .
LNG	Liquefied Natural Gas. Natural gas can be liquefied for use as a transport fuel.
LPG	Liquefied Petroleum Gas. A gaseous fuel, which is used in liquefied form as a transport fuel.
MtCO _{2e}	Million tonnes of CO_{2e} .
Natural gas	A gaseous fossil fuel, largely consisting of methane, which is used at low levels as a transport fuel in the EU.
NGV	Natural Gas Vehicle. Vehicles using natural gas as a fuel, including in its compressed and liquefied forms.
NO _x	Oxides of nitrogen. These emissions are one of the principal pollutants generated from the burning of fossil and biofuels in transport vehicles.
Options	These deliver GHG emissions reductions in transport and can be technical or non-technical.
Petrol	Also known as gasoline and motor spirit. The principal fossil fuel used in light duty transport vehicles, such as cars and vans. This fuel is similar to aviation spirit also used in some light aircraft in civil aviation.
PHEV	Plug-in hybrid electric vehicle, also known as extended range electric vehicle (ER-EV). Vehicles that are powered by both a conventional engine and an electric battery, which can be charged from the electricity grid. The battery is larger than that in an HEV , but smaller than that in an EV .
PM	Particulate matter. These emissions are one of the principal pollutants generated from the burning of fossil and biofuels in transport vehicles.
Policy instrument	These may be implemented to promote the application of the options for reducing transport's GHG emissions .
TTW emissions	Tank to wheel emissions, also referred to as direct or tailpipe emissions. The emissions generated from the use of the fuel in the vehicle, i.e. in its combustion stage.
WTT emissions	Well to tank emissions, also referred to as fuel cycle emissions. The total emissions generated in the various stages of the lifecycle of the fuel prior to combustion, i.e. from extraction, production and distribution.
WTW emissions	Well to wheel emissions. Also known as lifecycle emissions .

1 Introduction

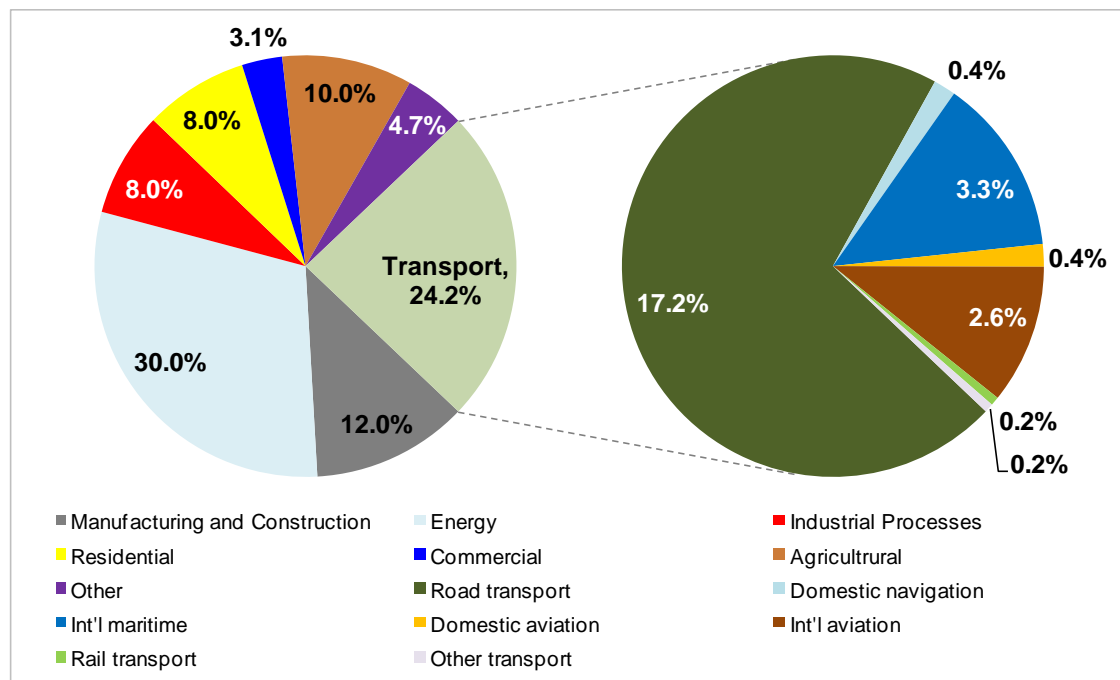
1.1 Topic of this paper

This paper is one of a series of reports drafted under the *EU Transport GHG: Routes to 2050 II* project. This paper focuses on **knock-on consequences of relevant potential policies**.

1.2 The contribution of transport to GHG emissions

Transport is responsible for around a quarter of EU greenhouse gas emissions making it the second biggest greenhouse gas emitting sector after energy (see figure below). Road transport accounts for more than two-thirds 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 modes².

Figure 1 EU27 greenhouse gas emissions by sector and mode of transport, 2007



Source: EC DG Energy (2010)³

Notes: International aviation and maritime shipping only include emissions from bunker fuels

While greenhouse gas emissions from other sectors are generally falling, decreasing 15% between 1990 and 2007, those from transport have increased by 36% in the same period. This increase has happened despite improved vehicle efficiency because the amount of personal and freight transport has increased.

² EC DG Climate Action (2010): http://ec.europa.eu/clima/policies/transport/index_en.htm

³ Based on historic data from DG Energy (2010) *EU energy and transport in figures Statistical Pocketbook 2010* Luxembourg, Publications Office of the European Union, 2010. Publication and data available for download at: http://ec.europa.eu/energy/publications/statistics/statistics_en.htm

In the run-up to the Conference of the Parties of the UN Framework Convention on Climate Change in December 2009, the leaders of the EU's Member States called for significant reductions in global greenhouse gas (GHG) emissions:

*"The European Council calls upon all Parties ... to agree to global emission reductions of at least 50%, and aggregate developed country emission reductions of at least 80-95%... It supports an EU objective, in the context of necessary reductions according to the IPCC by developed countries as a group, to reduce emissions by 80-95% by 2050 compared to 1990 levels."*⁴

The key role that transport has to play in this long-term economy-wide aspiration was underlined by European Commission President Barroso in his *Political Guidelines for the next Commission*⁵ where he emphasised the need to maintain the momentum towards a low carbon economy and towards decarbonising the transport sector in particular. In March 2010, the Commission, as part of its *Europe 2020* strategy⁶, announced that it would make proposals to decarbonise transport, and in doing so linked the need to decarbonise transport with the wider sustainable growth agenda.

These high level political statements set the framework within which the original *EU Transport GHG: Routes to 2050* project was undertaken. One of the main aims of this project was to provide information and analysis to assist the Commission with its early thinking on a co-ordinated approach to reducing the GHG emissions of all modes of transport.

The increasing political importance that is being attached to decarbonising transport reflects the fact that, of all the economy's sectors, transport has proved to be one of the most problematic in terms of reducing its GHG emissions. As mentioned earlier, since 1990, GHG emissions from transport, of which 98% are carbon dioxide (CO₂), had the highest increase in percentage terms of all energy related sectors⁷. Furthermore, transport's GHG emissions are predicted to continue to increase, without additional measures, to over 2,000 MtCO₂e by 2050. This increase is shown in the next figure, with a split by mode of transport. The figure is an output from an Excel-based illustrative scenarios tool (IST) called SULTAN (**S**ustainable **T**ransport), which was developed under the previous project in order to identify the GHG reductions that transport could potentially deliver by 2050.

An increase of the order projected in the next figure would leave transport's GHG emissions 74% higher in 2050 than they were in 1990 (when the sector's emissions were nearly 1,200 MtCO₂e) and around 25% above 2010 levels. Significant emissions increases between 2010 and 2050 are projected for road freight (for which an increase of more than 45% is projected), aviation (more than 50%) and maritime (more than 65%) without additional policy instruments. 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 slightly from 2010 levels, as anticipated improvements in the energy efficiency of vehicles negate projected increases in demand.

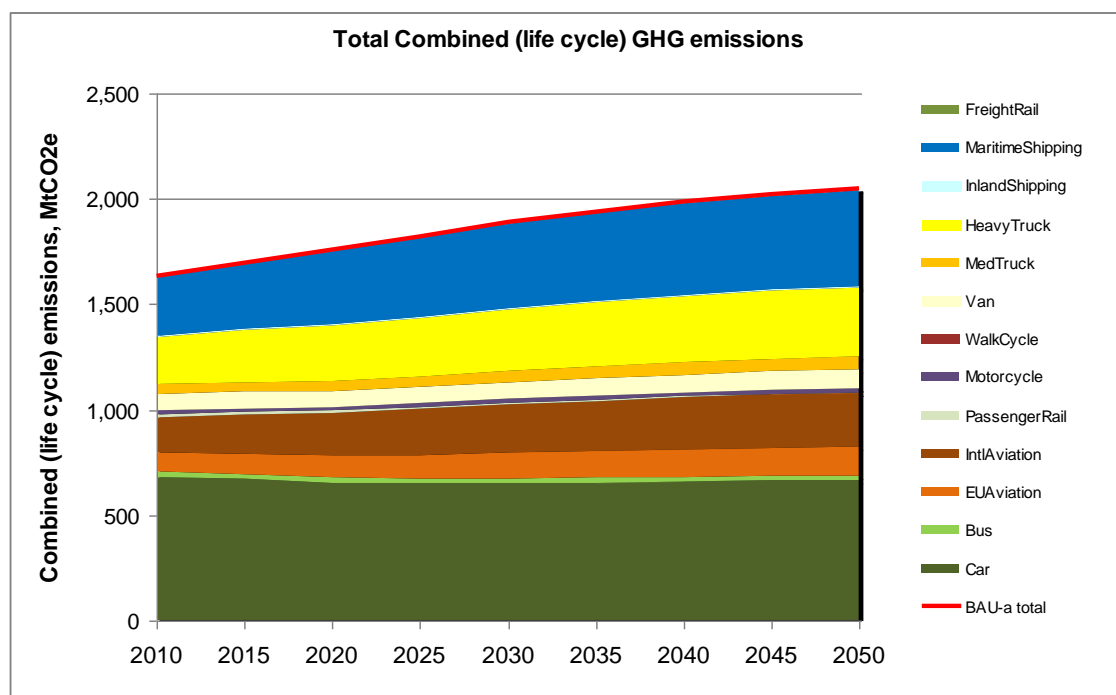
⁴ *Presidency Conclusions*, Brussels European Council, 29/30 October 2009; see <http://register.consilium.europa.eu/pdf/en/09/st15/st15265.en09.pdf>

⁵ Barroso, J (2009) *Political Guidelines for the next Commission*, September 2009, Brussels

⁶ European Commission (2010) *Europe 2020: A strategy for smart, sustainable and inclusive growth* COM(2010)2020, Brussels 3.3.2020.

⁷ DG TREN (2000) *Energy and transport in figures 2008-2009*

Figure 2 Business as usual projected growth in transport's GHG emissions by mode



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

Notes: International aviation and 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).

The figure above shows the baseline, as projected by SULTAN. This is consistent with the range of results from other models and tools, although many of these only project to 2030⁸. Clearly, the predicted continued growth in the EU-27's GHG emissions from transport has the potential to prevent the EU meeting the long-term GHG emission reduction targets that the European Council supports, if no action is taken to reduce these emissions.

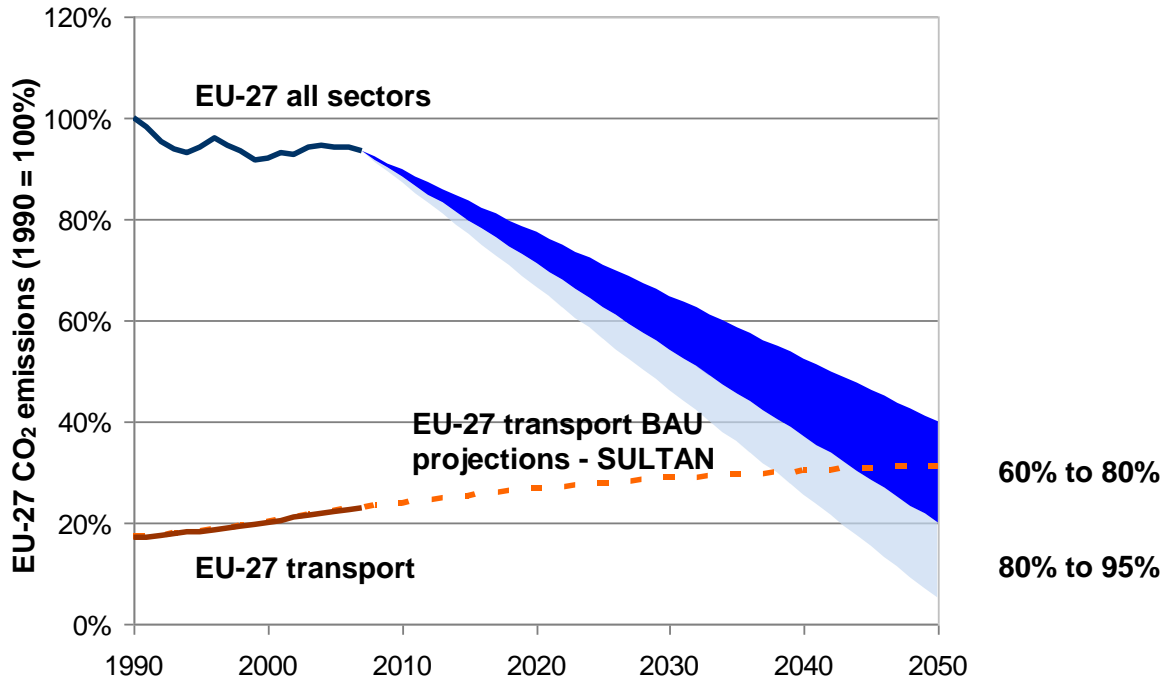
Figure 3 demonstrates that on current trends, transport emissions could be around 30% of economy-wide 1990 GHG emissions by 2050⁹. Whilst simplistic, in that it assumes linear reductions, the figure demonstrates that there is clearly a need for additional policy instruments to stimulate the take up of technical and non-technical options that could potentially reduce transport's GHG emissions. The EEA believes that all available policy instruments need to be used to achieve the ambitious GHG reduction targets¹⁰.

⁸ 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.eurtransportghg2050.eu>

⁹ 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.

¹⁰ EEA (2009) *Towards a resource-efficient transport system – TERM 2009: indicators tracking transport and environment in the European Union*, EEA Report No2/2010, Copenhagen.

Figure 3 EU overall emissions trajectories against transport emissions (indexed)



Source: EC DG Energy (2010) and SULTAN Illustrative Scenarios Tool¹¹

1.3 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 still the Commission's long-term objective for tackling climate change. The scope of the first project was very ambitious, and the outputs from the study were very detailed and have already proved to be of great 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 study team to carry out completely comprehensive research and analysis. In particular, as the project evolved, both the study team and the Commission Services became aware that there were a number of themes and topic areas that would benefit from further, more detailed research. This new project is a direct follow-on piece of research to the previous *EU Transport GHG: Routes to 2050?* study, building on the research and analysis carried out for that study and complementing other work carried out for the latest Transport White Paper. In particular, the outputs from this new study will 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.

Therefore, the key objectives of the *EU Transport GHG: Routes to 2050 II* are defined as to build on the work carried out in the previous project to:

¹¹ Projections based on data from the SULTAN Illustrative Scenarios Tool (BAU-a scenario) and historic data from DG Energy (2010) *EU energy and transport in figures Statistical Pocketbook 2010* Luxembourg, Publications Office of the European Union, 2010.

- 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 50-70% reduction target for transport from the European Commission's Roadmap for moving to a competitive low carbon economy in 2050¹²;

As before, given the timescales being considered, the project will take a quantitative approach to the analysis where possible, and a qualitative approach where this is not feasible. The project has been structured against a number of tasks, which are as follows:

- **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 is an important element of the project. The following meetings are being scheduled:

- A large stakeholder meeting currently planned for June 2011 at which the new project will be introduced to stakeholders and interim results presented.
- A series of four Technical Focus Group meetings TBC. These are currently scheduled to be held at the start of May 2011 and in November 2011.

¹² Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Roadmap for moving to a competitive low carbon economy in 2050, COM(2011) 112 final. Available from DG Climate Actions website at: http://ec.europa.eu/clima/policies/roadmap/index_en.htm

- A second large stakeholder meeting at which the draft final findings of the project will be presented and discussed, anticipated to be held in February 2012.

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

1.4 Background and purpose of the paper

This paper explores likely knock-on consequences, for the vehicle fleet, of three relevant potential policies contributing to the realisation of a long term sustainable mobility system in Europe:

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

Knock-on consequences in this context 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 (e.g. on CO₂ emissions) and thereby improve or deteriorate the policy's cost effectiveness.

The focus of this paper is on road transport. Knock-on consequences in this sector will be 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.

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, however, leads to higher vehicle prices and lower vehicle operating costs. 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 causing a shift in vehicle purchasing behaviour towards smaller and less powerful cars, may be expected to lead to second order behavioural effects wrt driving style and speeds. The lower fuel costs, on the other hand, may lead to increased travel.

Similarly **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.

These potential knock-on effects will be explored and mapped based on literature review and expert judgement.

2 Speed-related instruments

Objectives:

- Explore likely knock-on consequences, for the vehicle fleet, of Speed-related policies
- Order of magnitude estimates with respect to the impacts at fleet level for the relevant knock-on consequences
- Where possible, order of magnitude estimates with respect to the impact of relevant knock-on consequences on cost effectiveness of GHG mitigation instruments

Summary of Main Findings

- ⇒ 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.

2.1 Description of mechanisms leading to knock-on consequences

2.1.1 Definition of knock-on consequences / 2nd order impacts

Traffic speed can be influenced by a range of policy instruments, in particular speed limits, speed limit enforcement, mandatory speed limiters in vehicles and various types of traffic management measures. All these types of speed-related instruments are very common in road transport. The primary objective of such policy instruments is usually not GHG reduction, but rather improvement of traffic safety, reducing noise or improving air quality. Therefore in a sense all GHG impacts might be considered as knock-on consequences.

We can distinguish various mechanisms that are behind the potential impacts of speed-related policy instruments on the GHG emissions of transport. First of all, lower and/or smoother traffic speeds result directly in GHG reduction, because vehicles are more fuel efficient when operating at lower or more constant speeds. This effect is usually considered in studies considering the GHG emissions impacts of speed-related policy. We therefore regard this as the direct impact of speed-related policy.

In addition to this direct effect, speed-related policy could have a range of other consequences on modal split, transport demand, vehicle sales, vehicle design, etc. All of these effects, most of which will occur a relatively long time after introducing the policy, are considered knock-on consequences.

In the previous EU Transport GHG 2050 project, an assessment was made of the GHG effects of various speed-related policies. It was concluded that they can contribute significantly to GHG reduction¹³. The results were also included in the scenario analysis with the SULTAN tool. The scenario analysis included harmonised

¹³ See paper 5 and 8 and report Vii of EU Transport GHG: Routes to 2050?

motorway speed limits (scenario no. 8) and speed enforcement (scenario no. 7) across all roads and distinguishing cars, LDVs and HDVs.

The analysis in the previous project focused on motorways and was limited to the following effects:

- Higher fuel efficiency of vehicles;
- Impacts on the demand for transport and modal split (in the long term).

The second effect can be considered a knock-on effect. In this chapter a broader analysis is made of the possible knock-on effects of speed-related policy.

Very recently Spain reduced its speed limits on motorways from 120 km/h to 110 km/h. In the month afterwards (March 2011), the fuel consumption of road transport decreased by more than 8%, while it was changing with much smaller rates before (increases /decreases of less than 2%) in the months before (Spanish Ministry of Industry, Tourism and Commerce, 2011). It lacks an in-depth analysis of the relation between the fuel consumption and the speed limits. It is likely that this decrease can not entirely be contributed to the lowering of the speed limit. However, it is at least an indication that speed limits can indeed have a significant impact on CO₂ emissions.

Also a recent study by EEA (2011) and an older one from 2003 by ADEME¹⁴ show that lower speed limits on motorways can reduce traffic emissions considerably, with estimates ranging from 2% to even 18%, depending on the scenario and assumptions. However, both studies did only consider the direct impacts and not the indirect impacts, which is the main subject of this report.

2.1.2 Description of mechanisms leading to knock-on consequences

Speed-related policy instruments have a broad range of indirect effects. In this section we give an overview of these indirect effects and the mechanisms behind them. The assessment is limited to GHG emissions. Speed-related policy instruments may also have important impacts, like on noise, traffic safety, air pollution and congestion. However these type of effects are beyond the scope of this paper¹⁵. Below we discuss the key effects and the mechanisms behind them.

The first key effect that is relevant for all direct and indirect effects is the relation between speed-related policy and actual driving speeds. It is important to distinguish the various types of policies. Regarding speed limits, there is sufficient evidence that lower speed limits result in lower traffic speeds, particularly when they are strictly enforced. An older study from the USA suggests that the impact of speed limits on the actual driving speed is limited (US DoT, 1996). However, more recent cases in The Netherlands and France (see text box below) show that strictly enforced limits can have a large impact on driving speed.

¹⁴ See: <http://www.actu-environnement.com/ae/news/340.php4>

¹⁵ Note: some may be discussed in the paper on task 1 of this project, which will cover co-benefits of GHG policy for transport.

Impact of enforcement of speed limits on French motorways

In 2002, France started introducing an automated fining system, CSA, to enforce speed limits at motorways. In 2001, just before the introduction, 49% of the vehicles exceeded the limit and the average speed of cars and vans was about 126 km/h. After the introduction of CSA, the average speed dropped to 119 km/h and the non-compliant rate to 34%. The share of cars exceeding the speed limit with more than 10 km/h dropped from 35% to 19%.

Source: ONISR, 2006.

The impact of mandatory speed limiters on average driving speeds and average fuel consumption is much more straightforward and very significant. However, the impact of traffic management measures on traffic speeds and emissions is more complex. The impacts on traffic flows, average speed, depend strongly on local circumstances. In another task of this project, the relation between climate policy and congestion policy will be studied. As many traffic management policy instruments are also directed at reducing congestion, the complex relation between traffic management and GHG emissions will be assessed in more detail in that part of the study. In this chapter we will focus on speed limits and speed limit enforcement.

If we focus on speed-related policy that affect the average traffic speed, particularly speed limits and speed limit enforcement, what knock on effects can be expected? Table 1 gives an overview of the various knock-on effects of such policy and explains the mechanisms behind them.

Table 1 Overview of the mechanisms behind various GHG related knock consequences of policy that result in lower traffic speeds (e.g. speed limits and strict enforcement)

<i>Type of effect</i>	<i>Mechanism</i>	<i>Time indication</i>
Demand effects		
<i>Total transport demand</i>	<p>Lower transport speeds result in longer travel times. For passenger transport this results in shorter travel distances, particularly in the long run. The rule of constant travel times even suggests that on average all reduced travel time is compensated by additional travel elsewhere in the transport system (potentially by other modes, times, locations or even users).</p> <p>For freight transport, lower speed limits lead to higher transport costs per tonne-kilometre, because driver cost per kilometre increase linearly with the inverse of the average travel speed. Together with the longer transport times, this results in higher transport costs, which in the long run, will have an effect on total transport demand as alternatives with shorter freight chains become relatively cheaper.</p>	Mainly long term
<i>Modal shift to other modes</i>	<p>Longer travel times of road transport makes alternative modes more attractive resulting to some modal shift. For the share of cycling in the modal split in urban areas, this effect was confirmed by studies. Also in other cases where alternatives (fast rail, bus, tram, metro, aviation) are available and nearly competitive, these effects are likely to occur.</p> <p>This effect is related to the previous one, as a shift to slower passenger transport modes results in a decrease in transport demand. Also for freight transport some modal shift to alternative modes can be expected because of the higher cost and longer travel times.</p>	Mainly long term

Type of effect	Mechanism	Time indication
<i>Shifts between vehicle categories of the same transport mode</i>	Speed limits or mandatory speed-limiters for one type of vehicles can induce a shift to other vehicles of the same mode. An example is a shift from small trucks to vans.	Short to medium term
Effects on vehicle sales		
<i>Size of the fleet</i>	<p>The size of passenger car fleet could reduce because in some cases cars become less attractive and so car ownership is reduced.</p> <p>For freight transport, time constraints are often critical. Therefore slower transport might result in an increase of the vehicle fleet. At the other hand, the modal shift and demand effects will reduce vehicle the size of the fleet.</p>	Medium to long term
<i>Fleet composition (changes in sales): downsizing and/or downscaling</i>	Lower speed limits or stricter enforcement could make fast cars less attractive. This effect occurs particularly when a considerable share of the consumers chooses a slower car or less powerful engine power because of speed limit or enforcement.	Medium to long term
<i>Vehicle design (new vehicle models): downsizing and/or downscaling</i>	In the long run manufacturers might change vehicle design.	Long term
Other effects		
<i>Indirect GHG effects from reduced accident rates</i>	Lower speed limits result in lower accident rates. This can result in reduced GHG emissions from car manufacturing and end-of-life processes, as it could increase the average life time of cars. If significant, this will be (partly) compensated by the resulting lower fuel efficiency improvement rate due to slower fleet renewal. Reduced accident rates could also reduce congestion levels and so lead to more fuel efficient driving, but also higher average travel speeds and so in the long run more demand and more emissions.	Short term
<i>Indirect GHG effects from congestion effects¹⁶</i>	The relation between speed and congestion is complex. Lowering of speed limits below 80 km/h can lower the road capacity. However the precise effect is very dependent on local circumstances. Speed limit above 80 km/h have little impact on congestion, because congestion usually arises when the speed of the traffic flow is already far below the level of the free flow speed. Changes in congestion level usually also have impacts on modal split and transport demand and so also on the GHG impacts listed above under these categories.	Short to long term
<i>Less "highway avoidance" behaviour</i>	Lower speeds may make that people who currently avoid motorways, because they are afraid of too high speeds and speed differences, will start using motorways. This can have various impacts on CO ₂ : the fuel efficiency of their cars may improve, but the higher speed may result in additional transport demand.	
<i>Impacts on infrastructure</i>	Lower speed limits may change the design of roads. It is unclear how likely this effect is and whether any significant GHG impact can be expected.	

¹⁶ This effect is the subject of a separate task within this project on the potential interaction between GHG policy and congestion policy.

2.2 Summary of information from the literature

There is much literature available on the impacts of speed limits. However, most of this considers impacts on traffic safety. The impacts on GHG emissions, which is the subject of this paper, are considered in fewer studies.

Paper 8 of the previous project estimated the impact of speed limits of 100 km/h for passenger cars on motorways in the order of 7-15% for all motorway traffic, depending on the initial speed limit (120, 130 or no limit). Also for heavy goods vehicles, enforcing speed limit at 80 km/h could result in substantial reductions.

However, it should be noted that all these estimates are limited to quantification of the direct effects. UBA (2003) mentions also indirect effects, but does not estimate their size (apart from exemplary calculations of some *what-if* scenarios). Other studies on GHG impacts of speed limits such as EEA (2011) or ADEME (2003) do not consider any demand effects either.

The literature on the indirect CO₂ effects of speed limits is very limited. The main literature found that quantified indirect CO₂ effects of speed limits are from the UK energy research centre (2006) and CE Delft (2010). Both consider mainly the impacts on transport demand and conclude that these can be of the same magnitude as the direct effects from fuel efficiency improvements of the vehicles and are discussed in the section 2.4. No studies have been found that estimated other indirect CO₂ impacts. Therefore these effects are just included in the qualitative assessment in the next section.

For roads other than motorways, there are no estimates available from literature on the indirect effects of speed limits. As current vehicles deliver their lowest fuel consumption at a speed of around 80 km/h, lowering speed limits below this level could potentially increase emissions, at least when ignoring the impact of demand effects. As for motorways, also the impact of traffic dynamic can be very important.

However, also at lower speeds, the demand effects can be very substantial, as also in this case, lower speeds lead to longer travel times and in the long run very likely to a shift to slower and low-carbon modes and that way also to less transport demand. Therefore, the impact of speed limits below 80 km/h (e.g. in urban areas) is probably still be positive from the perspective of GHG reduction policy. The fact that particularly in urban areas there are usual various transport alternatives available may make that the effect is even larger or occurs at a shorter term than on motorways.

2.3 Qualitative identification of potential knock-on consequences

Table 2 gives an assessment of the magnitude of the various knock-on consequences. This assessment is based on the literature listed in section 2.1 and for a large part on expert judgement.

Table 2 Assessment of various GHG related knock consequences of speed limits

Type of effect	Assessment	Magnitude
Demand effects		
<i>Total transport demand</i>	The demand effects for passenger cars have been estimated and are likely to be very significant, probably in the same range as the direct effect (see section 2.4). For freight transport the effect will also occur but might be somewhat smaller.	High
<i>Modal shift to other modes</i>	The modal shift effect is highly dependent on local circumstances. When there are alternatives for road transport, some modal shift effects can occur. However, speed limits should in this context be regarded as part of a broader policy to be effective.	Medium
<i>Shifts between different vehicle categories of the same transport mode</i>	There is evidence that this effect can be quite significant, particularly between small trucks and LDV. A lift of speed limits for vans in 1997 and mandating speed limits for trucks in 2002 were followed by a strong shift from small trucks to vans. The GHG impact of this effect is unclear, but might in some cases be significant.	Unclear (might be significant)
Effects on vehicle sales		
<i>Size of the fleet</i>	The impacts on the vehicle fleet for passenger cars are likely to be very small. Also for freight transport, the net impact on fleet size is likely to be small.	Low
<i>Fleet composition (changes in sales): downsizing and/or downscaling</i>	Lower speed limits could make fast cars less attractive. However, until now there does not seem to be a correlation between speed limits and car/engine size. Also in countries with strict speed limits, powerful cars are still very popular (e.g. USA). High engine powers are popular for reasons such as fast acceleration, status and large cars for their comfort, perceived safety and again status. These arguments are unlikely to be affected by speed limits. Fleet composition is mainly influenced by income level and taxation scheme.	Low
<i>Vehicle design (new vehicle models): downsizing and/or downscaling</i>	In the long run, manufacturers may change vehicle design when low speed limits are introduced and enforced. However, if consumers ask for fast and powerful cars, vehicle design will remain focused on engine power. Speed limits can provide some downsizing incentive to manufacturers but it is a rather indirect way which is not likely to be very effective.	Unclear (probably low)
Other effects		
<i>Indirect GHG effects from reduced accident rates</i>	Lower speed limits result in lower accident rates. However, the GHG effects of reduced accident rates are likely to be relatively small, as the number of accidents is still relatively small compared to the total amount of kilometres driven. The GHG impact of reduced congestion is likely to be small or even negative, due to potential demand increase caused by travel time impacts.	Low

Type of effect	Assessment	Magnitude
<i>Indirect GHG effects from congestion effects</i>	The relation between speed and congestion is complex. However, congestion usually arises when the speed of the traffic flow is already far below the speed limit which is the level of the free flow speed. The GHG effects of congestion impacts of lower speeds are therefore likely to be small.	Low
<i>Less "highway avoidance" behaviour</i>	The number of users that fall within this category is generally small and the GHG effects per users are likely to be quite limited as well.	Low
<i>Impacts on infrastructure</i>	These impacts are unclear but likely to be very small	Low

2.4 Comparison of 1st and 2nd order impacts on GHG emissions

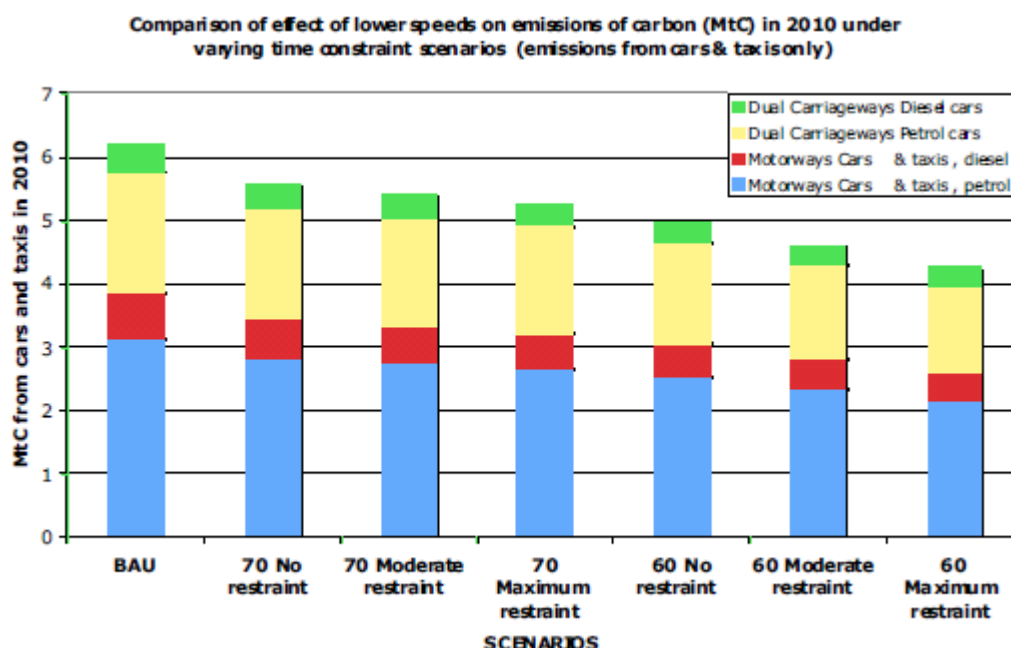
As noted above, there are two studies that explicitly compared the direct and indirect impacts of speed-related policy. Both studies consider motorway speed limits and only include the indirect effects of transport demand and modal shift. However, as can be concluded from Table 2 this is likely to be the main indirect effect. Both studies assume that the additional travel time caused by the lower speeds is compensated by a lower transport demand.

The study from the UK Energy Research Centre (2006) assessed various variants. The minimum restraint level assumed that the increase in average travel times do not reduce the overall transport demand. The moderate scenario assumes that the travel time losses due to the lower speed limits are partly compensated by reduced transport demand. Finally, the maximum restraint scenario assumes that all time losses are compensated by reduced transport demand, so this means assuming a constant time budget. The results of this study (see

Figure 4) show that the additional impact of demand effects is significant but smaller than the primary effect.

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Figure 4 Effect of lower speeds in the UK under various time restraint scenarios



Source: UK Energy Research Centre, 2006

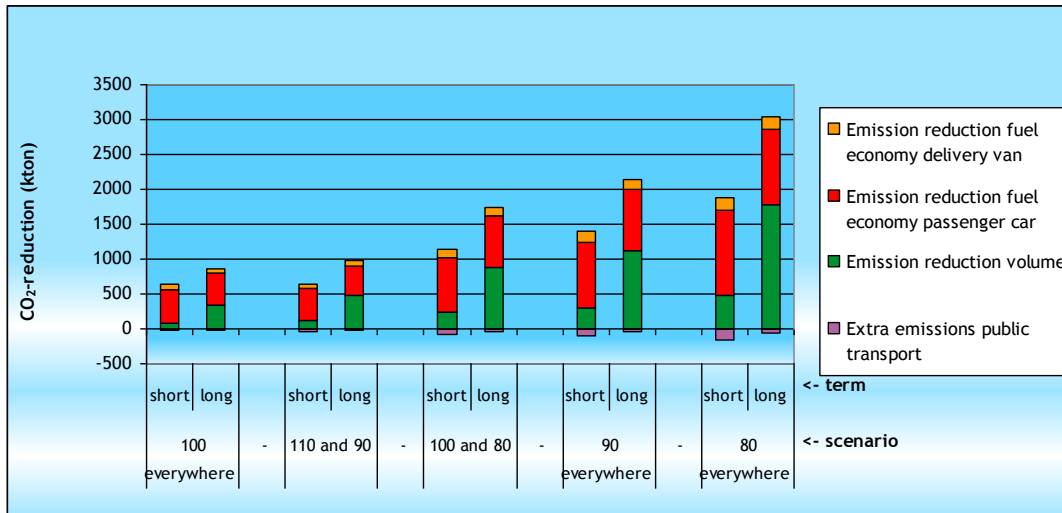
More recently, CE Delft assessed various scenarios for motorway speed limits in the Netherlands. This study used statistical data on current motorway speeds (based on real life traffic data of Dutch motorways) and assessed the direct and indirect impacts of various speed limits. It assumed that the new limits are strictly enforced, but also took account of the significant share of road users that currently travel at speeds that are below the speed limit. The study took account of additional emissions that would be the result of modal shift to public transport, using short term and long term travel time elasticities.

Regarding the demand effects, this study assumed that at the long term, the rule of constant travel time applies, which is the basically the same assumption as the maximum restraint scenario in the study by UK Energy Research Centre (2006).

The results of this study are shown in Figure 5. It is clear that in the short term, the primary fuel efficiency impact is dominant. The demand effect is considerably smaller than the primary impact in the short term and is significant only for relatively low speed limits. However, in the long run, the indirect effect is much more important and of the same order as the direct effect. In some cases, with low speed limits, it may even be dominant.

The difference between short term and long term impacts can be explained by the higher travel time elasticity (equal to -1) for the longer term, reflecting the wider range of options for changing ones travel behaviour that are available at the long term. Moving to another house or changing jobs can have large impacts on travel behaviour, but these options are only possible at the long run.

Figure 5 Effect of various speed limit scenarios on the motorway network in the Netherlands



Source: CE Delft, 2010

An important issue regarding potential for demand reduction and modal shift induced by speed limits is how fast such changes might happen. This strongly depends on local circumstances and the availability of alternatives. In general, many more alternatives are available at the long term than at the short term. While the average driving speed can be changed in the short term, options like moving closer to work, choosing a job closer to home, reduced car-ownership or tele-working will only be possible at the medium to long term. Lower transport speeds may at the long term even have impacts on the size and location of shops and other services because the number of people that can be served is dependent on the number of consumers that can reach the service within a reasonable time. This way, speed limits might at a very long term indirectly affect spatial and maybe even social structures.

2.5 Comparison of 1st and 2nd order impacts on costs and cost effectiveness

We limit the assessment of costs to speed limits, as for other speed-related policies, quantification of knock-on consequences was not possible. The costs of speed limits depend on a broad range of effects:

- Travel time losses.
- Fuel savings.
- Co-benefits on air pollution, noise, accidents and infrastructure.
- Impacts on road congestion.
- Potential long term impacts on spatial structures¹⁷
- Costs and revenues of enforcement.

Many of these effects, particularly the co-benefits and the congestion effects, depend very strongly on local circumstances. They can be important elements in the cost-benefit balance and therefore it is difficult to provide general cost estimates for speed limits. Below we present some examples.

¹⁷ This is about the way society adapts to lower speeds. These long term effects are very hard to quantify and therefore not included in cost benefit analysis.

In an article of Rietveld et al. (1996) the effects of climate change, air pollution, accidents, fuel consumption, and travel time have been quantified and expressed in monetary terms in a cost-benefit analysis. In this analysis it was concluded that from the point of view of total welfare, the most beneficial maximum speed limit on the motorway lies somewhere around 90 km/h. However, this study is yet quite old and therefore needs to be interpreted with some care.

More recently, Transport and Mobility Leuven (TML) issued a report on the impacts of speed limit on motorways (TML, 2009). In this report a cost-benefit analysis has been made for speed limit reduction on the Belgium motorways in which the effects of climate change, air pollution, traffic safety and travel time are incorporated. This study concludes that the most beneficial maximum speed limit of 110 km/h based on these effects. TML notes that in this study the volume effects of speed limit reduction are not taken into account. Other important effects not taken into account are the benefits of reduced fuel consumption and reduced expenses on infrastructure.

In another study, CE Delft (2009) estimated the cost effectiveness of the speed limit scenarios presented in Figure 5 and concluded that the CO₂ reduction cost of these policies would be in the order of € 250 to € 500 per ton of CO₂. These pretty high estimates are mainly the result of travel time losses, which are relatively high and were not included in the analysis by TML. This illustrates that the economic valuation of travel times is a key parameter in this type of analysis.

2.6 Conclusions

Speed-related policies usually primarily target accidents rates, air pollution or traffic noise. However, they can also have significant impacts on GHG emissions. Instruments such a 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 relative impact of speed-related policy on the overall transport demand and modal split is likely to be quite significant, particularly on the long term. Estimates of the impacts of strictly enforced speed limits indicate that these effects can even be in the same order of magnitude as the direct effect.

Also a shift between various vehicle categories of the same mode might be significant, in particular in the case of vans and small trucks. However, we lack quantification of potential GHG impacts of this type knock-on effect.

Other knock-on effects are impacts on fleet size and composition, vehicle design, accident rates, congestion, highway avoidance and infrastructure. All these effects are also 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 aforementioned demand and modal shift effect.

The impact of the knock-on effects of speed-related policy on the cost effectiveness is very high. The economic valuation of travel times appears to be a key parameter in assessments of the social costs of speeds limits which deserves further study.

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3 Fiscal instruments

Objectives:

- Explore likely knock-on consequences, for the vehicle fleet, of fiscal instruments
- Order of magnitude estimates with respect to the impacts at fleet level for the relevant knock-on consequences
- Where possible, order of magnitude estimates with respect to the impact of relevant knock-on consequences on cost effectiveness of GHG mitigation instruments

Summary of Main Findings

- ⇒ Second-order impacts from instruments targeting car purchasing are likely to be significantly greater than those targeting ownership
- ⇒ 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

This section focuses on the possible knock-on consequences on the vehicle fleet of economic instruments that could be used to stimulate the purchase of more energy efficient/low CO₂ emitting cars. The aim is to set out what the underlying mechanisms are, what the knock-on consequences might be, including the subsequent impact on CO₂ emissions and costs, and finally reach some conclusions as to the implications of CO₂ reduction policy for transport. While the focus is on cars, brief consideration will be given to other road vehicles, as well as to vehicles used by other modes, in order to identify whether, and if so how, the assessment (and conclusions) might be different. The work focuses on economic instruments that directly affect the purchase price of a car, such as purchase taxes and incentives, as well as those that affect car purchasing more indirectly as they affect the cost of ownership, e.g. circulation taxes. Hence, the assessment covers taxes and incentives on:

- **New cars**, including:
 - Differentiation of purchase and registration taxes by a car's CO₂ emissions.
 - Subsidies, tax reductions or tax exemptions for specified categories of cars (e.g. those that emit less CO₂ or are more energy efficient), e.g. using the CO₂ emissions of cars to identify the cars to which the benefits apply.
 - Tax "penalties" for inefficient or high CO₂-emitting cars.
 - CO₂ differentiation in the fiscal treatment of company cars.
- **All cars**, including:
 - Differentiation of circulation taxes by a car's CO₂ emissions.
 - CO₂ differentiation in the fiscal treatment of company cars.

In all cases, the analysis is comparing a change resulting from the introduction of the respective instrument with a baseline of no policy change, i.e. all the impacts are discussed in relation to the existing situation. In this respect, it is important to note that the way in which cars are taxed, and the incentives that are applied to improve the CO₂ performance of the car fleet, varies, sometimes significantly, between different Member States. While efforts have been made at the European level to harmonise vehicle taxation across the EU, this has proved to be challenging as

agreeing such policies at the European level requires unanimity. Consequently, the discussion is at times necessarily general in order to taken account of the differing vehicle taxation policies in EU Member States.

Finally, it is important to note that the following assessment only relates to the EU vehicle fleet and EU drivers. In some cases, the use of a vehicle in the EU accounts for only part of its total lifetime, as second-hand vehicles are often sold to non-EU countries, either in eastern or south-eastern Europe or even beyond, once they have reached the end of their lifetime in the EU. However, the implications of any subsequent non-EU use are not considered within this section. (Although not directly relevant to this discussion, Oko (2010) identified that even in the EU, between 4% and 5% of the car and van fleet in several of the new Member States, such as the Baltic States and Poland, are imported vehicles over 13 years in age.)

3.1 Description of mechanisms leading to knock-on consequences

The paper on the use of economic instruments for stimulating the uptake of greenhouse gas (GHG) reduction options, which was undertaken as part of the first EU Transport GHG 2050 project, covered vehicle taxes and charges (van Essen *et al*, 2010). This identified a number of points of intervention where economic instruments could be applied to contribute to the reduction of transport's GHG emissions. In this respect, the instruments under consideration in this assessment aim to change behaviour by directly affecting the purchasing decision and by indirectly affecting ownership and use. Consequently, the first step in describing the mechanisms that might lead to knock-on consequences is to identify how the instruments might affect the purchasing decision.

Identifying the first order mechanism is straightforward, as all of the instruments under consideration aim to change the relative price of the vehicle, either by changing the one-off price faced at the point of purchase or by changing any annual charges. The most direct means of using economic instruments to impact on the fleet's GHG emissions is to directly affect the price of a vehicle. For cars purchased by members of the public, this could be undertaken by: differentiating any purchase tax or initial registration tax by a car's fuel efficiency and/or CO₂ emissions; reducing the price of certain vehicles by providing a rebate or subsidy to assist with the purchase; or increasing the price of inefficient or high CO₂-emitting cars. The annual costs, which indirectly affect the cost of purchase, of a vehicle could be similarly changed by: differentiating any annual charges; reducing the taxes on more efficient vehicles or less polluting vehicles; and increasing the taxes on the more fuel inefficient and higher CO₂-emitting vehicles. In both cases, exemptions to initial one-off or annual taxes could even be applied for the most fuel efficient and least CO₂-emitting vehicles.

In many EU Member States, a significant proportion of new cars are purchased and subsequently owned by companies, for which different fiscal arrangements apply. The detail of the fiscal treatment of company cars differs in each Member State, but, in terms of using economic instruments to reduce the GHG emissions of such vehicles, similar mechanisms can be applied to any one-off initial payments or ongoing annual payments as for vehicles bought by members of the public that were described above. An additional relevant point with respect to company cars is that as the fiscal arrangements were often designed to enable company cars to be supplied as a benefit to employees, such arrangements are often inconsistent with the objective of reducing transport's GHG emissions (e.g. see Copenhagen Economics,

2009). It is also worth noting that while many cars start their useful life as a company car, most soon become private cars. Hence, a significant proportion of the lifetime CO₂ emissions of a company car will occur in the private sector. For example, a study for the Netherlands concluded that of the CO₂ emissions reductions that might occur as a result of company car tax reform, around 50% would be delivered when the car was in private ownership (CE Delft, 2008).

As with company cars, most other vehicles, including other road modes, but also non-road vehicles, are purchased by companies or at least by large public-owned enterprises, e.g. buses and rail where these services are still in public ownership. While it can be assumed that a more commercial approach to such purchases will be taken for these vehicles than would be the case with company cars (as other vehicles will not be purchased, at least in part, for their potential benefits), similar first order mechanisms to those described above probably apply.

The potential second order effects, i.e. knock-on consequences, within the EU of using economic instruments to stimulate the purchase of more fuel efficient/lower CO₂ emitting cars are the following impacts on:

- Size of the EU car fleet;
- Composition of the EU car fleet;
- Use of cars in the EU;
- Implications for the design of vehicles on the EU market; and
- Impacts on the EU second-hand market and the subsequent social impacts on EU citizens.
- Changes in the behaviour of retailers and buyers.

In each case, the mechanisms that lead to knock-on consequences are different.

In relation to the **size of the car fleet**, the relevant mechanism that delivers knock-on consequences is the net change in the total cost of purchasing and/or ownership across the fleet. The instruments discussed in this section could lead to either:

- A **net increase** in the total cost of purchasing and/or ownership due to an increase in the total amount of tax revenue received by the relevant authorities from relevant taxes. This would be the case, for example, when penalties for less fuel efficient/higher CO₂ emitting cars were the main instrument applied, or where the differentiation of taxation was designed to increase revenues.
- **No change** in the total cost of purchasing and/or ownership, as tax revenues neither increase or decrease. This could be the case, for example, if tax differentiation was designed to be revenue neutral, or comparable (in terms of net value) incentives and disincentives were put in place for the more fuel efficient and the less fuel efficient cars, respectively¹⁸.
- A **net decrease** in the total cost of purchasing and/or ownership due to an increase in the total amount of relevant taxes received by the authorities.

¹⁸ Note that when implementing a revenue-neutral change, there is a potential difference between ex ante and ex post revenue neutrality. Changes that are ex-ante revenue neutral do not take potential behavioural changes of car users into account, so are likely to lead to reduced revenues. Ex-post revenue neutrality takes account of such potential changes in behaviour to ensure that revenues remain neutral. In this case, tax rates would be higher than they would under ex ante neutrality. Ex ante neutrality can be preferred, from a political perspective, in order that some owners that respond in the desired manner are not "punished" by increased tax rates. In practice, as only some of those that change behaviour will be affected and then only marginally by purchase taxes, this is a marginal effect that is ignored in the assessment in this section.

This would be the case where, for example, the main instrument was a subsidy, rebate or exemption for the more fuel efficient cars.

Generally, if the cost of purchasing and/or ownership increases, it can be expected that there will be less purchasing and/or ownership. Hence, it might be expected that the impact on the size of the fleet of changes in vehicle taxation will be dependent on whether the total tax revenues increase, decrease or remains the same.

The impact of changes to vehicle taxation on the **composition of the vehicle fleet** will depend on the details of the changes. However, the mechanism of importance in this respect is the total cost of purchasing and/or ownership, or at least the relative costs of purchasing and/or owning different types of car. Generally, if the cost of purchasing and/or ownership increases, it can be expected that there would be less purchasing and/or ownership. Similarly, if the cost of purchasing and/or ownership of a particular type of car, e.g. large cars, increases relative to other types of car, then it might be expected that there would be less purchasing and/or ownership of large cars relative to smaller cars.

The impact on the **use of cars** is dependent on any subsequent changes to the cost of car use. As the purpose of applying the instruments under discussion is to stimulate the purchase of cars that emit less CO₂ and are more fuel efficient, such cars will use less fuel to travel the same distance. Hence, they will be cheaper to use. Additionally, as a result of being cheaper to use, there will be less incentive to drive cars in more fuel efficient ways in order to save money.

In relation to **vehicle design**, the intention of the instruments under discussion is to stimulate the development and introduction of technologies to reduce a car's CO₂ emissions, as noted above, which is therefore arguably not a knock-on consequence, but an intended impact. There are no other general knock-on consequences that can be identified, although it is possible that the detailed design of some instruments might have knock-on consequences.

As noted at the beginning of this section, the focus is on economic instruments that either directly or indirectly affect the purchase price of a car. While purchase taxes, and other instruments that directly affect the cost of purchasing, only affect new cars, circulation taxes directly affect all cars. As noted above, changes to taxation that increase the cost of purchasing new cars will reduce the amount of new car purchasing that takes place. Some of those who are dissuaded from buying a new car as a result of the changes in taxation may instead choose to purchase a second-hand car, which would have knock-on consequences for the **second hand market** in terms of higher prices for those cars which are now less likely to be bought new. Given that it is the poorer sections of society who are more likely to rely on the second-hand market for their car purchases, there could also be an **adverse knock-on social consequence** from such tax changes. Additionally, where there are changes in the relative costs of purchasing and/or ownership between, say larger and smaller cars, there might also be knock-on consequences on the second hand market and on different social groups due to changes in relative prices.

Changes in the **behaviour of retailers and buyers** cover changes that these stakeholders might make in order to lessen the effect of the tax, incentive or penalty. For example, those selling cars might choose to lower the pre-tax price of cars in order to counteract the impact of an increased tax or penalty. Alternatively, potential car purchasers might choose to buy a car from a neighbouring country to avoid paying an increased tax, or be tempted to buy a car in another country to benefit from incentives.

In relation to non-car modes, similar mechanisms probably apply to the size and composition of the fleet, and the use of the vehicles. It is also possible that there will be similar mechanisms that would lead to knock-on consequences for the second-hand market. However, given that most other vehicles are purchased by companies or public-owned enterprises, as noted above, the subsequent knock-on consequences will be felt by those companies or organisations that tend to buy second-hand vehicles from EU companies or enterprises. For some vehicles at least, the second-hand market is likely to be outside of the EU, which is where any knock-on consequences would be felt.

3.2 Summary of information from the literature

Vehicle taxes and charges impact directly on vehicle ownership and therefore also indirectly on modal shift and to some extent the overall transport volume, as the cost of road vehicle ownership increases (van Essen *et al*, 2010). Additionally, there is some evidence that car buyers do not make fully economically rational decisions with regard to fuel efficiency of vehicles on purchase, which is sometimes referred to as consumer myopia (Ecologic *et al*, 2010). Rather than taking into account the lifetime savings from improved fuel efficiency, car buyers often take no more than the first three years of fuel use into account, whereas from the perspective of society the reduced fuel use over the life time of the car is clearly beneficial (IEEP *et al*, 2006). Such myopia leads buyers to choose to buy less fuel efficient cars than if they took account of the life-time savings of more fuel efficient cars. Given such considerations, differentiating registration taxes may be a good instrument for giving additional incentives for the purchase of more fuel efficient cars.

Due to such potential benefits, ECMT (2007) stated that reform of vehicle taxation to provide a strong differentiation on the basis of vehicle's CO₂ emissions should be a priority in Europe, while IEA (2008) noted that differentiated incentives are effective tools for stimulating CO₂ reduction in transport, particularly when these are used with labels, and can also be used as a complementary instruments alongside vehicle standards. ECMT/ITF (2008) noted that the fact that the fact that different systems for differentiating taxes existed in different countries fragmented the market and thus weakened the power of incentives.

Ekins and Potter (2010) argued that strong purchase and circulation tax incentives to reduce relative purchase costs would stimulate the uptake of cars with low running costs. However, they noted that the increasing use of such vehicles will produce pressures to increase car use, so other policies, such as fuel taxes and user charges, are needed in parallel to realise the full reduction potential of this measure. In this respect, ICCT (2011) argued that stepped incentives, while easier to implement from an operational perspective, are not as effective as a tax that is continuously proportional to CO₂ emissions. This is because, within any particular step, the differences in CO₂ emissions have no value and manufacturers are likely to respond by supplying cars that have emissions levels just below the thresholds.

3.2.1 Taxes and incentives on new cars

In its review of policy instruments for reducing the CO₂ emissions of land-based transport, UKERC (2009) reviewed a range of taxes and incentives on new cars, including the French *bonus-malus* system and incentives in Denmark and the Netherlands. The report concludes that purchase taxes could be used to encourage

the purchase of lower emitting vehicles and, as they are not liable to discounting as say circulation taxes would be, they would help to overcome the problem of consumer myopia. ICCT (2011) concluded that such one time upfront charges can influence the purchase decision for similar reasons.

UKERC (2009) also suggested that feebates might produce strong incentives to purchase more fuel efficient cars. Additionally, they note that as such taxes increase the cost of ownership, they could reduce ownership levels and therefore lead to fewer journeys. However, the report identifies a number of potential issues with such incentives. First, incentives that increase the cost of ownership may slow down the renewal of the car fleet, although this could be partially overcome with a feebate system. They also concluded that purchase taxes should be linked to fuel efficiency and CO₂ emissions in a non-linear fashion, otherwise for more expensive models the tax would be a progressively smaller proportion of the total price. On the other hand, they noted that there might be welfare and equity impacts if some people can no longer afford a car, or have to downsize. However, the report noted that such welfare effects can be avoided by purchasing a more efficient vehicle in the same vehicle class.

OECD/ITF (2009) noted that differentiated vehicle purchase and registration taxes, as well as feebate systems, could help to encourage the purchase of lower CO₂ emitting cars, as they provide clear information to households with respect to the fuel economy performance of the cars they are considering purchasing. ECMT (2007), on the basis of the results of a Swedish EPA study, noted that the introduction of a registration tax, as well as providing CO₂ benefits, would increase vehicle age, as a result of a reduced rate of scrappage, and reduce the size of the car fleet, which would incur a welfare loss. Consequently, they concluded that CO₂ differentiated vehicle taxes are only likely to be cost effective if introduced in a revenue neutral way.

ICCT (2010) reviewed feebates, which are revenue-neutral as rebates for low emitting cars are financed by increased fees for high emitting vehicles, in more detail. The report considered that a feebate system could pay manufacturers for reducing CO₂ emissions, or force them to pay for not doing so. Hence, the impact is on manufacturers, so feebate values are not generally high enough to impact on the buying decisions of most consumers. Similarly to purchase taxes, feebates aim to incorporate fuel efficiency into purchasing decisions and reward consumers in a tangible, immediate way for the social benefits of lower fuel consumption and reduced CO₂ emissions. In doing this, they close the gap between the personal and the societal benefits of increasing the proportion of lower emitting cars in the car fleet. In the short-term, such a price signal can be a useful incentive for stimulating the uptake of advanced technology, if there is uncertainty as to whether there will be stricter standards in the future (and what these standards might be). They argue that cars of different CO₂ emissions performance should have different rebates/fees; hence a continuous feebate is best rather than a stepwise, system. The latter is less effective as there is no incentive to improve the performance of cars that are not close to the next step and there is more uncertainty for manufacturers about the value of adding technology to future vehicles.

Finally, it has been identified that in some countries, pre-tax prices of new cars decline in response to the introduction of purchase taxes (e.g. TIS *et al*, 2002). Consequently, the desired emissions reductions that were expected to result from such taxes might not be achieved. Additionally, it is possible that, where vehicle taxes or incentives differ significantly between neighbouring EU Member States, the introduction of, or increases in, vehicle purchase taxes or incentives can have border

effects, where some potential purchasers buy their cars from neighbouring countries in order to pay less tax.

3.2.2 Taxes and incentives on all cars

In its review, UKERC (2009) also reviewed circulation taxes and annual company car taxation and noted that both can also be differentiated according to CO₂ emissions. They concluded that, in order to be effective, the differentiation needed to be significant. However, they noted that such differentiation led to a potential loss of welfare, which could affect rural families or families with children, if such families had to buy a smaller car than they would otherwise have done. However, the report noted that it is often possible to purchase a car in the same class, which has lower CO₂ emissions, which would overcome such potential effects. The report also concluded that differentiating circulation tax in favour of CO₂ emissions has a potential impact on poorer families buying second hand cars, as the impact would be felt on cars of all ages. Scrappage schemes relating to older, higher emitting vehicles could offset potential impacts of differentiated circulation tax on poorer households.

The report notes that the existence of, or increase in, circulation taxes could reduce demand for cars by increasing the cost of ownership. On the other hand, the rebound effects of a more fuel efficient vehicle fleet on vehicle use could increase demand. In this respect, due to the fact that circulation taxes generally raise revenues, a second order, longer-term effect of differentiating such taxes is a reduction in revenue from fuel taxes as vehicles become more efficient. Citing a report for the UK's Energy Saving Trust, the report noted that increases in circulation tax reduce a car's resale value, thus increasing depreciation costs to the consumer. In this respect, differentiation of circulation taxes would affect purchasing decisions.

ICCT (2011) notes that regular taxes affect replacement decisions and can help to influence turnover in favour of lower emitting cars if taxes reflect CO₂ emissions. In cases, where technology on new vehicles is changing rapidly, they argue that annual taxes can act a regular reminder to consumers to consider the cost effectiveness of their cars. Differentiating charges by CO₂ emissions should also apply to cars leased annually. The report notes that annual charges can also encourage earlier replacement of older and high polluting vehicles, but noted that such charges complement, rather than replace, one-off charges.

3.3 Qualitative exploration of potential knock-on consequences

The discussion of the previous section split the review of the literature by taxes and incentives that applied to new cars only, and those that applied to all cars. This distinction is important as the former set of policy instruments target the purchase of cars directly, while the latter target ownership directly and therefore affect purchase only indirectly. Some of the literature also noted differences between whether or not taxes were differentiated in a revenue neutral manner. In the analysis that follows, a distinction is made between instruments targeting new or all cars is made, as well as approaches that increase, decrease or have no effect on the tax revenue¹⁹. An overview of the various knock-on effects is given in Table 3, which is based on the literature review as well as expert judgement and comments from internal reviewers

¹⁹ The analysis assumes that all changes in tax revenues directly lead to similar changes in net taxation, i.e. where tax revenue increases, the net cost of purchasing (or owning) cars for the public in general increases, while where revenue decreases, the net cost of purchasing (or owning) cars decreases. Similarly, where a change is revenue-neutral, it is assumed that there is no net change in the cost of car purchasing or car ownership. In other words, any administrative costs incurred are assumed to be negligible.

and stakeholders. For the sake of simplicity, in all cases it is assumed that all of the other factors that might influence the knock-on consequences identified, such as fuel prices and wider economic considerations, do not change.

As the aim of all of the instruments under discussion is to increase the proportion of lower CO₂ emitting cars in the vehicle fleet, this is not considered to be a knock-on consequence, so is not included in the table, below. This is achieved, at least in part, by stimulating the development and introduction of technologies that reduce a car's CO₂ emissions, so this effect is also not considered to be a knock-on consequence, as it is a direct impact of the instruments. However, it is likely that the cars that are put on the market as a result of these instruments will be smaller on average, which could have knock-on consequences on welfare, although taxes focusing directly on the cost of purchasing a car might have more direct impact. In this respect, it should be noted that it is often possible to purchase a more efficient car with lower emissions within the same class of vehicle. As noted above, if incentives or differentiation were stepwise, manufacturers might be tempted to produce cars that just qualify for steps that qualify for lower taxes or rebates. The shift towards smaller cars is likely to have welfare implications for some drivers.

Table 3: Key knock-on consequences on the car fleet of fiscal instruments to stimulate the purchase of lower CO₂ emitting cars (assuming that changes differentiate according to a car's CO₂ emissions)

Cars affected and behaviour affected: Impact on revenue:	Purchase of new cars only , e.g. instruments applied to car purchases, such as purchase taxes, penalties/rebates, the fiscal treatment of company car purchases	Ownership of all cars , e.g. instruments applied to car ownership, such as circulation taxes, treatment of annual benefits associated with company car ownership
Increasing , e.g. changes to purchase or circulation taxes that increase revenue, penalties for higher emitting cars (or net effect of penalties and rebates is increased revenue)	<p>Size of fleet:</p> <ul style="list-style-type: none"> Short-term: Reduction due to increased price delaying (or preventing) some purchases Long-term: Reduced costs of use could stimulate more car purchases, thus increase size of the fleet <p>Composition of fleet (short-term)²⁰:</p> <ul style="list-style-type: none"> Decrease in proportion of new (more efficient) cars in the fleet, as some car purchases delayed (or prevented) as a result of increased cost of purchase Older cars might be retained longer due to the higher car purchase prices, particularly higher emitting cars <p>Use of cars:</p> <ul style="list-style-type: none"> Lower CO₂ emitting/more fuel efficient cars are likely to be used more, thus average distances will start to increase Changes in driving style, as less incentive to drive in a fuel efficient manner <p>Implications for vehicle design²¹:</p> <ul style="list-style-type: none"> On average, it is likely that new cars will be smaller Potential for cars to be designed so that they just qualify for categories that benefit from significantly lower taxation rates/rebates (if differentiation or incentives are stepwise) <p>Second hand market:</p> <ul style="list-style-type: none"> People who might have otherwise purchased a new larger car 	<p>Size of fleet:</p> <ul style="list-style-type: none"> Medium-term: Slight reduction due to increased costs of ownership Long-term: Reduced costs of use could stimulate more car purchases, thus increase size of the fleet <p>Composition of fleet (short-term):</p> <ul style="list-style-type: none"> Slight decrease in proportion of new (more efficient) cars in the fleet due to increased costs of ownership On average the life span of a car might decrease due to increased costs of ownership, particularly for higher emitting cars <p>Use of cars:</p> <ul style="list-style-type: none"> Lower CO₂ emitting/more fuel efficient cars are likely to be used more, thus average distances will start to increase Changes in driving style, as less incentive to drive in a fuel efficient manner <p>Implications for vehicle design:</p> <ul style="list-style-type: none"> On average, it is likely that new cars will be smaller Potential for cars to be designed so that they just qualify for categories that benefit from significantly lower taxation rates (if differentiation or incentives are stepwise) <p>Second hand market:</p> <ul style="list-style-type: none"> Potentially similar indirect, but less significant, effects via the

²⁰ The fact that all of the instruments assessed in this table would lead to a higher proportion of lower CO₂ emitting cars in the fleet is not included here or elsewhere in this table, as it is an intended impact of the instrument not a knock-on consequence.

²¹ The fact that all of the instruments assessed in this table would stimulate the development and introduction of technologies to reduce a car's CO₂ emissions is not included here or elsewhere in this table, as it is an intended impact of the instrument not a knock-on consequence.

	<p>(i.e. one that is relatively fuel inefficient and higher CO₂ emitting) could turn to the second-hand car market, which could experience price increases for such cars as a result of this increased demand</p> <ul style="list-style-type: none"> • People who might have otherwise have bought a second-hand smaller car (i.e. relatively fuel efficient and lower CO₂ emitting) might instead by a similar new car, thus decreasing the demand and therefore prices of such cars on the second-hand market • In the longer-term, as there will be more fuel-efficient cars in the fleet, the supply of these cars to the second hand market will increase, and hence the prices of such vehicles will fall. For fuel inefficient cars, the opposite holds. • Changes to company car taxation can be particularly useful at stimulating the introduction lower CO₂ technologies into the market on large cars, which will lead to improved efficiency of large second hand cars. However, the residual value of alternatively-fuelled vehicles is often uncertain. <p>Social consequences:</p> <ul style="list-style-type: none"> • Potential welfare implications as instruments lead to increased proportion of more fuel efficient and lower CO₂ emitting cars, which on average will be smaller. • Large poorer families relying on the second hand market for large cars might be adversely affected by price increases of these cars • Poorer single people or couples, who rely on the second hand market for smaller cars, might benefit from reduced prices <p>Changes in the behaviour of retailers and buyers:</p> <ul style="list-style-type: none"> • For those cars where the costs or purchase increase, retailers might be tempted to lower pre-tax prices in order to lessen the impact of the price increase. There is the potential for an opposite effect on cars where costs decline, which could partly be used to offset the first effect. • For those cars where the costs or purchase increase, potential buyers might be tempted to make their purchase in a neighbouring country. For those cars where the cost of purchase declines, purchasers might be attracted from neighbouring 	<p>new car market, as described in the previous column</p> <ul style="list-style-type: none"> • For the second hand market alone, people will tend towards buying lower CO₂ emitting cars as these are less expensive to own, so the demand and prices of lower CO₂ emitting cars increase, while the opposite effect will be seen for higher emitting, larger cars • From the perspective of company cars, increases in circulation tax could decrease the residual value of cars • Changes to company car taxation can be particularly useful at stimulating the introduction lower CO₂ technologies into the market on large cars, which will lead to improved efficiency of large second hand cars. However, the residual value of alternatively-fuelled vehicles is often uncertain. <p>Social consequences:</p> <ul style="list-style-type: none"> • Potential welfare implications as instruments lead to increased proportion of more fuel efficient and lower CO₂ emitting cars, which on average will be smaller. • Large poorer families relying on the second hand market for large cars could benefit from reduced prices • Poorer single people or couples, who rely on the second hand market for smaller cars, might be adversely affected by price increases of these cars <p>Changes in the behaviour of retailers and buyers:</p> <ul style="list-style-type: none"> • It is not likely that there will be any significant impact on pre-tax prices. • Any cross-border impacts would be significantly less than for instruments targeting purchasing.
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	countries in order to benefit from the reduced costs.	
<p>Neutral, e.g. revenue neutral changes to purchase or circulation taxes, penalties for higher emitting cars balanced by rebates for low emitting cars, feebates</p>	<p>Size of fleet:</p> <ul style="list-style-type: none"> • Short-term: No impact on the size of the fleet • Long-term: Reduced costs of use could stimulate more car purchases, thus increase size of the fleet <p>Composition of fleet (short-term):</p> <ul style="list-style-type: none"> • No change in proportion of new cars • No change in average life span of a car; but older higher emitting cars might be retained for longer due to increased purchase prices, while older lower emitting cars might be scrapped earlier due to lower purchase prices <p>Use of cars:</p> <ul style="list-style-type: none"> • Lower CO₂ emitting/more fuel efficient cars are likely to be used more, thus average distances will start to increase • Changes in driving style, as less incentive to drive in a fuel efficient manner <p>Implications for vehicle design:</p> <ul style="list-style-type: none"> • On average, it is likely that new cars will be smaller • Potential for cars to be designed so that they just qualify for categories that benefit from significantly lower taxation rates/rebates (if differentiation or incentives are stepwise) <p>Second hand market:</p> <ul style="list-style-type: none"> • On average, no impact on the second hand car market, but <ul style="list-style-type: none"> ○ People who might have otherwise bought a high emitting new car might turn to the second-hand car market instead, thus increasing the prices of high emitting second hand cars, while ○ People who might have otherwise bought a low emitting second hand car might instead buy a new car, thus reducing prices of low emitting second-hand cars • In the longer-term, as there will be more fuel-efficient cars in the fleet, the supply of these cars to the second hand market will increase, and hence the prices of such vehicles will fall. For fuel inefficient cars, the opposite holds. 	<p>Size of fleet:</p> <ul style="list-style-type: none"> • Short-term: No impact on the size of the fleet • Long-term: Reduced costs of use could stimulate more car purchases, thus increase size of the fleet <p>Composition of fleet (short-term):</p> <ul style="list-style-type: none"> • No impact on proportion of new cars • No change in average life span of a car; but older higher emitting cars might be scrapped earlier due to the increased costs of ownership, while older lower emitting cars might be retained for longer due to lower costs of ownership <p>Use of cars:</p> <ul style="list-style-type: none"> • Lower CO₂ emitting/more fuel efficient cars are likely to be used more, thus average distances will start to increase • Changes in driving style, as less incentive to drive in a fuel efficient manner <p>Implications for vehicle design:</p> <ul style="list-style-type: none"> • On average, it is likely that new cars will be smaller • Potential for cars to be designed so that they just qualify for categories that benefit from significantly lower taxation rates/rebates (if differentiation or incentives are stepwise) <p>Second hand market:</p> <ul style="list-style-type: none"> • Potentially similar indirect, but less significant, effects via the new car market, as described in the previous column • For the second-hand market alone, no impact on average, but people tend towards buying lower CO₂ emitting cars as these are less expensive to own, so second hand prices of lower CO₂ emitting cars increase, while the opposite effect will occur for higher emitting cars • From the perspective of company cars, no average impact on residual values of cars, but the residual value of higher emitting cars could decrease, while those of lower emitting cars might increase • Changes to company car taxation can be particularly useful at

	<ul style="list-style-type: none"> Changes to company car taxation can be particularly useful at stimulating the introduction lower CO₂ technologies into the market on large cars, which will lead to improved efficiency of large second hand cars. However, the residual value of alternatively-fuelled vehicles is often uncertain. <p>Social consequences:</p> <ul style="list-style-type: none"> Welfare implications, but less compared to a revenue-increasing change, as incentive for increasing proportion of more fuel efficient and lower CO₂ emitting cars, would be less. Similar, but less significant (then for revenue-increasing changes), potential adverse effect on large poorer families and potential beneficial impact on poorer single people or couples <p>Changes in the behaviour of retailers and buyers:</p> <ul style="list-style-type: none"> No net impact, but effects could be similar to those identified for revenue-raising instruments for cars whose relative costs of purchase change. 	<p>stimulating the introduction lower CO₂ technologies into the market on large cars, which will lead to improved efficiency of large second hand cars. However, the residual value of alternatively-fuelled vehicles is often uncertain.</p> <p>Social consequences:</p> <ul style="list-style-type: none"> Welfare implications, but less compared to a revenue-increasing change, as incentive for increasing proportion of more fuel efficient and lower CO₂ emitting cars, would be less. Similar, but less significant (then for revenue-increasing changes), potential benefit for larger poorer families and potential adverse effect on poorer single people or couples <p>Changes in the behaviour of retailers and buyers:</p> <ul style="list-style-type: none"> No significant impacts.
<p>Decreasing, e.g. rebates for low emitting cars (or net impact of rebates and penalties is decreased revenue)</p>	<p>Size of fleet:</p> <ul style="list-style-type: none"> Short-term: Increase due to lower price bringing forward (or generating) car purchases Long-term: Reduced costs of use could stimulate more car purchases, thus increase size of the fleet <p>Composition of fleet (short-term):</p> <ul style="list-style-type: none"> Increase in proportion of new (more efficient) cars in the fleet, as some car purchases brought forward (or generated) Older cars might be scrapped earlier due to the lower car purchase price, although there might be less of an impact on higher emitting cars (indeed older, larger cars might be retained for longer if their average price increases) <p>Use of cars:</p> <ul style="list-style-type: none"> Lower CO₂ emitting/more fuel efficient cars are likely to be used more, thus average distances will start to increase Changes in driving style, as less incentive to drive in a fuel efficient manner 	<p>Size of fleet:</p> <ul style="list-style-type: none"> Medium-term: Slight increase due to decreased costs of car ownership Long-term: Reduced costs of use could stimulate more car purchases, thus increase size of the fleet <p>Composition of fleet (short-term):</p> <ul style="list-style-type: none"> Slight increase in proportion of new (more efficient) cars in the fleet due to decreased costs of ownership On average the life span of a car might increase due to decreased costs of ownership <p>Use of cars:</p> <ul style="list-style-type: none"> Lower CO₂ emitting/more fuel efficient cars are likely to be used more, thus average distances will start to increase Changes in driving style, as less incentive to drive in a fuel efficient manner <p>Implications for vehicle design:</p> <ul style="list-style-type: none"> On average, it is likely that new cars will be smaller

	<p>Implications for vehicle design:</p> <ul style="list-style-type: none"> • On average, it is likely that new cars will be smaller • Potential for cars to be designed so that they just qualify for categories that benefit from significantly lower taxation rates/rebates (if differentiation or incentives are stepwise) <p>Second hand market:</p> <ul style="list-style-type: none"> • People who might have otherwise purchased a second hand car could purchase a new car, which could reduce prices in the second-hand car market. The impact will be more significant for smaller, more efficient vehicles, as the impact could even be opposite for larger, more inefficient cars if the prices of these increase • In the longer-term, as there will be more fuel-efficient cars in the fleet, the supply of these cars to the second hand market will increase, and hence the prices of such vehicles will fall. For fuel inefficient cars, the opposite holds. • Changes to company car taxation can be particularly useful at stimulating the introduction lower CO₂ technologies into the market on large cars, which will lead to improved efficiency of large second hand cars. However, the residual value of alternatively-fuelled vehicles is often uncertain. <p>Social consequences:</p> <ul style="list-style-type: none"> • Welfare implications, but less compared to a revenue-increasing and revenue neutral changes, as incentive for increasing proportion of more fuel efficient and lower CO₂ emitting cars, would be less. • Similar, but less significant (then for revenue-increasing and revenue-neutral changes), potential beneficial impact on poorer people, apart from possibly those large families who buy the largest cars <p>Changes in the behaviour of retailers and buyers:</p> <ul style="list-style-type: none"> • No significant net impact; potential minor effects, as noted above, for cars whose relative costs of purchase change.. 	<ul style="list-style-type: none"> • Potential for cars to be designed so that they just qualify for categories that benefit from significantly lower taxation rates/rebates (if differentiation or incentives are stepwise) <p>Second hand market:</p> <ul style="list-style-type: none"> • Potentially similar indirect, but less significant, effects via the new car market, as described in the previous column • For the second hand market alone, people tend towards buying lower CO₂ emitting cars as these are less expensive to own, so second hand prices of lower CO₂ emitting cars increase, while the second hand prices of higher emitting cars decrease • In the longer-term, as there will be more fuel-efficient cars in the fleet, the supply of these cars to the second hand market will increase, and hence the prices of such vehicles will fall. For fuel inefficient cars, the opposite holds. • From the perspective of company cars, decreases in circulation tax could increase the residual value of cars • Changes to company car taxation can be particularly useful at stimulating the introduction lower CO₂ technologies into the market on large cars, which will lead to improved efficiency of large second hand cars. However, the residual value of alternatively-fuelled vehicles is often uncertain. <p>Social consequences:</p> <ul style="list-style-type: none"> • Welfare implications, but less compared to a revenue-increasing and revenue neutral changes, as incentive for increasing proportion of more fuel efficient and lower CO₂ emitting cars, would be less. • Similar, but less significant (then for revenue-increasing or revenue-neutral changes), potential benefit for poorer people <p>Changes in the behaviour of retailers and buyers:</p> <ul style="list-style-type: none"> • No significant impacts.
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One of the most important knock-on consequences of **all of the instruments under consideration**, no matter what their effect on revenues or whether they focus on only new or all cars, is that the cars that are subsequently bought or owned would be more fuel efficient and so would be cheaper to use, everything else being equal. Hence, it is likely that such fuel efficient cars would be used more and potentially differently, as incentives for driving in fuel efficient ways would decline. In the longer-term, the lower costs of use associated with an increase in the proportion of more fuel efficient vehicles could lead to an increase in the size of the fleet, as the total costs of ownership (including fuel) decline.

On the other hand, as all of the instruments will, in the longer-term, increase the proportion of more fuel-efficient cars in the fleet, the supply of these cars to the second hand market will increase, and hence the prices of such vehicles will fall. For fuel inefficient cars, the opposite holds.

If company car taxation is amended to stimulate the purchase and use of more fuel efficient or low CO₂ emitting cars, then this has the potential to stimulate the introduction of low CO₂ engine and fuel technologies into the market, particularly in larger vehicles, as more of these begin their lives as company cars. In this respect, such changes can help to improve the fuel efficiency of the second-hand market for large cars. This could have beneficial social impacts on larger, poorer families. However, for cars with alternative technologies, the residual value of company cars can be uncertain.

Where **revenue increases**, the size of the fleet can be expected to decline in the short-term due to increased costs of purchase and ownership, although it is likely that the impact will be less significant, and will be potentially longer to materialise, for those instruments targeting ownership directly. Revenue-increasing changes to taxes or incentives also have the potential to slow down the rate of turnover of the fleet, thus decreasing the proportion of the fleet that can be considered to be new. In turn, this could slow down the rate of improvement in the fuel efficiency of the fleet. This effect is also likely to be more significant and immediate for instruments that increase the cost of purchasing a car, compared to those that increase the cost of ownership.

The impact on a car's lifespan from revenue-increasing changes is likely to be different depending on whether the instruments target purchasing or ownership directly. Changes that increase the cost of *purchasing* could lead to older cars, particularly higher emitting cars, being retained for longer periods. On the other hand, changes that increase the cost of *ownership* have the potential to decrease the lifespan of cars, particularly higher emitting cars, due to the increased costs of ownership.

Increases in the absolute or relative costs of *purchasing* higher CO₂ emitting new cars could have knock-on effects on the second-hand market, and thus on people who would generally buy second-hand cars, who are likely to be poorer on average²². For larger cars, i.e. those that are more inefficient and high CO₂ emitting, some prospective purchasers of new cars will be put off from buying a new car and instead turn to the second hand market. This will in turn increase the demand for larger cars on the second-hand market, and thus increase their prices. This could have an adverse impact on larger, poorer families who rely on the second hand market to buy large cars. On the other hand, some prospective buyers of second hand smaller cars (i.e. those that are fuel efficient and emit less CO₂) might instead choose to buy a new smaller car, which could decrease the demand, and therefore the prices, of smaller, second-hand cars. This could benefit poorer single people or couples, who rely on the second hand market for the purchase of smaller cars.

²² For the UK, research has concluded that 69% of new car buyers are in the AB and C1 demographic groups, i.e. those people in managerial, administrative and professional positions (Lane, 2005).

Additionally, particularly for those cars for which the cost of purchase increases (in absolute terms or relatively speaking), there is the potential for knock-on consequences such as retailers reducing the pre-tax price of cars in order to reduce the impact of any tax increases, as well as for the stimulation of some cross-border purchases in order to avoid the tax increases.

Where changes directly affect the cost of *ownership*, there will be indirect effects on purchasing of a similar, but less significant, extent to those that directly affect the cost of purchase, as described above. However, there is likely to be an opposite, and potentially stronger, direct effect on ownership. The instruments under consideration that directly increase the cost of car ownership will stimulate the ownership of smaller (i.e. more efficient and less CO₂ emitting) cars, which could increase the demand for such vehicles in the second-hand market, which could in turn increase their prices. This would have an adverse impact on poorer single people and couples, who rely on the second-hand market for purchasing smaller cars. Opposite knock-on consequences might be expected for larger, fuel inefficient cars.

Where changes are **revenue-neutral**, there would be some knock-on consequences, such as those discussed at the beginning of this section, that would be similar to those of revenue-increasing instruments, but less in magnitude, as a result of the fact that total costs do not increase. Revenue-neutral instruments should also have no impact on the size of the fleet, as neither purchasing nor ownership will on average become more expensive. However, there are some knock-on consequences that will be more subtle or more pronounced than for revenue-neutral instruments than for revenue-raising instruments, which are discussed below²³.

Where revenue-neutral instruments directly affect the cost of *purchasing* new cars, there is likely to be different knock-on consequences for higher CO₂ emitting and lower CO₂ emitting cars, as there would be an incentive for retaining higher emitting cars for longer (as their costs of purchase would increase), while there would be the opposite incentive for lower CO₂ emitting cars. On the other hand, where a revenue-neutral instrument directly affects the cost of *ownership*, the incentives are likely to be opposite, i.e. older, high emitting cars might be scrapped earlier due to increased costs of ownership, while older low emitting cars might be retained for longer.

Similarly, on average, there is likely to be no knock-on effect of revenue-neutral changes to the second hand car market, but the impacts on lower and higher CO₂ emitting cars might be different. For instruments that target the cost of *purchasing* a car, some people who might otherwise have purchased a new higher CO₂ emitting car might instead turn to the second hand market instead due to the relative increase in the purchase price of new cars. In turn, this would increase the price of higher emitting second hand cars, which could have knock-on consequences on poorer people with large families, who are more likely to buy high CO₂ emitting second hand cars. On the other hand, such changes could persuade those who might have bought a second-hand low CO₂ emitting car to buy a smaller new car instead, which could reduce the second-hand prices of such cars, thus benefiting poorer single people and couples who tend to buy small cars from the second-hand market.

Revenue-neutral changes to instruments that directly target *ownership* experience opposite and potentially conflicting knock-on consequences. The indirect impacts on the *new car market* of changes to the costs of ownerships would have similar, but less significant, knock-on consequences to those described for instruments that directly affect the cost of purchasing. However, an opposite and potentially more significant consequence might be caused by changes in the relative costs of ownership, as people would tend towards buying

²³ For example, revenue-raising instruments are likely to effect smaller, more efficient cars more significantly than larger, inefficient cars, but the effect could still be in the same direction, depending on the extent of the revenue raising.

small cars, as these would be cheaper to own, which could increase the second hand price of these cars. An opposite consequence might be expected for larger cars. In this respect, the social consequences would be similar to, but less than, the equivalent consequences for revenue-raising instruments that target ownership directly.

Any changes that **reduce the revenue received** from either purchase or circulation taxes could increase the size of the fleet as the costs of purchase and/or ownership would decrease on average. However, such a change would be likely to increase the rate of renewal of the fleet and reduce the age of the fleet, particularly for instruments that increase the costs of purchase directly. Revenue-reducing instruments that target the cost of the car *purchase* are likely to lead to older cars being scrapped earlier as a result of the lower cost of car purchasing, although the effect will be less for larger cars (and might even be the opposite for the largest cars if the costs of purchasing these cars do increase). In turn, this is likely to reduce prices (particularly for smaller cars) on the second-hand market, which would be beneficial for the poorest groups in society, who are more likely to rely on this market for their car purchases.

For revenue-reducing instruments that target the costs of *ownership*, on average the lifespan of cars is likely to increase, as the costs of ownership decline (although again the exception might be the largest cars for which the opposite effect might be seen). In turn, this would have positive social impacts on the poorest people who rely on the second-hand market for their car purchases (expect for possibly those large families that buy the largest second-hand cars).

As noted above, decisions relating to the purchase and ownership of other road modes, as well as **vehicles used by other modes**, are likely to be made on a more commercial basis than for cars. Hence, the knock-on consequences resulting from changes in costs are likely to be larger, whichever direction they act. For other road modes, the second-hand market is likely to be mainly used by smaller operators of commercial or public transport vehicles; hence it will be these operators that will be affected within the EU by changes to the taxation structure, rather than the poorer individuals within society. For vehicles used by other modes, a similar argument might apply to some vehicles, but more of the second-hand market is likely to be outside of the EU, which is not covered by this assessment.

3.4 Comparison of 1st and 2nd order impacts on GHG emissions

The first and second order impacts on GHG emissions of the potential knock-on consequences of the instruments being assessed in this section will ultimately be dependent on the level of taxes, incentives, penalties or tax differentials that are introduced, as well as other factors such as oil prices, existing taxation levels and the wider economic situation.

At the high level, a sense of the potential impact of changes to taxation to ownership and use can be drawn from the respective elasticities that have been estimated for the various effects and assume that these elasticities impact on GHG emissions on average in similar orders of magnitude. For example, TIS et al (2002) concluded that the following elasticities applied:

- A 10% decline in registration taxes would lead to an increase in pre-tax prices of 1.1%.
- A 10% increase in annual circulation taxes would lead to a decline in pre-tax prices of 0.1%
- A 10% decline in the retail price would lead to an increase in the demand for cars per capita of 1.1%.
- An increase in annual circulation taxes or registration taxes (expressed as life cycle costs) of 10% could lead to an increase in the age of vehicles by 0.28 years.

This suggests that the level of registration taxes have significantly more influence on car prices, and therefore of demand for cars, than the level of annual circulation taxes. In an assessment of the impact of changes to registration and circulation taxes, the Swedish EPA (2002) used an elasticity of -0.6 based on a review of other studies meaning that a 10% increase in the price of cars would lead to a 6% decline in the car fleet. They also note that their findings were very sensitive to the elasticity chosen.

An idea as to the potential size of the knock-on consequence on car use can be found from a number of studies that have looked into whether there is an impact on energy use of the use of more energy-efficient products, i.e. whether energy use increases as a result of the lower costs of use. This consequence is known as the “rebound effect” and in developed countries has been estimated as being around 10% for personal transport (e.g. UK ERC, 2007) and between 30% to 80% for commercial road transport (e.g. XXX, 2011). More generally, the Breakthrough Institute (2010) suggested that energy price increases are needed to avoid such rebound effects and suggested that if below-cost efficiency measures (i.e. where the pay back is more than the cost) reduce energy intensity by 30%, then avoiding rebound effects (and securing a lasting 30% decline in net energy consumption) would require the imposition of policies to increase energy costs by 30%.

In attempting to estimate the impact on residual value of circulation tax increases, EST (2007) estimated that a 1% increase in the purchase price of a new car in the UK could increase the costs of ownership by 12%. In turn, this could reduce the residual value of the car by an additional 5% over three years.

The first order impact, which is the aim of the instruments, would be reduced CO₂ emissions from the car fleet, as a result of a higher proportion of low CO₂ emitting cars in the car fleet, which has been enabled by, among other things, the development and introduction of CO₂ reduction technologies in their vehicles. As noted above, the impact on CO₂ emissions of such instruments is dependent on a number of different factors. ECN and COWI (2003, in a benchmarking study for the Dutch government) suggested that the CO₂ emissions reductions resulting from the introduction of revenue-raising CO₂ differentiation of vehicle purchase taxation could be between 2% and 3% on the basis of a Dutch scheme, and 1% for a revenue neutral scheme targeting car ownership taxes, on the basis of UK experience. The potential impact on CO₂ emissions of the knock-on consequences (i.e. second order impacts) that were identified in Table 3 will be different depending on whether revenue increases, decreases or stays the same, and whether the instrument targets the purchase of new cars only or the ownership of all cars (see

Table 4).

Table 4: Potential GHG impacts of knock-on consequences identified in Table 3

Behaviour and cars affected:	Purchase of new cars only	Ownership of all cars
Increasing revenue	<p>Size of fleet:</p> <ul style="list-style-type: none"> Short-term: CO₂ emissions decline, as fleet size declines Long-term: CO₂ emissions begin to rise, as fleet grows again (due to reduced costs of use) <p>Composition of fleet (short-term):</p> <ul style="list-style-type: none"> CO₂ emissions increase as fleet turnover declines and older cars retained for longer <p>Use of cars:</p> <ul style="list-style-type: none"> CO₂ emissions increase, as use increases and driving styles become less fuel efficient 	<p>Size of fleet:</p> <ul style="list-style-type: none"> Medium-term: CO₂ emissions decline, as fleet size declines Long-term: CO₂ emissions begin to rise, as fleet grows again (due to reduced costs of use) <p>Composition of fleet (short-term):</p> <ul style="list-style-type: none"> CO₂ emissions increase as fleet turnover declines, but... CO₂ decrease as a result of reduced car life spans <p>Use of cars:</p> <ul style="list-style-type: none"> CO₂ emissions increase, as use increases and driving styles become less fuel efficient
Revenue neutral	<p>Size of fleet:</p> <ul style="list-style-type: none"> Short-term: No impact on CO₂ emissions, as no change in fleet size Long-term: CO₂ emissions begin to rise, as fleet grows again (due to reduced costs of use) <p>Composition of fleet (short-term):</p> <ul style="list-style-type: none"> CO₂ emissions increase as larger, less fuel efficient cars retained for longer <p>Use of cars:</p> <ul style="list-style-type: none"> CO₂ emissions increase, as use increases and driving styles become less fuel efficient 	<p>Size of fleet:</p> <ul style="list-style-type: none"> Short-term: No impact on CO₂ emissions, as no change in fleet size Long-term: CO₂ emissions begin to rise, as fleet grows again (due to reduced costs of use) <p>Composition of fleet (short-term):</p> <ul style="list-style-type: none"> CO₂ decrease as a result of reduced car life spans for larger, less fuel efficient cars <p>Use of cars:</p> <ul style="list-style-type: none"> CO₂ emissions increase, as use increases and driving styles become less fuel efficient
Decreasing revenue	<p>Size of fleet:</p> <ul style="list-style-type: none"> Short-term: CO₂ emissions decline, as fleet size increases Long-term: CO₂ emissions continue to rise, as fleet continues to grow (due to reduced costs of use) <p>Composition of fleet (short-term):</p> <ul style="list-style-type: none"> CO₂ emissions decrease as more new efficient cars in the fleet and older cars scrapped earlier <p>Use of cars:</p> <ul style="list-style-type: none"> CO₂ emissions increase, as use increases and driving styles become less fuel efficient 	<p>Size of fleet:</p> <ul style="list-style-type: none"> Medium-term: CO₂ emissions decline, as fleet size increases Long-term: CO₂ emissions continue to rise, as fleet continues to grow (due to reduced costs of use) <p>Composition of fleet (short-term):</p> <ul style="list-style-type: none"> CO₂ emissions decrease as more new efficient) cars in the fleet, but... CO₂ emissions increase as result of increased life spans <p>Use of cars:</p> <ul style="list-style-type: none"> CO₂ emissions increase, as use increases and driving styles become less fuel efficient

For *revenue raising* instruments targeting car *purchasing*, a reduction in the size of the fleet could be expected to deliver CO₂ reductions. On the other hand, there are knock-on consequences that potentially increase CO₂ emissions, including the slower turnover of the

fleet, older cars being retained for longer and cars being used more. The latter could reduce the anticipated savings by around 10% (see above), which might cancel out the potential reductions delivered by reduced fleet size. Overall, therefore, it might be concluded that, in the short-term, the CO₂ impacts of the knock-on consequences with respect to revenue raising taxes on car purchasing could cancel each other out, as long as the impacts of the slower turnover of the fleet and older cars being retained for longer have together less than half of the impact of increased car use, which is possible as it is likely that these effects will be smaller as they impact on a small proportion of the fleet. In the longer-term, the increased size of the car fleet resulting from lower costs of use might begin to negate the emissions reductions from the instruments.

For *revenue raising* instruments targeting car *ownership*, CO₂ emissions reductions from knock-on consequences arise from two potential sources: a reduction in the size of the fleet; and a decrease in the lifespan of older, more polluting vehicles. On the other hand, CO₂ emissions would increase from the knock-on consequences of lower fleet turnover and the increased use of cars, which could be in the order of 10% of the first order impacts, as noted above. Given the significantly lower impact on demand of circulation taxes, it is likely that these second order CO₂ increases would more than cancel out the decreases.

For *revenue-neutral instruments*, the lack of further CO₂ emissions reductions from reductions in fleet size, lessen the chances that the impacts on CO₂ emissions of the knock-on consequences would cancel each other out for instruments that focus on purchasing and would increase the CO₂ increases from instruments focusing on ownership. For instruments targeting car *purchasing*, all of the knock-on consequences would act to increase CO₂ emissions, either in the short- or longer-term, hence for such instruments the knock-on consequences would erode the first order CO₂ reduction benefits. For instruments targeting car *ownership*, the negative will be less, as there one knock-on consequence, that of shorter life spans for older, less efficient cars, acts to reduce emissions, but this probably does not negate the impacts of the consequences that increase CO₂ emissions.

For instruments that *reduce revenues*, the picture is likely to be more negative than for revenue-neutral instruments, as these instruments also act to increase CO₂ emissions by increasing the size of the car fleet.

For other road modes and vehicles used by **other transport modes**, which are likely to be operated on a more commercial basis, it is likely that the mechanisms will be the same, but that the impacts will be larger, e.g. the higher estimated rebound effect for commercial road transport noted above.

3.5 Comparison of impacts on costs and cost effectiveness

There are a number of potential costs associated with the implementation of the instruments under consideration, e.g. costs to:

- **Manufacturers**, whose costs **will increase** compared to the baseline, as the instruments stimulate the purchase and ownership, and therefore development and production, of cars that emit less CO₂, which will have more expensive, CO₂ reducing technologies fitted. Generally speaking, manufacturers' costs will increase as CO₂ emissions reductions, i.e. the benefits of the instruments, increase.
- **Government**, whose costs **will decrease, stay the same or increase**, depending on whether the instruments are revenue increasing, revenue neutral, or if revenue declines. Additionally, there are likely to be some administrative costs associated with the changes, which could be taken into account when designing the instruments, e.g. to ensure overall neutrality if this is the aim.

- **Society**, who *will lose some welfare benefits*, as cars are likely to be smaller on average, and where instruments, such as those that increase revenues, lead to fewer cars.
- **Drivers**, whose costs of:
 - Purchase and ownership would *increase, not be affected* or *reduce*, depending on whether revenues increase, remain the same or decrease.
 - Use would *decline*, as a result of savings caused by improved fuel efficiency.

Against these costs, it is important to note that the CO₂ reductions delivered would bring general benefits to society as a whole, as well as co-benefits, particularly in the form of reduced emissions of air pollutants.

In relation to the cost-effectiveness of the various instruments, ECN and COWI (2003) concluded that the cost-effectiveness of such instruments varies, while ECMT (2007), on the basis of having reviewed Swedish EPA (2002), concluded that tax differentiation is only cost effective if introduced in a revenue-neutral fashion due to the negative impacts identified on the age of the fleet and the welfare losses²⁴. However, as noted above, the impacts on CO₂ emissions, and therefore likely cost-effectiveness, is sensitive to the various elasticities used.

3.6 Conclusions

This section has shown that there are potentially a number of knock-on consequences, i.e. second order impacts, that result from the introduction of instruments that aim, either directly or indirectly, to stimulate the uptake of more fuel efficient/less CO₂ emitting vehicles, e.g. knock-on consequences on the:

- Size of the fleet.
- Composition of the fleet.
- Use of cars.
- Design of cars.
- Second-hand market.
- Different social groups.
- 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 will 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.

²⁴ Swedish EPA (2002) assumed an elasticity of -0.6 for the impact of car prices on fleet size.

For revenue-neutral instruments, there are often no consequences on average, but consequences differ in their effects on smaller, more efficient cars and larger, more inefficient cars. For instruments targeting purchasing, larger cars will be retained for longer, thus potentially increasing 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, 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 sizes 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 elasticities used.

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 (e.g. see Skinner et al, 2010).

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4 Vehicle CO₂ legislation

Objectives:

- Explore likely knock-on consequences, for the vehicle fleet, of vehicle CO₂ legislation
- Order of magnitude estimates with respect to the impacts at fleet level for the relevant knock-on consequences
- Where possible, order of magnitude estimates with respect to the impact of relevant knock-on consequences on cost effectiveness of GHG mitigation instruments

Summary of Main Findings

- ⇒ The 130 g/km target for 2015 is likely to generate negative knock-on consequences or rebound effects, reducing its intended effect and very likely its cost-effectiveness
- ⇒ Most likely the 95 g/km target will lead to small but net positive knock-on consequences enhancing the effect and effectiveness of the legislation
- ⇒ 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

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

4.1 Introduction

Knock-on consequences of vehicle CO₂ legislation, in the context of this paper, are defined as implications of the "existing EU legislation on the CO₂ emissions of new passenger cars" on composition and usage of the vehicle fleet.

Some knock-on consequences have been identified in the course of the studies and transport model assessments that have been carried out on this topic. An important source is the REMOVE calculations that have been performed in support of the development of the legislation. An important issue will be trying to ensure that the impacts from the CO₂ legislation can be decoupled from that of national fiscal measures.

In line with what has been agreed with the Commission in the Inception Report for this project, this chapter focuses on possible knock-on consequences of the CO₂ legislation for cars and light commercial vehicles with targets set for 2015 and 2020. Some attention will also be paid to the CO₂ legislation for heavy duty vehicles, for which exploratory studies are now being undertaken, and possible longer-term options for CO₂ legislation of road vehicles.

4.2 Identification of main knock-on consequences related to CO₂ legislation

4.2.1 Identification of main mechanisms leading to knock-on consequences from CO₂ legislation

The following paragraphs will qualitatively describe the mechanisms underlying a number of possible knock-on consequences of the CO₂ legislation for cars.

Knock-on consequences in the context of CO₂ legislation, aimed at reducing the average type approval CO₂ emissions of cars, are defined as 2nd order effects that increase or decrease the net relative reduction in overall, real-world CO₂ emissions compared to the

relative reduction in emissions per kilometre at the vehicle level as measured on the type approval test. The main mechanisms for knock-on consequences of CO₂ legislation, as analysed in this chapter, are:

- impacts of changes in vehicle price and fuel costs per kilometre on purchasing behaviour, vehicle usage and overall transport demand;
- 2nd order impacts on the net effect on CO₂ emissions resulting from manufacturer' responses to the CO₂ legislation;
- impact on CO₂ emissions resulting from changes in the ratio of real world emissions over type approval.

4.2.2 2nd order impacts on other aspects than CO₂

CO₂ legislation may not only have 1st and 2nd order impacts on the CO₂ emissions of transport, but may also influence the safety of transport and its impacts on e.g. local air quality and accessibility. Within the context of this paper these are not considered knock-on consequences in the strict meaning of the word but are rather qualified as ancillary benefits or rebounds. For completeness sake, however, they are briefly discussed here. A more elaborate assessment of co-benefits is worked out in Task 1.

Knock-on consequences with respect to pollutant emissions

As discussed in section 4.3.1, CO₂ legislation may result in a shift between sales of petrol and diesel vehicles. This will have impact on the fleet average pollutant emissions, specifically NO_x and PM. Real-world emissions of Euro 5 diesel passenger cars or vans are 10 times higher than those of equivalent petrol vehicles. With Euro 6 the NO_x limits for passenger cars and vans on petrol and diesel will become almost the same (0.06 vs. 0.08 g/km), and the Euro 6 legislation is also expected to contain a number of provisions to better control real-world emissions. Due to lack of available test vehicles and measurement results, the ratio of real-world NO_x emissions for Euro 6 diesel and petrol vehicles is not yet known, but it is expected that a factor of 3 will still be possible. With respect to PM differences between petrol and diesel will also become smaller, but in this case this is due to the increased PM emissions of petrol vehicles using direct injection engines.

Besides impacts through the sales ratio of petrol and diesel vehicles, impacts on air pollutant emissions may also result from the choice of technologies that are used to meet the targets set by the CO₂ legislation. Engine related measures may improve or reduce the effectiveness of certain exhaust aftertreatment and other emission reduction technologies. Power train hybridisation leads to reduced dynamics in the engine load, which generally improves the effectiveness of emission reduction technologies. This may be used to achieve lower emissions or to cut costs on applied emission reduction technology.

If measures to reduce CO₂ emissions lead to decreased effectiveness of exhaust emission reduction technologies, these technologies will be adjusted to make sure that on the type approval test the applicable Euro standards are still met. But the impact on real-world emissions depends on the intricate interplay between applied technologies in dependence on the real-world driving loads.

Knock-on consequences with respect to safety

Effects of using lightweight materials

The consequence of using mass as a utility parameter for the 130 g/km target is that mass reduction as a technical option for reducing CO₂ emissions of cars is not strongly rewarded. At the same time advanced mass reduction options, specifically in body-in-white through application of lightweight materials, are relatively expensive and are not necessary for reaching the 130 g/km target in 2015. For the 95 g/km target set for 2020 and possible further reduced targets beyond 2020 applying lightweight materials is expected to become an

important reduction option. In recent years the use of aluminium and fibre reinforced composites has already increased, especially in higher end models. The cost of manufacturing using carbon fibre composites appears to be going down fast.

The widespread application of advanced weight reduction, and specifically the use of new materials, may have significant impacts on the body structure of future vehicles. These in turn may have implications on safety, or on the passive and active safety measures required to meet crash safety standards. Lighter vehicles lead to less energy to be absorbed in the case of collisions. This may have positive impacts on safety.

Effects of a shift towards smaller cars

In section 4.3.1, under point 2, shifting sales towards smaller cars is mentioned as a possible compliance mechanism in response to CO₂ legislation. If it is believed that smaller cars are less safe, then a manufacturer strategy of moving sales towards smaller vehicles might reduce overall safety at least in the short term. Over the longer term, when the whole fleet downsizes, small vehicles will be less likely to encounter larger vehicles so that safety will be less compromised.

4.3 Exploration of knock-on consequences of CO₂ legislation for LD vehicles in the 2010-2020 period

4.3.1 Knock-on consequences resulting from changes in vehicle purchase price and usage costs

Estimated impacts of the CO₂ legislation for passenger cars on average vehicle prices and fuel costs

Assessments by TNO and various partners underlying the design of the CO₂ legislation²⁵ are all carried out under the assumption that the legislation in 1st order has no impact on the sales portfolio of manufacturers, specifically with respect to the distribution of sales over models in different segments and over different variants of models on offer. This means that for the calculated costs for meeting the target it is assumed that the required CO₂ reductions are all realised by applying efficiency improving / CO₂ reducing technologies to the cars. Application of these technologies leads to additional manufacturing costs, and thus a price increase relative to the autonomous price development in a baseline situation without the CO₂ legislation. At the same time the CO₂ reduction measures applied translate into reduced fuel consumption and thus lower running costs for the vehicle user.

According to the engineering estimates made in [IEEP/CE Delft/TNO 2007], application of efficiency improving technology in response to the current CO₂ legislation for passenger cars (130 g/km in 2015) leads to an average retail price increase per car of around € 1100 (equivalent to 5% of the retail price in 2006, when the sales average CO₂ emission was around 160 g/km). The average net present value of the lifetime fuel cost savings²⁶ compared to the 2006 reference situation is € 2240 at a fuel price²⁷ of 1 €/litre or € 3460 at a fuel price of 1.5 €/litre, which is around the current average price at the pump in Europe. The impact on vehicle retail price is thus significant but more than outweighed by the lifetime fuel cost savings, resulting in a net decrease in total cost of ownership.

A detailed assessment of the impacts of the 95 g/km target for 2020 is currently being undertaken²⁸. Final results are not yet available, and obviously depend on the modalities for implementing the 95 g/km target, including the chosen utility parameter and details of the utility-based limit function. Preliminary indications of the cost impacts, from work in the on-

²⁵ -See [TNO/IEEP/LAT 2006] and [IEEP/CE/TNO 2007]

²⁶ Assuming a vehicle lifetime of 13 years, annual mileage of 16,000 km, an RW/TA value of 1.195 and an discount rate of 4%

²⁷ EU average for petrol and diesel

²⁸ Service request #1 "Support for the revision of Regulation (EC) No 443/2009 on CO₂ emissions from cars" under the Framework Contract on Vehicle Emissions (Contract No ENV.C.3./FRA/2009/0043), carried out by a consortium led by TNO

going project, are that the average manufacturer costs per vehicle for meeting 95 g/km will be higher than for the previous step. The cost curves for CO₂ reduction in passenger cars through application of efficiency improving technology show strong non-linearity. As a result the marginal costs increase for every additional g/km emission reduction, leading to longer payback times and reduced cost effectiveness. In view of this, preliminary indications are that for the reduction from 130 g/km to 95 g/km the payback time will be longer than for the 130 g/km target, and depending on the fuel price this could even exceed the vehicle lifetime. In the latter case the impact on the TCO per kilometre is a net increase.

It should be noted that the increases in purchase price estimated in the above-mentioned studies is relative to a business-as-usual baseline scenario. This baseline contains price developments that may or may not continue in the presence of CO₂ legislation. In general vehicle prices are affected by a multitude of factors, including:

- learning effects and innovations in production processes reducing the production costs of vehicles;
- relocation of production facilities reducing the production costs of vehicles;
- competition between brands in a market characterised by overcapacity in production facilities, putting pressure on prices and influencing cost pass-through levels for application of new technologies;
- application of new comfort or performance enhancing technologies and accessories leading to increases in production costs.

Especially the latter aspect provides room for influencing net price developments in response to CO₂ legislation. If powertrain costs increase due to legislation, net vehicle costs can be kept constant by postponing the application of new new comfort or performance enhancing features. This means that application of efficiency improving technologies does not necessarily lead to an observable net increase in consumer prices. As a result the knock-on consequences of CO₂ legislation the effects of lower fuel costs per kilometre are not necessarily (partly) counteracted by the impact of increased sales prices on purchasing behaviour.

Qualitative description of mechanisms

CO₂ legislation for road vehicles results in changes in fuel consumption as well as other vehicle characteristics and will affect vehicle purchase price and usage costs. The application of technical measures to improve a vehicle's energy efficiency result in an increase of the production costs, leading to an increased sales price, and a reduction in the energy costs per kilometre driven. These changes are likely to lead to 2nd order impacts on purchasing behaviour as well as vehicle usage.

Depending on e.g. the size of the cost implications these knock-on consequences may be positive or negative. Positive knock-on consequences enhance the CO₂ emission reduction caused by the legislation compared to what would be achieved without changes in fleet composition and usage or reduce the overall costs of achieving a given level of CO₂ emission reduction. Both effects improve the cost-effectiveness of the policy measure. Negative knock-on consequences, or “rebound effects”, on the other hand reduce the CO₂ emission reduction caused by the legislation compared to the situation with without changes in fleet composition and usage or increase the overall costs of achieving CO₂ emission reductions, leading to reduced cost-effectiveness of the policy measure.

Depending on additional purchase cost and the reduced fuel costs associated with the CO₂ reduction the following knock-on consequences may occur:

- a. more/less people buying new cars*
- b. people buying larger/smaller cars*
- c. shifts in sales between petrol and diesel*

- d. *people driving more/less per car*
- e. *net increase/decrease in demand for car transport*
 - *reflected as the combined effect of effects a. and d. on new vehicle sales plus the impact on the composition and usage of the fleet of existing vehicles*

The magnitude of these knock-on consequences is strongly influenced by fuel price developments as well as by fiscal systems, specifically fiscal incentives for buying fuel efficient cars.

The overall mechanisms leading to knock-on consequences are sketched in Figure 6. Mechanisms involving a shift in sales between petrol and diesel are excluded from the graph, but are fairly similar.

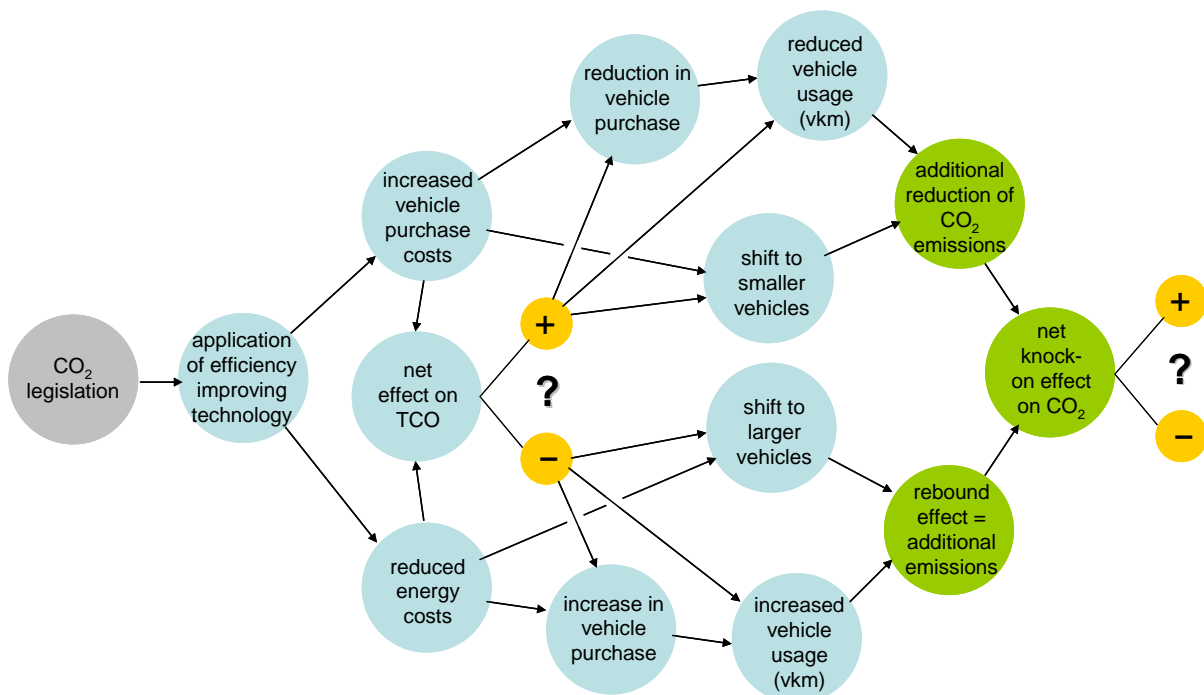


Figure 6 Mechanisms through which changes in vehicle price and usage costs resulting from CO₂ legislation lead to knock-on consequences with respect to the net CO₂ emission reduction (impacts through fuel switch are excluded for sake of simplicity)

The impact of purchase price increase and a decrease in fuel cost per kilometre on purchasing behaviour is complex. Consumers respond to purchase price changes as well as to changes in the total cost of ownership. Private car buyers tend to undervalue savings in the longer term. This is known as “consumer myopia”. Therefore the lifetime fuel cost savings need to be significantly higher than the price increase to motivate consumers to buy a fuel efficient model. An increase in sales price may already motivate people to buy a smaller car even when the application of efficiency improving measures leads to a strong reduction of the total costs of ownership (TCO). For lease companies and fleet owners, which tend to have a more rational evaluation of the total cost of ownership, the mechanisms described in this section will work out differently.

A shift to smaller or larger cars as a result of CO₂ legislation is not only caused by the (average) impact on purchase price and usage costs, but also on the distribution of price increases over different size segments. Assuming full and even cost pass-through, the [IEEP/CE Delft/TNO 2007] predicts that the 130 g/km target leads to higher relative price increases for larger vehicles. In reality, however, the price changes are not only determined

by the cost-optimal distribution of reduction measures over different vehicle classes, but also on the cost pass-through and pricing strategies adopted by manufacturers.

Not included in Figure 6 is the impact on the fuel choice. If the price differential between petrol and diesel vehicles or the difference in fuel consumption change due to CO₂ legislation this may shift sales from one fuel to the other. Assuming full and even cost pass-through, the [IEEP/CE Delft/TNO 2007] predicts that the 130 g/km target leads to a higher relative price increase for petrol than for diesel vehicles. At the same time the relative efficiency improvement in petrol cars is also larger. Also here prices may not follow costs as a result of strategic pricing by manufacturers.

If the net knock-on consequences are determined by a "detailed balance" of large positive and negative effects, accurate prediction of the net effect depends more heavily on accurate assessment of the detailed mechanisms. An ex-ante assessment can be used to predict changes in vehicle manufacturing costs, as is done in the [TNO/IEEP/LAT 2006] and [IEEP/CE/TNO 2007] studies, but actual effects of CO₂ legislation on prices for different models, segments, fuel types, etc. are difficult to forecast and may be very different from the underlying changes in costs. Prices are determined by manufacturers, taking into account detailed considerations on the market and the competitive position of their models in that market. Furthermore prices are heavily influenced by fiscal regimes.

Rebound effects

If the combination of price increase and reduced running costs resulting from improving the energy efficiency of cars is such that the real or perceived costs of owning a car go down, this may lead to rebound effects in terms of increased sales of new cars, a possible shift to larger cars and an increase in car use. This will certainly happen if the efficiency improvement is achieved without a significant effect on the price of vehicles.

Over the last years various authors have been raising attention to rebound effects of climate policies in general. In literature on the subject the rebound effect in passenger car transport is one of the better studied examples.

According to [de Haan, 2006] and [Berkhout, 2000] one can distinguish three different types of rebound effects:

- increased demand for the same service as it has become cheaper (direct rebound effect), in the case of cars: people buying more cars and driving more kilometres;
- increased demand for other services as money (i.e., purchasing power) has become available (indirect rebound effect; also called secondary rebound effect), in the case of cars: people using the savings on driving costs to pay for a holiday to the Bahama's or for purchasing other energy consuming products or services;
- structural effects on larger parts of the economy due to changed demand, production and distribution patterns (macro-scale rebound effect; also called economy-wide or tertiary rebound effect).

Other sources (see e.g. [UKERC, 2007] and [Sorrell, 2009]) propose a slightly different categorisation, in which the substitution effects, above indicated as secondary rebound effects, are considered part of the direct rebound effects. This is illustrated in Figure 7.

In the assessment of rebound effects many studies focus on the impact of costs on energy consumption in road transport only. Part of the rebound effect, however, may be a shift from other modes of transport (e.g. slow modes or public transport) to car transportation. In assessing the total impact on CO₂ emissions the reduced demand for other modes should be taken into account. Conversely, if the change in costs of car transport lead to a modal shift towards other modes of transport, the increased emissions from these modes should be accounted for as knock-on consequences.

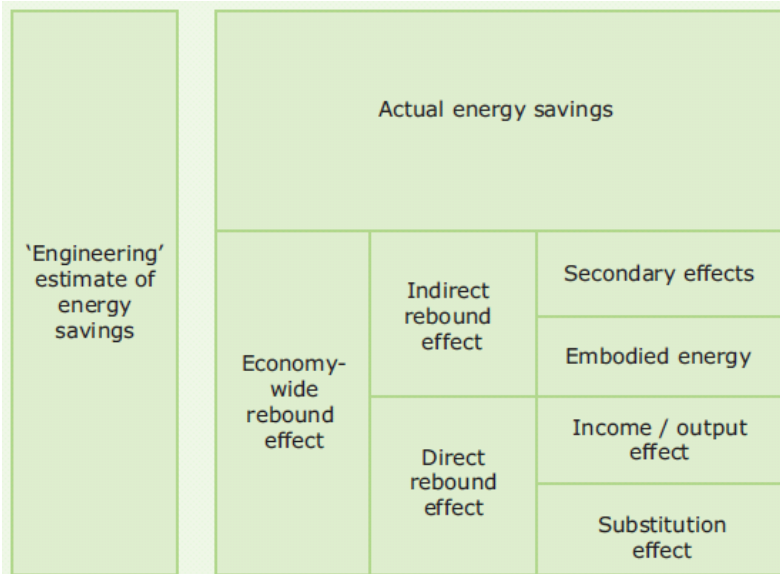


Figure 7 Categorisation of direct and indirect rebound effects [UKERC, 2007]

[Sorrell, 2009] discusses rebounds starting with Jevons' Paradox, already formulated in 1865 based on observations regarding efficiency improvements in steam engines, which implies that all economically justified energy-efficiency improvements will increase energy consumption above where it would be without those improvements. Jevons' Paradox thus claims that the economy-wide rebounds of increasing the energy efficiency of a given product or service actually outweigh the direct gains of reduced energy consumption due to product improvements. This level of rebound is also referred to as "back-firing". The main conclusion from [Sorrell, 2009] is that evidence to support such a strong claim does not (yet) exist, but that the existing evidence does show that rebounds can significantly reduce the net overall benefits of efficiency improvements. Or as the paper states: "Arguing that the economy-wide rebound effect is greater than zero is different from arguing that it is greater than one – as Jevons' Paradox suggests."

[Sorrell, 2009] suggests that it is possible that the rebound effects may not follow for "energy-efficiency improvements in mature and/or non-energy-intensive process technologies, producing goods that have a relatively narrow range of applications." The first part of this suggestion can be interpreted as applying to saturated markets, where cost reductions do not lead to increased consumption within that market. This may indicate that the size of the rebound effects from improving energy efficiency of cars may be country-specific, depending on the maturity of the passenger car market in different countries. For the case of the European Union this may mean that rebound effects could be more substantial in Eastern European countries where car ownership and use are still catching up to reach the levels seen in Western European countries. Obviously second order rebounds may still take place through increased consumption in other markets as a consequence of the increased disposable income resulting from cost effective efficiency improvements in cars. Similarly, [Sorrell, 2009] suggests that rebound effects "may also not follow from improvements in consumer technologies that supply energy services with a low own-price elasticity and where energy represents only a small share of total costs". This, however, seems not to apply to the lion's share of activities in the transport sector.

An interesting aspect of rebound effects, mentioned in [de Haan, 2006], is that for the case of fuel efficient vehicles economic costs may not be the only driver for rebound effects. The reduction of socio-psychological costs of ownership might also have this effect. Neighbourhood pressure and norms of a peer group may prevent some people from buying sport-utility vehicles (SUVs). This could change when SUVs with hybrid powertrain –which green up the image of SUVs– enter the market.

Rebound effects may depend on the drivers that induce application of energy efficiency improving measures

For existing efficiency-improving or CO₂-reducing measures, which are cost-effective but nevertheless not (fully) applied, apparently the net economic benefits do not outweigh certain disadvantages. An increase in energy prices may stimulate increased application of these technologies. At the margin these cost-effective options then do not lead to a net cost reduction, with possible rebound effects as a consequence, but merely help to avoid increasing energy cost. As far as rebound effects from applying energy efficient vehicles are concerned, therefore a distinction needs to be made between the different types of mechanisms that induce application of these CO₂ reduction options.

If cost-effective options are taken up autonomously, i.e. in the absence of economic incentives such as energy price increases or fiscal stimulation, their uptake is induced by the lower costs and they will thus lead to net cost savings which are likely to directly or indirectly induce rebound effects. The same is true if the use of cost effective options is "enforced" through regulation (e.g. CO₂ standards) and even more so if fiscal stimulation policies increase overall cost reduction at the user level.

If, on the other hand, the use of efficiency improving options is promoted by fiscal incentives or other economic instruments that increase the price of energy or more generally of vehicle usage, their uptake helps to (partly) avoid an increase in net costs, but does not lead to a net reduction in usage costs and therefore not to rebound effects. In fact, if the uptake of fuel efficient technology is such that it does not totally compensate the cost increases resulting from the fiscal incentives (or the energy price increase), the resulting increase in net costs will lead to positive knock-on consequences in the form of e.g. reduced vehicle usage, which further enhance the impact of the policy instrument on energy use and CO₂ emissions.

The above reasoning can also be found in [UKERC, 2007]. According to this study rebound effects may be mitigated through carbon/energy pricing – whether implemented through taxation or an emissions trading scheme. [UKERC, 2007] states that carbon/energy pricing can reduce direct and indirect rebound effects by ensuring that the cost of energy services remains relatively constant while energy efficiency improves. As such, carbon/energy pricing needs to increase over time at a rate sufficient to accommodate both income growth and rebound effects, simply to prevent carbon emissions from increasing. It needs to increase even more rapidly if a net reduction in emissions is to be achieved. In line with conclusions from the previous GHG 2050 project²⁹, [UKERC, 2007] furthermore concludes that policy mix is required to reach decarbonisation goals effectively. Carbon/energy pricing may be insufficient on its own, since it will not overcome the numerous barriers to the innovation and diffusion of low carbon technologies and could have adverse impacts on income distribution and competitiveness, while similarly policies to address market barriers may be insufficient, as rebound effects could offset much of the energy savings.

An interesting parallel can be found in measures to reduce congestion, as also stated in [Hymel 2010], which claims that any policy that reduces congestion without otherwise making driving more expensive, will tend to attract new traffic that at least partially offsets the policy's effect on congestion. Increasing road capacity by means of constructing additional lanes or new highways leads to reduced travel times in the short term, but in the longer term reduced travel time induces demand leading to increased road use. Several years after the increase in capacity traffic intensities are often back to a level that results in similar congestion levels and travel times as before the measure was taken. Road pricing on the other hand leads to a net reduction in demand, which also results in less congestion and reduced travel times. As this reduction takes place at the margin, i.e. those trips are avoided for which the cost increase exceeds the existing consumer surplus (difference between benefits and costs of

²⁹ See Chapters 3 and 5 of "Towards the decarbonisation of the EU's transport sector by 2050", main report of the project "EU Transport GHG: Routes to 2050?", <http://www.eustransportghg2050.eu/cms/assets/EU-Transport-GHG-2050-Final-Report-22-06-10.pdf>

the trip), the reduced travel time is not expected to affect trips which have a consumer benefit that is far larger than the cost increase resulting from the road pricing. As a consequence road pricing is expected to have a remaining impact on congestion and accessibility.

As far as fiscal policies are concerned, the above reasoning applies to impacts within the transport sector. The total impact on energy consumption and CO₂ emissions, however, obviously also depends on the way in which net increases or decreases in government revenue, as resulting from the fiscal policies, are compensated in the economy.

Knock-on consequences on the fuel mix

The Cars & CO₂ legislation is expected to affect petrol and diesel cars differently. The relative price increase of petrol vehicles is likely to be higher than that of diesels, due to the larger potential for cost effective reductions in petrol vehicles. Diesel vehicles already all have very efficient DI engines. DI petrol engines have become available in recent years but their fleetwide application of is one of the expected responses to the CO₂ legislation. As a result the costs curves for diesel vehicles are steeper. Therefore the average costs per g/km reduction will be lower for petrol than for diesel. This may cause a shift from diesel to petrol, especially in the period up to 2015. Beyond 2015 the marginal costs for further CO₂ reductions in petrol and diesel vehicles will have become more comparable.

A shift from diesel to petrol or the other way around is determined by the development of vehicle prices in combination with fuel consumption and fuel prices. This means that tax regimes in Member States have a significant impact. It also means that possible positive or negative knock-on consequences on cost effectiveness from a societal point of view can not be judged a priori.

Qualitative evaluation of the 130 g/km and 95 g/km targets

Based on the 1st order impacts of the CO₂ legislation for passenger cars on average vehicle prices and fuel costs, as summarised at the beginning of this section, one expects the following 2nd order effects to take place in response to the 130 g/km target for 2015:

<i>Effect of 130 g/km (rel. to 160 g/km in 2006)</i>	<i>Impact on CO₂ emission reduction</i>
- Increased purchase costs lead to:	
o Shift towards smaller vehicles	+
o Reduced demand for vehicles	+
- Reduced fuel costs per km lead to:	
o Increased vehicle use	-
- Reduced total cost of ownership per kilometre leads to:	
o Shift towards larger vehicles	-
o Increased demand for vehicles	-
o Increased vehicle use	-
=====	
- Net effect, based on qualitative reasoning	-

Given the payback time of 5 to 6 years for the required CO₂ reduction measures one might expect the 130 g/km target to lead to net negative knock-on effects, i.e. a rebound that reduces the net GHG impact of the policy compared to the 1st order engineering estimate.

<i>Effect of 95 g/km (rel. to maintaining 130 g/km up to 2020)</i>	<i>Impact on CO₂ emission reduction</i>
- Increased purchase costs lead to:	
o Shift towards smaller vehicles	+
o Reduced demand for vehicles	+
- Reduced fuel costs per km lead to:	
o Increased vehicle use	-

- Lower or higher total cost of ownership per kilometre (depending on fuel price) leads to:	
o Small shift towards larger resp. smaller vehicles	-/+
o Small increase resp. decrease in demand for vehicles	-/+
o Small increase resp. decrease in vehicle use	-/+
=====	
- Net effect, based on qualitative reasoning	+

The impact through changes in TCO depends heavily on the fuel price. At present fuel prices the payback time for the applied technologies is around 10 years, but this increases to values that may even exceed the vehicle lifetime when fuel prices are lower. Given the above discussed "consumer myopia" one would expect that TCO reductions with a payback time of 10 years still lead to positive feedbacks by reducing vehicle use and the demand for vehicles. Due to the much longer payback time for the CO₂ reduction measures needed to make the step from 130 g/km to 95 g/km, one might thus expect the 95 g/km target to lead to net positive knock-on effects compared to the situation in which 130 g/km is maintained, i.e. 2nd order impacts that enhance the net GHG impact of the policy compared to the 1st order engineering estimate.

Available quantitative information

Information from literature on rebound effects

[Sorrell, 2009] states that at constant energy prices, improved energy efficiency leads to reduced costs per kilometre driven. This leads to increased demand for transport. Whether it leads to a net increase or decrease in the energy demand for transport depends on the price elasticity of kilometres driven with respect to the costs per kilometre driven.

[de Haan, 2006] uses surveys of Toyota Prius buyers in Switzerland to assess the size of possible rebounds of fuel efficient cars with respect to specifically the shift towards larger vehicles and the increase in car ownership. Results of the survey do not show significant rebound effects of this nature.

A review of 17 existing studies, as carried out in [UKERC, 2007] suggests that the long-run direct rebound effect for personal automotive transport lies somewhere between 10% and 30%. According to [UKERC, 2007], the relative consensus on estimates, despite wide differences in data and methodologies suggests that the findings are relatively robust. The conclusions are largely based on evidence from the US but available European studies are found not to show significantly different results.

Most of the studies reviewed in [UKERC, 2007] are found to assume that the response to a change in fuel prices is equal in size to the response to a change in fuel efficiency, but opposite in sign. Few studies test this assumption explicitly and those that do are either unable to reject the hypothesis that the two elasticities are equal, or find that the fuel efficiency elasticity is less than the fuel cost per kilometer elasticity. The implication of that, according to [UKERC, 2007], is that the direct rebound effect may lie towards the lower end of the above range. Moreover, partly based on evidence from earlier research by the authors of [Hymel 2010], [UKERC, 2007] expects the direct rebound effect to decline in the future as demand saturates and income increases.

[UKERC, 2007] furthermore concludes that there are relatively few quantitative estimates of the indirect and economy-wide rebound effects, but several studies are found to suggest that economy-wide effects may exceed 50%.

An econometric analysis of time series data across a long period from various US states, reported in [Hymel 2010], concludes that the estimate of the average rebound effect across the states and years in our sample, stated as a positive percentage, is 4.7% in the short run and 24.1% in the long run. In other words: the short- and long-run VMT elasticities with respect to fuel cost are -0.047 and -0.241. The effect is found to declines drastically in

magnitude over the duration of the sample analysed in [Hymel 2010], due mainly to rising real incomes. The effect is found to rise in magnitude with fuel costs.

[Hymel 2010] furthermore states that the responsiveness of travel to fuel prices or to fuel-efficiency regulations will be dampened to a smaller or lesser extent by the additional congestion it creates. The magnitude of rebound effects may thus depend on the level of congestion present.

According to [Nässén, 2009] the total rebound effects (price and income effects) of energy efficiency improvements appear to be in the range of 5–15% in most cases, but these results are sensitive to assumptions on energy service price elasticities. Cases with low or negative capital costs for energy efficiency may result in much higher rebound effects as the income effect becomes more important. As an example, [Nässén, 2009] states that the choice to buy a smaller car may save both fuel and capital costs which give room for increasing consumption of other goods and services and, hence, high rebound effects. At the other extreme, environmentally driven early adoption of new technologies (e.g. as a result of CO₂ legislation) may in fact be rather costly, resulting in reduced consumption of other goods and services and, hence, low rebound effects.

From the studies cited here it is generally not clear whether or to what extent the efficiency improvements observed in the analysed data are accompanied by vehicle retail price increases related to the application of technical innovations that enable these efficiency improvements. It is therefore not entirely clear how the conclusions should be translated to the case of the EU CO₂ legislation.

Insight from literature on price elasticities

As part of an on-going service contract to DG CLIMA [TML/CE Delft, 2011]³⁰ reviews literature on elasticities in order to assess possible rebound effects of improved fuel efficiency. The central assumption is that the impact of reduced fuel cost per kilometer, resulting from efficiency improving technologies applied in response to a CO₂ legislation, on vehicle kilometers travelled and vehicle purchasing behaviour is similar to the effects caused by a decrease in the fuel price.

An elasticity is an economic indicator to measure price sensitivity, defined as the percentage change in consumption of a good (or service) caused by a one-percent change in its price (or other characteristics). Elasticities are presented as “the elasticity of x with regard to y”, which means that the relative change of x is compared as a reaction to the initial relative change in parameter y. For example, the elasticity ϵ of fuel consumption with regard to fuel price is the ratio of the % change in fuel consumption as a result of a given % change in fuel price.

Elasticities are derived from times series of recorded data using econometric analysis. Different kinds of elasticities exist, and with each, it is important to always keep in mind the assumptions that were made to measure them. Elasticities are always measured in a given set of circumstances, and are in theory only applicable under the same circumstances. For example, the mileage elasticity with regard to fuel price measured in the US can not be applied in Europe without caution, given how different the share of fuel costs is in Total Cost of Ownership (TCO) of the vehicle. For that reason, a range of elasticities is presented in most cases.

Another caveat that should be mentioned is that elasticities often represent a combination of effects, which are not always measurable on their own. For example, the elasticity of fuel consumption with regard to fuel price combines driving behaviour and vehicle choice. If a car becomes cheaper to drive, it will likely be driven more. But consumers might also decide to buy bigger cars, if they feel the extra comfort outweighs the higher driving cost (which is still lower than it was before the fuel price decrease).

³⁰ Draft report, to be published as part of the deliverables from Service request #1 "Support for the revision of Regulation (EC) No 443/2009 on CO₂ emissions from cars", under the Framework Contract on Vehicle Emissions (Framework Contract No ENV.C.3./FRA/2009/0043) for DG CLIMA carried out by a consortium led by TNO.

Based on a comparative review of literature on price elasticities [TML/CE Delft, 2011] comes to the following conclusions:

- The fuel price elasticity with regard to fuel demand is greater than that for mileage, due to changes in driving style and (in the long term) fleet evolution providing additional means to respond to an increase in fuel price.
- Short term elasticities are lower than long term elasticities, due to the fact that effects on fleet composition have a longer lead time.
- While some studies make mention of the elasticity of fuel consumption with regard to vehicle price, they are unable to reach firm conclusions on this matter. According to [TML/CE Delft, 2011] the case could be made that these are second order effects rather than first order, so that these effects can be ignored in first instance.
- The range that was found in literature for elasticities of vehicle kilometers driven with regard to fuel price goes from -0.01 to -0.24 for the short term, and from -0.07 to -1.02 for the long term. [TML/CE Delft, 2011] proposes to use cautious averages set at -0.15 (ST) and -0.30 (LT).
- Estimates for the elasticity of fuel consumption with regard to changes in fuel price range from -0.1 to -0.34 for the short term, and from -0.3 to -0.84 for the long term. As average values, [TML/CE Delft, 2011] proposes to take -0.25 and -0.6, with the notion that for application to the assessment of rebound from CO₂ legislation these values will need to be corrected for the efficiency gains that are the cause of the decrease of driving costs.

[TML/CE Delft, 2011] notes that all of the reviewed documents refer to an increase in fuel price as cause for the observed effects, whereas the issue under study deals with the effects of a decrease in price per vkm (*ceteris paribus*). While the effects are fairly similar, special attention needs to be paid to the subtle differences. Elasticities are not necessarily symmetric under all circumstances. For example, when fuel prices increase, people may be more inclined to buy new cars that are more efficient but also more expensive to buy due to applied efficiency improving technologies. If prices would decrease again, they can not revert to a cheaper vehicle that uses more fuel, as the new technologies will generally continue to be applied.

As an example one can apply the above stated estimates for elasticities of fuel consumption with regard to cost per vkm of around -0.25 in the short run and -0.6 in the longer term to the step from meeting 130 g/km in 2015 to meeting the 95 g/km target in 2020. This corresponds to a 27% fuel efficiency improvement and an equivalent reduction in fuel costs per km. This then results in a rebound effect in terms of an increase of the emissions of those new cars, relative to the reduced levels achieved by applying efficiency improving technologies, of 6% (short run) to 15% (long run).

The big caveat to this reasoning is that the increased purchase cost of the more fuel efficient vehicles is not reflected in the effects described by literature on fuel price elasticities.

Evidence from REMOVE studies

[TML/CE Delft, 2011] also reviews results of several sets of runs carried out with the REMOVE model in support of the development of the current CO₂ legislation for passenger cars. REMOVE³¹ is a policy assessment model, designed to study the effects of different transport and environment policies on the emissions of the transport sector. The model estimates for policies as road pricing, public transport pricing, emission standards, subsidies for cleaner cars etc., the effects on transport demand, modal shifts, vehicle stock renewal and scrappage decisions as well as the emissions of air pollutants and greenhouse gases and the welfare impacts. REMOVE models both passenger and freight transport, and covers the period 1995-2030. At the moment, input databases are calibrated to feed the model for 31 countries (EU-27 plus Croatia, Norway, Switzerland and Turkey). The model contains a module that predicts changes in vehicle purchasing behaviour and vehicle use resulting from changes in vehicle prices, vehicle energy consumption and fuel prices.

³¹ See <http://www.remove.org/>

TREMOVE has been used to assess overall impacts on the transport system, including overall impacts on greenhouse gas emissions and costs, of various options for the CO₂ legislation for passenger cars. To this end the engineering estimates³² for each vehicle segment of fuel consumption / CO₂ emission per kilometre and corresponding estimates for retail price increases resulting from application of new technology in order to meet specific targets have been fed into the model, after which TREMOVE assesses direct and indirect impacts on overall CO₂ emissions and costs at the level of national and EU-wide vehicle fleets.

The main conclusion from analysing six TREMOVE simulation runs, which all deal with the assessing the combined impact of an increase of purchase price in exchange for a decrease in the cost per km driven, is that the knock-on consequences related to implementing CO₂ legislation can be positive as well as negative, i.e. a larger/smaller decrease in net CO₂ emissions relative to the direct impacts of applying efficiency improving technologies as assessed in engineering estimates. The net effect of knock-on consequences assessed by TREMOVE is generally small: not more than a few percent of the absolute value of the 1st order reduction estimate. The net effect strongly differs between scenarios and seems to depend on the target level as well as on the slope of the mass-based limit function. In all cases the

The net effect on CO₂ emissions is mainly the result of a change in vehicle purchase behaviour, rather than in driving behaviour. It appears that as cars become more expensive due to CO₂ regulation, overall car sales decrease. Annual average mileage per car does increase in most runs (but generally not more than a few percent), yet in various scenarios the lower amount of cars sold more than offsets this increase.

The size of the knock-on effect is found to depend on the way in which the required emission reductions are divided over different vehicle segments. This depends on the slope of the utility-based limit function. When more of the burden is carried by larger cars, a smaller part of the potential is achieved. This is due to the lower price sensitivity of luxury car buyers: they are willing to absorb the additional cost in order to keep the same level of comfort, performance and utility.

The most benefit in terms of CO₂ emissions can be reaped from small cars: they are the most efficient, and buyers are rather sensitive to cost increases. If they are to become more efficient, they need to become much more expensive, and sales will drop. From the perspective of CO₂ emissions, this is the optimal situation. From an economic and social point of view, such an approach may raise questions.

The elasticity of driving behaviour (annual mileage per vehicle) in TREMOVE is found to be on the lower end of the spectrum, compared to results from literature review, but certainly not out of the expected range on the short term. If this would indeed be higher in the longer term, as literature suggests, the rebound effect on travel demand will be more important, and a smaller share of the potential will be achieved.

4.3.2 Knock-on consequences related to manufacturer' responses to the CO₂ legislation

The effects described in this section may or may not be considered knock-on consequences of the CO₂ legislation as they refer to manufacturer responses and compliance mechanisms rather than to changes in consumer / user behaviour resulting from changes in the purchase price and fuel consumption of vehicle. Nevertheless these effects do influence the characteristic of vehicles and the composition of the fleet, and can have an impact on the cost effectiveness of the legislation both in terms of the net CO₂ emission reduction and the total costs for meeting the targets.

³² -E.g. from the [TNO/IEEP/LAT 2006] and [IEEP/CE/TNO 2007] studies

Selling more cars, especially in the small and medium segments, can be a means for manufacturers to reduce company average emissions, but this may lead to increased net emissions.

Shifting sales from large cars to small cars will reduce the manufacturer specific target. In the case of the 130 g/km target for 2015, however, the associated limit function with 60% slope makes the target easier to meet for manufacturers of small cars. As a consequence selling smaller cars may be a means to reduce the effort a manufacturer needs to make to meet its target. If all manufacturers would do this, the resulting fleet average would end up below 130 g/km.

The CO₂ legislation for 2015 indicates the possibility for the Commission to adapt (= tighten) the limit function in case of a proven trend towards heavier cars. It is not clear whether a shift towards smaller / lighter cars would also lead to an adjustment (in this case a relaxation) of the limit function. For the 95 g/km target for 2020 the modalities are still to be determined, so that it is not yet clear to what extent similar mechanisms could also apply there.

A shift of the sales distribution to smaller cars can be established in two ways:

- One way is a net shift of sales from larger to smaller segments at equal total sales. Such a response would be a positive knock-on consequence in the sense that it may increase the CO₂ reduction and will certainly reduce the associated direct costs. There are, however, welfare costs associated with a shift to smaller cars.
- The second option is to increase total sales by selling additional small vehicles. Depending on how the second option works out on overall vehicle use and on the existing vehicles in the fleet, this may lead to increased net emissions and can in that case be considered a negative knock-on consequence.

Both trends can be promoted by strategic pricing and product development by manufacturers, and are significantly promoted by progressive CO₂-based taxation systems. These taxation policies have a tendency to reduce the net costs of driving small cars, and in that sense the effect described here may be more a rebound effect of the tax policies for stimulating purchase of fuel-efficient cars rather than of the CO₂ legislation as such.

In the last decade we have already seen a trend of manufacturers developing new vehicles in the small segment or acquiring companies that manufacture such cars. The offer of small cars has greatly improved in both numbers and quality. This is reflected in the increased share of small vehicles in the car sales in recent years, although this shift can not be entirely attributed to CO₂ legislation. The economic crisis and changed fiscal regimes in Member States appear to have been more important drivers.

Effects of gaming with mass or another utility parameter selected for the 130 and 95 g/km targets.

Increasing the mass (or value of other utility parameter used in future CO₂ legislation) of vehicles leads to a higher target. If the impact of increased mass on CO₂ is smaller than the increase in target this effectively moves vehicles closer to the target line, making the higher target easier to meet. This is considered "gaming". The design of the current legislation, specifically the 60% slope of the limit function for 2015, tries to avoid such "perverse incentives" but in specific cases they can not be entirely ruled out. The choice of footprint instead of mass as utility parameter, which is considered as an option for the 95 g/km target for 2020, is also expected to reduce opportunities for gaming.

If such gaming would occur it can be considered a negative knock-on consequence, reducing the net CO₂ emission reduction resulting from the legislation. Costs would also be reduced so the net avoidance costs might not be significantly affected.

As already mentioned above the CO₂ legislation for 2015 allows the Commission to adapt (= tighten) the limit function in case of a proven trend towards heavier cars. For the 95 g/km

target for 2020 the modalities (utility parameter and limit function) are still to be determined. It is therefore not yet clear to what extent similar mechanisms could also apply there.

Besides applying CO₂-reducing technology or shifting sales to smaller cars, manufacturers may decide to stop selling certain high-emitting models / variants.

Although the present CO₂ legislation is not specifically intended to have this effect, it is clear that the target set by the utility-based limit function is more difficult to meet for manufacturers of vehicles with above average CO₂ emissions (compared to other cars of the same utility). Depending on the marginal costs of the final reductions required to meet the target, the level of the penalty for non-compliance and the potential of the specific market to absorb these costs, a manufacturer may opt to terminate production of certain high-CO₂ emitting models.

For the 95 g/km target the use of a vehicle-based limit in addition to the sales-average based limit is considered. Such a provision would be intended to prevent the sales of high-emitting models, although the strictness of the provision would depend on possible buy-out options.

The compliance mechanism of stopping sales of high emitting models can be considered a positive knock-on consequence in the sense that it in first order reduces the costs of meeting target. There are, however, societal and welfare costs associated with terminating sales of vehicles which to their users have a high perceived added value and consequently allow large profit margins for manufacturers. These costs are difficult to judge and quantify.

Cars with high CO₂ emissions are often high-performing sports cars. These tend to have a low annual mileage. Taking these vehicles out of the product portfolio, may thus have a slightly negative impact on the net real-world GHG emission reduction.

Selling vehicles with CO₂ < 50 g/km (electric and plug-in hybrid vehicles, and at a later stage also vehicles running on hydrogen) reduces the need to improve conventional vehicles. Depending on the CO₂ emissions associated with the use of electricity and hydrogen, this may lead to a reduction of the net well-to-wheel CO₂ impact of the legislation.

The use of electricity or hydrogen does not produce CO₂ emissions on the type approval test. Pure electric and hydrogen-fuelled vehicles therefore are zero-emission vehicles in the context of the CO₂ legislation for cars. Plug-in hybrid vehicles may have extremely low CO₂ emissions on the TA test depending on their electric range.

Selling vehicles with extremely low CO₂ emissions reduces the need to improve conventional vehicles for meeting the target. By selling one EV in 2015 a manufacturer can on average avoid 1 g/km CO₂ reduction in 130 conventional vehicles. Until 2014 the present legislation even provides “super-credits” for vehicles with CO₂ < 50 g/km (electric and plug-in hybrid vehicles).

Given that at the target of 130 g/km the marginal costs of the last g/km are estimated at around 85 € per g/km, the reduced costs for improving conventional vehicles create a financial leverage of around 10 k€ in favour of every EV sold. This may lead to manufacturers increasing their offer of low-CO₂ vehicles. This may be considered a positive and desired effect of the legislation, but will go at the expense of the average CO₂ emission of conventional vehicles. Depending on the well-to-tank CO₂ emissions associated with the use of electricity and hydrogen, this may lead to a reduction of the net well-to-wheel CO₂ impact of the legislation.

Further knock-on consequences with respect to a shift towards alternative propulsion and energy carriers are discussed in section 4.4.

4.3.3 Knock-on consequences through impacts on the RW/TA ratio

Real-world (RW) CO₂ emissions and fuel consumption of passenger cars are generally some 15 to 20% higher than the type approval (TA) values (RW/TA ratio = 1.15 – 1.2). This deviation is caused by a wide range of influences. First of all the NEDC driving cycle, used in the TA test, is less dynamic and less demanding than most real-world driving patterns. RW driving patterns depend heavily on e.g. the vehicle application (division of kms driven over different road types) and the driving style of the driver. Tyres and tyre pressure are generally also different in practice compared to the ideal test situation created in the TA test. Furthermore the TA value does not include energy use from auxiliaries such as lighting and air conditioning.

Recent work by TNO has shown that for vehicles that are very efficient on the TA test (emissions < 100 g/km) the average RW/TA ratio may increase to 1.4, as indicated in Figure 8, with a spread between 1.2 and 1.6 (one standard deviation) depending on vehicle application and driving style [TNO, 2010]. According to the trendline in Figure 8 a 28% reduction of the TA CO₂ emission from 160 to 115 g/km leads to a reduction of the TA CO₂ emission from 160 x 1.2 = 192 to 115 x 1.4 = 161 g/km, which equals 16%.

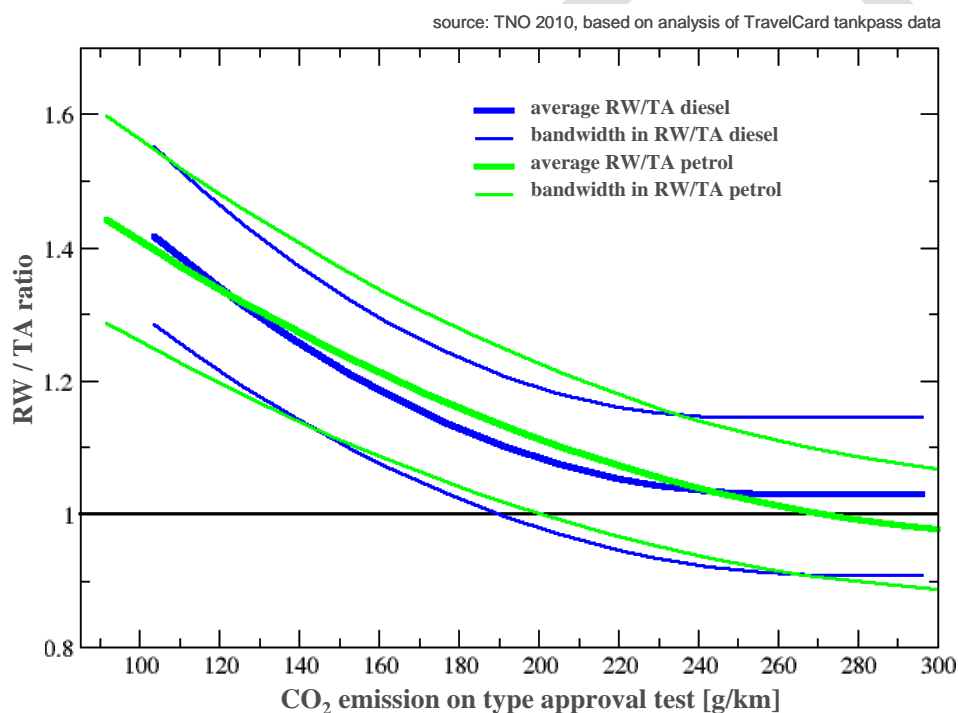


Figure 8 Relation between the ratio of real-world and type approval CO₂ emissions (or fuel consumption) and the CO₂ emission value measured on the type approval test, derived from statistical analysis of tank card data [TNO, 2010]

It is to be expected that the future development of RW/TA ratios depends on applied technologies as well as changes in fleet composition and usage, such as:

- Small vehicles are lighter and thus have good fuel economy in urban driving, but in highway driving their limited length leads to poor aerodynamics.
- Hybrid propulsion offers its advantages mostly in dynamic driving conditions (urban or congested highway driving). When driving at constant high speeds on highways the advantages will generally be limited or absent. Optimising the yield of regenerative braking requires a proactive, forward-looking, non-aggressive driving style, which may

not be natural to many company car drivers that currently drive a large share of the hybrids on the road.

Part of the divergence may be the result of flaws in the current type approval test procedure which allow manufacturers to optimize test vehicles and test conditions in such a way that on the TA test CO₂ emission reductions are achieved that can not be reproduced by actual vehicles on the road.

Changes in the type approval test procedure, as currently under development in the WLTP³³, may improve the correlation between TA and RW CO₂ emissions and fuel consumption as well as reduce the discrepancy (i.e. bring RW/TA value closer to 1), but the fact will remain that different technologies will have different impacts under different traffic conditions and in dependence on driving style.

The contribution of different possible causes to the observed shift in the RW/TA ratio is not yet properly understood. More research is needed, which will not only shine light on this issue but will also help to a) develop optimal driving strategies suiting different technological routes for increasing powertrain efficiency and b) create insight in which technologies as most suited for which vehicle applications.

A net increase in the RW/TA ratio means that the net impact on overall CO₂ emissions of the legislation is less than what could be expected on the basis of improvement in TA values. This negatively affects the cost effectiveness of the measure. At the same time it also reduces the rebound effects caused by the decrease in fuel costs per kilometre. In the assessment of net GHG impacts of CO₂ legislation these two effects may partly cancel each other.

4.4 Knock-on consequences of future CO₂ legislation

In line with what has been agreed with the Commission in the Inception Report for this project, the above has focused on possible knock-on consequences of the CO₂ legislation for cars and light commercial vehicles with targets set for 2015 and 2020. As the project looks at policies for sustainable mobility up to 2050 it makes sense to devote some attention to possible future CO₂ legislation for road vehicles.

4.4.1 CO₂ legislation for HD vehicles

Also for trucks and buses efficiency improvements leading to a decrease in total cost of ownership are expected to lead to increases in transport volumes or transport distances. CO₂ legislation for HD vehicles may thus also invoke rebounds and other knock-on consequences.

Currently preparatory assessments are being made in support of the development of CO₂ legislation for heavy duty vehicles. Besides assessing the potential and costs of available technologies, an important issue is the development of appropriate test procedures.

In the operation of heavy duty vehicles fuel costs are a significant share of the total operating costs, so that optimising fuel consumption has been an important driver for development over the past decades. As a result many cost-effective options for reducing fuel consumption have already been implemented. It may thus be expected that there will be less remaining "low hanging fruit", i.e. options with short payback times, than in the passenger car and van sectors. As a consequence rebound effects resulting from CO₂ legislation might thus be less likely than in light duty applications.

³³ Worldwide harmonized Light-duty Test Procedures (WLTP): activity under UNECE-GRPE aiming to establish a worldwide test procedure to measure light duty vehicle emissions and energy consumption

On-going assessments are identifying the potential for further reduction and the feasibility of setting various target levels. The recent [AEA/Ricardo, 2011] report still identifies various options with payback over a reasonable period (2-3 yrs) together with a larger number of options with significantly longer payback times. To what extent the fuel cost savings associated with future CO₂ legislation for HD vehicles will outweigh the additional manufacturing costs therefore heavily depends on the target level. This also depends on fuel price developments and cost development of more advanced reduction options.

4.4.2 Future CO₂ legislation for LD vehicles

Impacts on petrol and diesel vehicles

Although targets and modalities have not yet been discussed, it seems likely that continuation of the CO₂ legislation for road vehicles beyond 2020 will be a useful instrument for establishing long term sustainable mobility. Even when transport would in the longer term become subject to a CO₂ cap & trade system (as part of or independent from the EU ETS), CO₂ legislation can be an effective means to make sure that technological options become available that allow vehicle owners and users to respond to the economic incentives provided by the cap & trade system.

For possible knock-on consequences of longer term CO₂ legislation the future developments in the costs of energy and in the costs of technology appear the most important issues. At present fossil fuel prices and with the currently foreseen technology costs, reductions in the CO₂ emissions of passenger cars far beyond 95 g/km are likely to lead to net increases in the total cost of ownership. The same is true for vans. These TCO increases in turn are expected to lead to 2nd order effects in terms of shift of sales to smaller cars and reduced car use. These 2nd order effects will increase the CO₂ reduction resulting from the legislation and will improve its cost effectiveness (apart from possible welfare impacts).

For the longer term, however, strong increases of the oil price are becoming very likely. These will be able to tip the scale and reduce the abatement costs of CO₂ reducing technologies in cars and vans while at the same time reducing the positive 2nd order effects in terms of fleet composition and vehicle usage.

Future CO₂ legislation for LD vehicles: Impacts through marketing of vehicles with alternative propulsion systems and / or energy carriers

Targets below the values agreed for 2020 (95 g/km for passenger cars and 147 g/km for vans) are expected to create a strong incentive for marketing battery-electric and plug-in hybrid vehicles as well as vehicles running on hydrogen. These longer term targets will thus have a significant impact on the composition of the fleet in terms of applied propulsion technologies and energy carriers used. The effect of these changes in technology of sales of vehicles in different segments and on vehicle usage will again depend on the increase in vehicle manufacturing costs and the associated change in usage (mainly energy) costs. The latter are difficult to predict as these also depend on taxation that will or will not be applied to these new energy carriers.

Knock-on consequences through marketing of vehicles with energy carriers depend on the WTW GHG emissions of the applied alternative energy carriers. The net WTW impact of the CO₂ legislation is equal to or smaller than in case the target is met through efficiency improvement in conventional cars on petrol and diesel alone. Due to EU-ETS rebounds will be dampened, but the extent to which this is the case depends on the watertightness of EU-ETS in the short term and the development of the emission ceiling in the longer term.

Future CO₂ legislation for LD vehicles: New vehicle designs

Already in the short to medium term manufacturers are planning to market vehicles with unconventional designs and configurations (see two recent examples below). To what extent these vehicles are intended to significantly contribute to meeting the 130 g/km target for 2015 is as yet not clear. In the longer term the introduction of "fit for purpose" concepts, however, may and should be an important compliance mechanism for meeting CO₂ targets.

VW XL1, 24 gCO₂/km, plug-in hybrid (PHEV/EREV?) with 800 cc / 48 hp TDI 2-cylinder common rail diesel motor + 27 pk electric motor + 5 kWh battery + DSG, empty mass 795 kg, 35 km electric range, small series production announced for 2013



Renault Twizy, urban full electric vehicle, version which requires a driver's licence is powered by a 15kW (20hp) motor, while version that doesn't require a licence (depending on country) comes with a 4kW (5hp) motor, 7kWh lithium-ion battery, empty weight 450kg, including batteries (100kg), electric range 100km (combined cycle), series production announced for end 2011



The introduction of "fit-for-purpose" designs may be expected to have significant impacts on the composition and usage of the fleet.

Depending on how such novel vehicle designs are treated by future CO₂ legislation and fiscal systems, as well as on longer term shifts in consumer preferences and behaviour, "fit-for-purpose" vehicles may significantly help to reduce the costs for meeting targets or increase the impact of future CO₂ legislation. Crucial in this is that they effectively replace (the use of) larger multi-purpose vehicles rather than become attractive options for 2nd and 3rd cars in households.

4.5 Comparison of 1st and 2nd order impacts on GHG emissions

The existence of knock-on consequences as a result of CO₂ legislation appears indisputable, as the mechanisms by which changes in vehicle price and fuel costs per kilometre affect vehicle sales and usage are well recognised in a qualitative way.

Quantification of the individual impacts as well as the resulting net effect, however, appears much more difficult and uncertain. In runs with the TREMOVE model, carried out in support of the development of CO₂ legislation, the size and sign of the net effect appears to depend on details of the legislation and the 1st order assessment of the consequences of those details on costs and efficiency improvements in vehicles of different size classes and fuel types.

Rebound effects due to reduced fuel costs per kilometre may be of the order of 10 to 30% of the 1st order impact of improved fuel economy, according to econometric studies. The TREMOVE model shows very limited impacts on the annual distance driven per vehicle, but more significant effects on the sales of vehicles. From econometric studies the impact of changes in vehicle price on sales and usage is not known.

An overview of impacts, based on the qualitative assessment presented above, is below:

Table 5 Assessment of various GHG related knock consequences of CO₂ legislation

<i>Type of effect</i>	<i>Assessment</i>	<i>Magnitude</i>	<i>Time indication</i>
Effects of changes in vehicle purchase and usage costs			
<i>Effect of higher purchase price</i>	Positive 2 nd order impact in GHG emission reduction through reduced vehicle sales and shift to smaller cars.	Evidence from econometric studies and model runs is inconclusive	Effects on purchase behaviour can happen on short term.
<i>Effect of lower fuel costs per km</i>	Negative 2 nd order impact in GHG emission reduction through increased vehicle use and shift to larger cars.	wrt size of the effects.	
<i>Effect of net decrease or increase in TCO</i>	Net change in TCO strongly depends on fuel price and will be different for 130 g/km target for 2015 and 95 g/km target for 2020. For payback times > 5 years a reduction in TCO is not expected to lead to rebounds.	Net positive or negative knock-on effects are expected to be significantly smaller than 1 st order effect.	Effects on vehicle use are small in short term and larger in long term.
<i>Net overall effect</i>	For 130 g/km target for 2015 a net negative knock-on effect (rebound) on overall GHG emissions is expected. For the 95 g/km target for 2020 a net positive knock-on effect is expected.		
Manufacturer' responses to the CO₂ legislation			
<i>Selling more smaller cars</i>	Manufacturer may promote the sales of small vehicles to. This results in a lower target that is, however, easier to meet due to the 60% slope of the mass-based limit function.	Size and sign depend on net impact on fleet size and vehicle use	Short term
<i>Gaming with mass or</i>	Due to 60% slope of mass-based	Small negative	Short to

<i>other utility parameter</i>	limit function gaming is not expected to pay off for most manufacturers. When it happens the impact can be reduced by EC through adjustment of limit function.	effect	medium term
<i>Stop selling certain high-emitting models / variants</i>	Does not impact fleet average, but does reduce costs of meeting the target. Net effect may be slightly negative due to often low annual mileage of high-performing cars.	Small negative effect	Short to medium term
<i>Selling vehicles with CO₂ < 50 g/km</i>	Depending on the well-to-tank GHG emissions associated with the use of electricity and hydrogen, this may lead to a reduction of the net well-to-wheel GHG impact of the legislation.	Zero to negative	Medium term
Knock-on consequences through impacts on the RW/TA ratio			
<i>Divergence between CO₂ reduction on TA test and in RW</i>	Leads to lower CO ₂ emission reduction per km, but also reduces rebound effect resulting from lower fuel costs per kilometre.	Net negative effect may be small.	Short to medium term
Knock-on consequences of future CO₂ legislation			
<i>Impacts on fleet composition and usage of HD vehicles</i>	Due to limited amount of remaining options with short payback time, rebound effects of first steps in reduction are expected to be small. More ambitious targets are expected to lead to positive knock-on consequences.	Unknown	--
<i>Impacts of future LD legislation on petrol and diesel vehicles</i>	Targets beyond 95 g/km are likely to lead to net increases in the total cost of ownership. The same is true for vans. These TCO increases in turn lead to positive 2 nd order effects: shift of sales to smaller cars and reduced car use	Size increases with increased marginal costs of further CO ₂ reductions	--
<i>Impacts through marketing of vehicles with alternative propulsion systems and / or energy carriers</i>	Depending on WTW GHG emissions of alternative energy carriers the net WTW impact of the CO ₂ legislation is equal to or smaller than in case the target is met through efficiency improvement in conventional cars on petrol and diesel	Due to EU-ETS rebounds will be limited	--
<i>New vehicle designs, specifically "fit for purpose"</i>	If "fit for purpose" does not lead to increased fleet size, the impacts on GHG emissions will be zero under a CO ₂ legislation, but costs will be reduced. If fleet size increases through increased 2 nd and 3 rd car ownership, this has negative knock-on consequences on net GHG emission reduction.	Unknown	--

4.6 Impacts on cost effectiveness

Knock-on consequences not only affect the net GHG emission reduction realised by CO₂ legislation for cars, but will affect the net costs associated with the achieved GHG emission reduction. In general this will have an impact on the costs effectiveness or GHG abatement costs associated with the policy measure.

Due to the uncertainties regarding the size of the various knock-on consequences, as already apparent above in the assessment of impacts on CO₂ emissions, it is at this stage not possible to give a detailed assessment of the impact of knock-on consequences on costs and cost effectiveness. In general, however the following reasoning should hold:

Positive knock-on consequences are a means for consumers to escape undesired costs impacts associated with the CO₂ legislation. The combination of increased GHG emission reduction and reduced costs at the user level reduces the abatement costs as seen from a user perspective. Due to complex fiscal systems applied to the transport sector, improved cost-effectiveness at the user level does not necessarily translate into reduced GHG abatement costs from a societal perspective³⁴. Furthermore knock-on consequences in terms of a shift to smaller cars or reduced vehicle kilometres invoke welfare costs that can not be ignored but are difficult to include in the assessment.

Negative knock-on consequences or rebound effects generally result from consumers using cost reductions resulting from efficiency improvement for additional consumption of CO₂-emitting products or services. The net impact on abatement costs from a user perspective is depending on the share of the 1st order cost reduction being used for additional consumption and the ratio of the additional emissions to the 1st order emission reduction, as follows:

Abatement costs in 1st order can be written as:

$$-\Delta C/\Delta E$$

with $-\Delta C$ the net reduction in costs ($\Delta C > 0$), including additional investment costs and fuel cost savings, and ΔE the reduction in emissions. Abatement costs including 2nd order effects can be written as:

$$(-\Delta C + a \Delta C)/(\Delta E - \Delta E')$$

with $a \Delta C$ the costs of additional consumption, a being generally smaller than 1, and $\Delta E'$ the additional emissions associated with the additional consumption.

If the ratio of abatement costs incl. 2nd order effects over abatement costs in 1st order is larger than 1, the 2nd order effects lead to a reduction in the cost effectiveness. This is the case if:

$$\Delta E'/\Delta E < a$$

With $a < 1$, this at least requires $\Delta E'/\Delta E < 1$. The outcome is thus determined by the CO₂ intensity (emissions per unit cost) of the additionally consumed products or services.

Here, however, a flaw in the abatement cost formula should be noted, which occurs for reduction options with negative abatement costs. Suppose that a technology that has negative abatement costs is improved in such a way that its GHG emission reduction increases while the net costs remain the same. This is e.g. the case when the additional investment costs equal the additional energy cost savings. In that case the numerator value of $-\Delta C/\Delta E$ remains the same while the denominator increases, making the ratio less negative, i.e. smaller cost saving per unit of emission reduction. This is incorrect as the additional emission reduction in this example was achieved at zero costs.

While knock-on consequences on GHG emissions and cost effectiveness are uncertain for the passenger car CO₂ legislation in force in the 2010 – 2020 timeframe, it appears quite

³⁴ Due to the different shares of taxes in the prices of vehicles and fuels, reduction options with negative abatement costs at the user level (incl. taxes) may have positive abatement costs at the societal level (costs assessed excluding taxes) and vice versa.

clear that further tightening of targets beyond the 95 g/km for 2020 will lead to net increases in costs at the user level. Currently known additional technologies that can be applied for meeting these targets will have payback times exceeding the lifetime of vehicles. CO₂ legislation for the period beyond 2020 will therefore likely not suffer from rebounds, while positive knock-on consequences may enhance its effect and effectiveness.

Dedicated model runs with TREMOVE could provide more insight in the impacts of knock-on consequences on cost effectiveness of CO₂ legislation.

4.7 Conclusions

CO₂ legislation will lead to a reduction on 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 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 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 negative knock-on consequences or rebound effects, reducing its effect and very likely its cost-effectiveness.
- 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, but whether they are smaller than, equal to or larger than the vehicle lifetime will strongly depend on fuel price developments. Most likely the 95 g/km target leads to small but net positive knock-on consequences enhancing the effect 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. The net WTW impact of the CO₂ legislation is equal to or smaller than in case the target is met through efficiency improvement in conventional cars on petrol and diesel. Due to EU-ETS rebounds will be dampened, but the extent to which this is the case depends on the watertightness 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, while the applicability of the reported elasticities to the case of CO₂ legislation turns out not to be straightforward. Available TREMOVE runs devoted to assessing overall impacts of CO₂ 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.

Knock-on consequences can be significant and are a concern for the development of effective CO₂ reduction policies in transport. 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 CO₂ legislation with a generic economic instrument, that gives CO₂ a price, could provide an effective safeguard against rebound effects.

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5 Overall conclusions from this task

Task 3 looked at the knock-on consequences of three types of policy instruments for reduction of GHG from transport (speed-related, 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.

In general it was concluded that significant knock-on effects will take place and should thus be considered in policy development and posterior assessment.

Namely, for **speed limit** instruments, the knock-on effects on transport demand and modal split are the most significant. They are expected to have the same direction, and potentially reach 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 small.

Regarding **fiscal** instruments, *i.e.* fiscal stimulation of fuel-efficient vehicles, second-order impacts from instruments targeting car purchasing are likely to be significantly greater than those targeting ownership. 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. 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 (e.g. see Skinner et al, 2010).

Lastly, for **vehicle CO₂ legislation**, given the relatively short payback time of required technical reduction measures, the 130 g/km target for 2015 is likely to generate negative knock-on consequences or rebound effects, reducing its intended effect and very likely its cost-effectiveness. 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, but whether they are smaller than, equal to or larger than the vehicle lifetime strongly depends on fuel price developments. Most likely the 95 g/km target will lead to small but net positive knock-on consequences enhancing the effect 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. These assessments assume that the application of efficiency improving technology does lead to a net increase in purchase price.

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. Proper assessment of their implications on the cost-effectiveness of policy measures appears to require some methodological development.

Combining CO₂ legislation with a generic economic instrument, one which gives CO₂ a price, could provide an effective safeguard against rebound effects.



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