Consideration of alternative approaches to regulating CO$_2$ emissions from light duty road vehicles for the period after 2020

Service request #4 for Framework Contract on Vehicle Emissions

Framework Contract No ENV.C.3./FRA/2009/0043

Final report

Date: October 21, 2013

Executive Summary

Introduction

A very important and challenging goal of the European Union is to reduce greenhouse gas emissions until 2050 by 80% or more relative to 1990. In order to achieve this goal, increasing GHG constraints are required in every sector of the economy. Specifically for transportation, the objective has been set to cut EU-27 greenhouse gas emissions by 60% in 2050 relative to 1990 [EC 2011]. While this ambition is defined at a sectoral level as 'total GHG emitted' according to IPCC procedures, the current vehicle emissions regulations are defined on the level of 'Type approval TTW CO_2 emissions' in g/km. This causes a divergence between the regulatory approach and actual direct GHG emissions from road vehicles. Since manufacturers cannot directly influence driving behaviour and distance driven, the discrepancy between regulating g/km emissions and an overall target set at the level of absolute emissions cannot easily be overcome. Besides these factors, also the drivetrain types, chosen by manufacturers to meet the target, greatly influence the 'total GHG emitted' according to IPCC definitions and well-to-wheel (WTW). Even though manufacturers can also not directly influence the well-to-tank (WTT) emissions associated with production of energy carriers used in the vehicles, the regulation could be defined in such a way that manufacturers take account of these WTT emissions in their technology choices.

Vehicles with very low or no direct CO_2 emissions (e.g. electric vehicles or hydrogen fuelled vehicles, further on referred to as ZEVs or zero tailpipe emission vehicles) are expected to make up a significant part of the new registrations before 2050. In the current CO_2 regulation, based on the TTW emissions, ZEVs count as 0 gCO_2/km. Selling such vehicles therefore lowers the effort that manufacturers have to put into reducing CO_2 emissions from ICEVs (in order to meet their sales average TTW CO_2 target). Since in reality CO_2 is emitted to generate electricity or hydrogen, the increased WTW CO_2 emissions by ICEVs are not (fully) compensated by ZEVs, resulting in higher overall WTW CO_2 emissions. This undesirable "WTW CO_2 leakage" can potentially be neutralised by introducing alternative regulatory approaches. Obviously this effect also depends on how emissions from electricity or hydrogen production are attributed to electric and fuel cell vehicles. As large scale energy production plants are part of the EU-ETS, it could be argued that marginal emissions associated with additional energy production for electric and fuel cell vehicles are zero. It appears more justified, however, to attribute emissions to all energy consumers on the basis of average emissions, i.e. total emissions from energy production divided by the amount of energy produced.

More generally, the challenge is to define post-2020 regulation for light duty vehicles in such a way that the response of manufacturers to this regulation contributes towards meeting overall GHG reduction targets in the most cost effective way.

Objectives

The main goal of this study has been to develop a framework for analysis of impacts of different regulatory options, and to use this framework for a first indicative analysis of how the efficiency and effectiveness of vehicle GHG regulation is affected. It will also indicate how total GHG emissions from road transport activities will be affected by a range of different penetration scenarios for alternative vehicle propulsion system and the use of alternative energy carriers. The framework consists of the following elements:

- identification of relevant criteria for evaluating different options and qualitative evaluation of different options against these criteria;
- use of a simplified model to assess impacts of varying ZEV shares and WTT emissions of alternative energy carriers on the average WTW GHG emissions of new vehicles;
- use of a simplified fleet model to assess fleet wide TTW and WTW GHG emissions over a longer time period for scenarios with varying ZEV shares and WTT emissions of alternative energy carriers for the period 2020-2050;
- identification of pros and cons for the different metrics and regulatory options.
- evaluation of a range of relevant issues for post-2020 regulation;

A more detailed assessment of the costs for meeting targets, defined on the basis of different regulatory metrics, from a manufacturer, end user and societal perspective has been made in Service Request 8 [TNO 2013].

Options for alternative metrics and regulatory approaches

The main options for metrics and approaches for regulating CO_2 emissions from light duty vehicles beyond 2020, as identified by the Commission and required to be analysed in this study, are:

a.   vehicle CO_2 emissions

- tailpipe CO_2 emissions as in existing Regulation (= TTW CO_2 emissions)
- tailpipe CO_2 emissions for ICEs with exclusion of Zero Emission Vehicles
- tailpipe CO_2 emissions with notional GHG intensity for Zero Emission Vehicles
- tailpipe CO_2 emissions adjusted to take account of WTW emissions (= WTW GHG emissions)

b.   vehicle energy use

- energy used in the vehicle per vehicle-km (= TTW energy consumption)
- energy use per vehicle-km adjusted for WTW consumption (= WTW energy consumption)

c.   inclusion of road fuel use in the EU ETS

d.   a vehicle manufacturer based trading scheme based on lifetime vehicle GHG emissions

Additional options that can be defined on the basis of other elements of the terms of reference for this project are:

e.   a cap and trade system for vehicle manufacturers, of total CO_2 emissions or energy consumption of vehicles sold

f.   inclusion of embedded emissions in the WTW approaches listed above

Relevant criteria and issues for comparing options

Alternatives for the current TTW CO_2 based regulatory approach may include a different regulatory metric, e.g. WTW CO_2 emissions, TTW energy use or WTW energy use. Other possibilities for regulatory approaches are accounting for mileage, inclusion of road fuel use in the EU ETS or inclusion of embedded emissions. Such possibilities for regulatory approaches should preferably:

- ensure net GHG emission reduction;
- have a positive impact on technology development and implementation, including the metric's impact on the transition towards a future sustainable transport system;
- be cost effectiveness from a manufacturer, user and societal perspective;
- have a positive impact on energy dependence;
- be compatible with other policy instruments;
- be easy to implement and maintain;
- be accepted by relevant stakeholders.

Many of these criteria are interconnected. Impacts on costs e.g. depend on different technology choices which may be promoted by different metrics, and these in turn affect impacts on WTW emissions and the extent to which a metric fosters the transition towards a longer term sustainable transport system.

Impact of various metrics on WTW emissions

Equivalent targets

An alternative metric would require an adapted target appropriate for that metric. If the starting point is a TTW CO_2 based target, as in the current legislation, the calculation of equivalent targets for alternative metrics such as WTW CO_2 emission or TTW respectively WTW energy consumption depends on the technologies that are assumed to be deployed in order to reach the TTW CO_2 based

target. Definition of equivalent targets is in any case necessary for quantitative comparisons of the impacts of different metrics.

Assuming the target is met by ICEVs only, the TTW CO_2 based target can be translated to the other metrics using the TTW and WTT CO_2 emission values (in g/MJ) for conventional fuels. WTT CO_2 emissions may change over time as function of changes in the fossil energy chains and an increasing share of blended biofuels.

Assuming that the target is met by a mix of ICEVs and ZEVs, the new vehicles sales average WTW CO_2 emissions or TTW respectively WTW energy consumption is calculated using the TTW and WTT CO_2 emission values (in g/MJ) for conventional fuels, combined with the WTT emissions from the production of alternative energy carriers and the assumed energy consumption of alternative vehicles using these energy carriers.

For short term targets (up to 2025 or 2030) both options are generally feasible. For longer term targets on a trajectory that is compatible with the Commission's ambition to reduce CO_2 emissions from transport by 60%, the target values can in principle not be met by ICEVs only, unless one assumes currently unknown technologies to be available or drastic changes in the size and performance of vehicles.

Impact of various metrics on WTW emissions of new vehicles in the target year and interaction of technologies

For the different metrics the following two aspects were specifically investigated:

- the impact of the share of ZEVs and the WTT emissions of energy carriers used by these ZEVs on the WTW GHG emission of the new vehicle fleet under different metrics;
- the flexibility under the various metrics for meeting a given target with different combinations of improved ICEVs, shares of ZEVs and efficiency levels of these ZEVs.

Results are summarized in Table 1.

WTW CO_2 leakage with increasing ZEV shares

With respect to the first aspect it can be concluded that the "WTW CO_2 leakage" as function of an increasing ZEV share under a TTW CO_2 based metric is most pronounced in the medium term, with the ZEV share becoming significant while WTT emissions of their energy carriers are still relatively high. A WTW CO_2 based metric obviously safeguards against "WTW CO_2 leakage" as function of an increasing ZEV share.

A TTW energy based target can be considered to solve the problem of "WTW CO_2 leakage" as observed in a TTW CO_2 based metric, as WTW emissions decrease rather than increase with an increasing share of ZEVs if WTT emissions of these ZEVs are sufficiently low. A WTW MJ/km based metric shows similar behaviour. Whether WTW CO_2 emissions under this metric are more sensitive to variations in the share of ZEVs and their WTT emissions than under a TTW MJ/km based metric depends on the relation between WTT GHG emissions and WTT energy consumption. This relation is not straightforward. An increased share of renewables leads to lower WTT emissions and energy consumption, but the application of CCS on fossil fuelled power plants lowers WTT emissions while increasing WTT energy consumption. For a WTW M/km based metric in the medium to long term the sensitivity to variations in the actual share of ZEVs do appear less pronounced than for a WTW CO_2 based metric.

Using a TTW CO_2 based metric with notional WTT factors for ZEVs reduces the "WTW CO_2 leakage", but introduces similar sensitivities with respect to the technology mix (see next paragraphs) as a WTW CO_2 metric.

Flexibility with respect to the technology mix for meeting a target

The analyses also clearly show that there is hidden complexity attached to all metrics when applied to a single target for the average performance of the entire new vehicle sales. This complexity becomes apparent especially in the longer term.

A single target offers inherent flexibility and room for internal averaging by manufacturers with respect to distribution of reduction efforts over models and segments and the choice of advanced conventional or alternative technologies for meeting the target. In the short term a lot of combinations of improved ICEVs and ZEV-shares can lead to the same average performance on a given metric. In the medium to long term, however, targets need to be set so low that they can no longer be met by improvements in conventional technologies alone. The contribution of alternative technologies, specifically of zero tailpipe emission technologies (ZEVs), to meeting a target is determined by their share in the new vehicle fleet and their performance under a given metric.

Setting targets that are beyond what is technically feasible with conventional cars requires assumptions about feasible market shares of new ZEV technologies. Under a given TTW CO_2 based target, variations in the share of ZEVs can only be compensated by adjustments of the efficiency of the remaining share of conventional vehicles. If in the longer term the remaining share of ICEVs becomes very small, and ICEVs are already at or near the end of their improvement potential, the room to compensate for ZEVs not meeting their expected market share becomes extremely limited. Under TTW or WTW energy based targets and under a WTW CO_2 based target variations in the share of ZEVs can also be compensated by adjustment of the energy efficiency of these ZEVs. The room for that, however, is expected to be much more limited than the current improvement potential for ICEVs, as e.g. electric powertrains already have a high energy efficiency.

Table 1   Summary of results of the evaluation of sensitivities of different metrics

Metric	TTW GHG	TTW GHG with notional GHG intensity		WTW GHG		TTW energy		WTW energy	
		ICEVs only	ICEVs + ZEVs	ICEVs only	ICEVs + ZEVs	ICEVs only	ICEVs + ZEVs	ICEVs only	ICEVs + ZEVs
Sensitivity of WTW emissions to WTT electricity GHG intensity									
2020	+	+	+	o	o	+	+	+/o	+/o
2030	+++++	+++++	+++++	o	o	+++++	+++++	+++++	+++++
2050	+	+	+	o	o	+	+	+	+
Sensitivity of WTW emissions to ZEV share									
2020	+++++	+++/o	+++/o	o	o	+++++ (-)	+++++ (-)	++++++ (-)	+++++ (-)
2030	+++++	+++/o	+++/o	o	o	+++++ (-)	+++++ (-)	+++++ (-)	+++++ (-)
2050	+	+/o	+/o	o	o	+++++ (-)	+++++ (-)	+++++ (-)	+++++ (-)
Sensitivity of ICE TTW emissions to ZEV share									
2020	+++	++	++	+	+	+++	+++	+/o	+/o
2030	+++	++	++	++	++	+++	+++	++ (-)	+
2050	+++++	+++++	+++++	+++++	+++++	+++++ (-)	+++++	+++++ (-)	+++++

o   =   not sensitive
+   =   weak sensitivity
+++   =   moderate sensitivity
+++++ =   strong sensitivity
(-)   =   sign of sensitivity reversed compared to TTW GHG based metric
score in red means that case is not realistic

Impacts of different metrics on emissions and energy consumption at the fleet level

The effects of applying the different regulatory metrics on the WTW CO_2 emissions on fleet level depend highly on the assumed fleet composition and the WTT emissions of the energy carriers that have a high share in the fleet. In the EC's White Paper on transport (the basis for this analysis), high shares of (PH)EVs are assumed to be introduced from 2030 onwards and WTT CO_2 emissions are assumed to decrease significantly. Based on these assumptions, the WTW CO_2 emissions will decrease rather rapidly towards 2050. Moreover, the WTW CO_2 emissions are similar for the various fleet compositions and metrics assessed. Greater variations in fleet composition and WTT emissions than assessed in this study are likely to result in more divergent WTW CO_2 emission trends towards 2050. Such deviating scenarios are assessed in more detail in Service Request 8 from a cost effectiveness point of view.

Pros & cons of different options

Tailpipe CO_2 emissions as in existing Regulation

From 2025 or 2030 onwards a significant share of new registrations may be expected to (partly) use electricity as energy carrier. As a result, the WTW emissions will vary strongly with the actual WTT emissions from electricity production. This is caused by the high share of EVs on the one hand and the significant WTT emissions from electricity production on the other hand. Although the share of EVs further increases towards 2050, the sensitivity of WTW emissions to variations in WTT emissions from electricity production decreases, as a result of the fact that these emissions are becoming very small. Obviously, higher WTT emissions from electricity generation would lead to a larger impact of the introduction of EVs to average new vehicle WTW CO_2 emissions under a TTW CO_2 based target.

Pros:

- Focus on CO_2 implies that the goal of contributing to CO_2 reductions is more likely to be achieved.
- Tight targets promote a more rapid transition to alternative energy carriers with low TTW emissions (electricity and hydrogen).
- Similar approach currently used in the US, Japan and other regions worldwide.
- This regulatory approach is currently generally accepted by vehicle manufacturers and automotive industry.

Cons:

- Vehicles with zero TTW emissions are overstimulated if overall goal is to reduce WTW emissions.
- Upstream emissions continue to be ignored.
- Increasing the share of vehicles with zero TTW emissions such as EVs and FCEVs to meet the TTW target leads to increase in WTW emissions compared to the situation where the target is met without zero TTW emission vehicles or with a lower share of ZEVs.
- Overstimulates electric and hydrogen vehicles in comparison with other, possibly more cost-effective CO_2 reduction options.
- Provides no incentive for efficiency improvement for zero TTW emission vehicles
- Does not provide intrinsic credits for biofuel vehicles.

Tailpipe CO_2 emissions for ICEVs with exclusion of Zero Emission Vehicles

Under this metric the energy efficiency and CO_2 emissions of ICEVs are not affected by the share of EVs nor by the assumed WTT GHG emissions of electricity production. The impact of an increasing share of EVs (or other alternative vehicles) on new vehicle average WTW emissions depends on the assumed targets for ICEVs, the efficiency of the alternative vehicles and the WTW GHG emissions of the various energy carriers. For this metric average WTW emissions are expected to decrease with an increasing share of EVs in all target years, even if the WTT emissions from electricity production would be significantly higher than what is assumed in the White Paper.

Pros:

- Targets for conventional vehicles are not compromised by introducing other technologies. This option avoids the leverage by zero-emission vehicles on the overall average WTW emissions.
- Focus on CO_2 implies that the goal of contributing to CO_2 reductions is more likely to be achieved.

Cons:

- It is not a fundamental long term solution.
- Does not promote the transition to low-carbon or renewable energy carriers.
- Provides no incentive for efficiency improvement for zero TTW emission vehicles
- Does not provide intrinsic credits for biofuel vehicles.

Tailpipe CO$_2$ emissions with notional GHG intensity for Zero Emission Vehicles

Under this metric ZEVs count towards the target on the basis of their energy consumption multiplied by notional WTT emission factors for the energy carriers used. These notional factors do not necessarily need to reflect the actual WTT emissions.

If the equivalent target, for the option of using notional WTT emission factors for ZEVs, is based on the assumption that the TTW CO$_2$ target is met by ICEVs only, the target for this alternative metric is equal to the original TTW CO$_2$ target and does not vary with the assumed notional WTT emission factor for ZEVs. For a given share of ZEVs, the TTW emissions of ICEVs decrease with increasing notional WTT factor for ZEVs. The TTW emissions of ICEVs still increase with an increasing share of ZEVs, but this increase is less for higher notional WTT emission factors.

The use of notional WTT factors makes the average WTW emissions of new cars less sensitive to changes in the share of ZEVs. The impact of EVs on average WTW emissions is completely cancelled if the notional WTT factor is based on the actual WTT factor of electricity generation divided by the WTW/WTT factor for conventional fuels.

For 2030 and 2050 the impact of the share of ZEVs on the TTW emissions of ICEVs is quite significant. For 2050, if the share of EVs is low, the TTW emissions of ICEVs need to be reduced to levels that cannot be reached by presently known technologies and existing vehicle configurations. The TTW emissions of ICEVs is especially sensitive for ZEV shares that are higher than expected value. In 2030 and 2050 a 10% higher share already brings the TTW emissions of ICEVs back to levels compatible with the 2020 target of 95 g/km.

If the equivalent target is based on the assumption that the TTW CO$_2$ target is met by a mix of ICEVs and ZEVs, the target for this alternative metric increases with an increasing notional WTT emission factor for ZEVs. As a result for a given ZEV share the TTW emissions of ICEVs are not affected by the assumed notional WTT factor for ZEVs. Consequently the assumed notional WTT factor for ZEVs does not affect the average WTW emissions of new cars. This means that this alternative metric does not reduce the adverse impact of ZEVs on the new vehicle average WTW emissions, if the equivalent target is based on the assumption that the TTW CO$_2$ target is met by a mix of ICEVs and ZEVs.

Changes in the actual share of ZEVs compared to what was assumed for setting the equivalent target still affect the new vehicle average WTW emissions. If the actual share of ZEVs is higher than the value assumed for setting the equivalent target, the use of notional WTT factors will lead to lower WTW emissions than in the case of the TTW CO$_2$ based target. However, if the actual ZEV share is lower than the assumed value, this alternative metric leads to higher WTW emissions. This presents a realistic danger that this alternative metric, in combination with setting the equivalent target based on an assumed share of ZEVs, actually enhances the problem it is intended to solve. This danger is most prominent for the medium term.

The sensitivity of the TTW emissions of ICEVs for different notional WTT factors as a function of the share of ZEVs is the same as for the case when the equivalent target is based on 100% ICEVs, but centres around the assumed ZEV share rather than around 0% ZEVs. Again the TTW emissions of ICEVs increase less with an increasing share of ZEVs for higher notional WTT emission factors.

Pros:

- Focus on CO$_2$ implies that the goal of contributing to CO$_2$ reductions is more likely to be achieved.
- Under the condition that WTT and/or WTW/TTW factors are chosen correctly this method avoids the problem that an increased share of zero TTW-emission vehicles leads to increased WTW emissions.

- Notional WTT and/or WTW/TTW factors do not need to be very exact (i.e. true WTT factors) and do not require a complex monitoring system.

Cons:

- Requires definition of, and agreement on, notional WTT and/or WTW/TTW factors.
- OEMs might oppose it arguing that they are not responsible for these WTT emissions.
- More frequent updates of WTT factors would make planning more difficult for OEMs.

Tailpipe CO_2 emissions adjusted to take account of WTW emissions

A WTW GHG based metric effectively makes the average WTW emissions of new vehicles insensitive to the WTT emissions of ZEVs and to the share of ZEVs that is used to achieve the target.

Changes in the share of ZEVs or their WTT emissions, compared to what was assumed in setting the WTW-based target, need to be compensated by changes in the energy efficiency of ICEVs or ZEVs. Especially in the longer term these parameters become very sensitive to small variations of the share of ZEVs or their WTT emissions from the assumed values.

Pros:

- Focus on GHG emissions.
- Focus on the most important parameter with respect to world-wide climate impacts.
- Technology neutral.

Cons:

- Determining actual WTT and/or WTW emission factors requires complex monitoring system.
- OEMs might oppose it arguing that they are not responsible for these WTT emissions.
- Using actual WTW or WTT emission factors, or very frequent updates of these factors, would make planning more difficult for OEMs.

Energy used in the vehicle per vehicle-km

If the equivalent target, for the option of using a TTW energy based metric, is based on the assumption that the TTW CO_2 target is met by ICEVs only, ICEVs by 2050 need to have negative energy consumption to meet the target when the fleet 2050 contains a significant share of ZEVs. This is because the TTW energy consumption of ZEVs is higher than the fossil fuel consumption that corresponds to a level of TTW CO_2 emissions per kilometre that would be consistent with meeting the 2050 target for the transport sector as defined in the European Commission's white paper [EC 2011]. Therefore it is necessary to determine the equivalent target on the basis of the assumption that the target for TTW GHG emissions is met by a mix of ICEVs and ZEVs, for a TTW energy consumption based target.

If the equivalent target is based on the assumption that the TTW CO_2 target is met by a mix of ICEVs and ZEVs, ZEVs still have a leverage on the emissions of ICEVs, leading to increasing WTW emissions as a function of the WTT emissions from electricity generation for a given share of ZEVs. The sensitivity is exactly the same as for the TTW GHG emission based target. Also in this case average WTW emissions decrease with an increasing ZEV share. If the ZEV share equals the value on which the equivalent target is based the WTW emissions under the TTW energy based metric equal those under the TTW GHG emissions based target. To meet the target in 2050 with low levels of ZEVs still requires very efficient ICEVs, more efficient than is currently foreseen possible with existing vehicle configurations and specifications, but the required values stay positive.

The sensitivity to the share of ZEVs is reversed and somewhat smaller in case of a TTW energy based target.

Going to a TTW energy-based metric may therefore in the short term somewhat reduce the impact of ZEVs on the net WTW emissions achieved by the regulation, but certainly in the longer term cannot be considered a fundamental solution for the problem identified with the TTW CO_2 based metric.

Pros:

- Reduces the overstimulation of electric and fuel cell vehicles and other vehicles with zero TTW emissions.
- Reduces the leverage of zero TTW emission vehicles on WTW emissions.

Cons:

- If the goal of a TTW energy-based regulation would be to improve TTW energy efficiency, this option can be considered technology neutral. If a TTW energy-based regulation is implemented with the overall aim to reduce WTW CO_2 emissions, this option can be considered not technology neutral in the sense that the energy efficiencies of ICEVs and various ZEVs do not necessary reflect their respective contribution to reducing WTW CO2 emissions. Electric propulsion intrinsically has about a factor 3 better energy efficiency than a conventional powertrain with an internal combustion engine, but their WTW emissions are largely determined by the WTT emissions of electricity generation.
- Does not fundamentally solve the issue of TTW CO_2-based regulation. For WTT emission values that are above a certain value the WTW emissions still increase with increasing share of EVs or FCEVs compared to when the target is met without ZEVs.
- Focus on energy efficiency could reduce effectiveness of achieving reduction goal with respect to WTW GHG emissions.

Energy use per vehicle-km adjusted for WTW consumption

If the equivalent target, for the option of using a notional WTT emission factor for ZEVs, is based on the assumption that the TTW CO_2 target is met by ICEVs only, the (2050), ICEVs need to have negative energy consumption to meet to the target. Therefore it is necessary to determine the equivalent target on the basis of the assumption that the target for TTW GHG emissions is met by a mix of ICEVs and ZEVs, for a TTW energy consumption based target.

If the equivalent target is based on the assumption that the TTW CO_2 target is met by a mix of ICEVs and ZEVs, the sensitivity of the average WTW emissions of new vehicles to variation in the WTT emissions from electricity production is most pronounced in 2030, while negligible in 2020 and very small in 2050.

The WTW emissions of new vehicles go down with increasing shares of ZEVs for a WTW energy consumption based metric. In this case, however, the sensitivity of the TTW energy consumption of ICEVs and EVs deserves further attention.
If the

For 2030 the end of the reduction potential for ICEVs may come into sight. In that case smaller shares of ZEVs than assumed for the equivalent target, would require significant efficiency improvements in ZEVs for the target to be met.

In 2050, if the efficiency of ZEVs is assumed constant, the energy consumption of ICEVs is particularly sensitive if the ZEV share is higher than assumed for the target and quickly rises to levels above those needed to meet the 95 g/km target in 2020. In case the efficiency of ICEV is assumed constant, the energy consumption of ZEVs needs to reduce drastically if ZEV shares are below the level assumed for setting the equivalent target.

Pros:

- Promotes overall resource efficiency.
- Improves impact relative to option b1 with respect to reducing the leverage of zero-emission vehicles.
- Promotes energy efficiency in vehicles running on alternative energy carriers.

Cons:

- Comparing primary energy use of fossil and renewable sources is an "apples & pears" comparison. Fossil sources are finite.
- WTW energy consumption does not correlate with WTW GHG emissions.

- Not technology neutral in case of overall sales average target, due to intrinsic differences in WTW energy efficiency of various propulsion systems.
- Focus on energy efficiency could reduce effectiveness of achieving reduction goal with respect to WTW GHG emissions.

Inclusion of road fuel use in EU ETS

Under the currently active EU Emissions Trading Scheme (ETS), CO_2 emissions of large emitters, e.g. the vast majority of the electricity and hydrogen production, are capped on a national level. However as the share of CO_2 emissions from electricity and hydrogen production for transportation purposes is small relative to the total CO_2 emissions from these industries, the marginal CO_2 emissions (and therefore also the costs) of these industries resulting from the increased use of these energy carriers in transportation is expected to be small. As a result, this extra demand may not be a sufficient incentive for these industries to reduce CO_2 intensities. A way to account for WTT emissions may therefore be an important instrument to effectively reduce the total CO_2 emissions from transportation.

In case road fuel use is included in EU ETS, the uptake of ZEVs depends on the CO_2 price itself as well as on the difference in vehicle costs and energy costs of these ZEVs compared to ICEVs, which in turn depend on the extent to which the CO_2 price stimulates further efficiency improvement in ICEVs.

The main disadvantage of including road transport in the existing ETS, is that the current CO_2 price is very low and that this will –at least for the short to medium term– not be significantly affected by the addition of the transport sector. A CO_2 price of 15 €/tonne translates into a fuel price increase of 0.04 €/litre. This will not have a significant impact on driving and purchasing behaviour. A CO_2 price of at least 100 €/tonne (or 0.25 €/litre) would be needed before significant impacts on energy efficiency and choice of energy carriers in the transport sector can be expected.

Pros:

- Theoretically economic instruments such as a cap & trade system promote the most cost effective reduction options.
- The advantage of a cap & trade system over a CO_2 tax is that the target is set and the CO_2 price follows from the reductions that are necessary to meet the target. With a CO_2 tax, the price incentive is given but the total CO_2 emission reduction is uncertain.
- Technology neutral.

Cons:

- At current CO_2 prices under EU-ETS the impact on fuel prices is very small.
- Recent evidence from the Commission's Impact Assessment shows that achieving the 2020 LDV targets has a negative cost for consumers and society and that further reductions beyond those targets are also possible at negative cost. This illustrates the existence of some market barriers to achieving economically optimal levels of GHG reduction and fuel efficiency for LDVs which would also inhibit the effective operation of a market instrument.
- A cap & trade system does not automatically stimulate timely action that is required to get longer term, transitional options (such as EVs) implemented.
- No significant CO_2 emission reduction in the transport sector is guaranteed (since it may be possible that the CO_2 cap is reached by implementing reduction measures in other economic sectors).

A manufacturer-based trading system based on lifetime GHG emissions or a cap & trade system for vehicle manufacturers based on CO_2 emissions

If a manufacturer-based trading scheme is implemented in addition to a manufacturer-based target with one of the above metrics, it is not expected to directly affect the net impact on average WTW GHG emissions. The fleet average target set in the applied metric will be reached with or without trading, but in case of trading the costs for meeting the target may be smaller. Indirect impacts on the WTW GHG emissions only occur if the metric is not WTW GHG emissions and in that case depend on the choice of technologies for meeting the target.

In the medium term, when large-scale application of ZEVs is not necessary for meeting the target, the option of trading may in fact slow down their introduction as it allows some manufacturers to avoid application of ZEVs for meeting the target and instead to buy credits from other manufacturers that have less difficulty in meeting their target by further improvements in ICEVs.

If the metric is TTW CO_2 based, trading does not solve the leverage between the share of ZEVs and the emissions of ICEVs. Manufacturers selling ZEVs can still increase the TTW emissions of the remaining ICEVs they sell. Using lifetime GHG emissions rather than g/km emission may somewhat alleviate the leverage if the lifetime mileage of ZEVs is smaller than that of ICEVs, but is this only to be expected for EVs. In any case it will be difficult to predict lifetime mileage for technologies that are not yet applied in the market at large scale and in a mature way.

Pros:

- Overall cap on total vehicle CO_2 introduces joint responsibility of OEMs and shared interest in reducing CO_2. This could encourage more collaboration.
- Not only targets vehicle efficiency / CO_2 emissions but also total sales, and thus avoids market growth leading to increased emissions.

Cons:

- Makes the engineering target for vehicle efficiency very dependent on economic / market fluctuations (i.e. total sales of passenger cars).

Inclusion of embedded emissions in WTW approaches

Including embedded emissions in the metric only affects the impact of ZEVs on the average WTW GHG emissions of new vehicles if embedded emissions of ZEVs differ significantly from those of ICEVs. There is evidence for EVs and PHEVs that this is the case. As such the purpose of this metric is to avoid possible undesired rebound effects on global GHG emissions through increased embedded emissions resulting from the increased uptake of ZEVs that may be promoted by vehicle regulation.

Pros:

- Provides incentive for manufacturers to take account of differences in embedded emissions for different technologies in planning product portfolio.

Cons:

- As with WTT emissions and lifetime mileage some may argue that OEMs do not have full control over embedded emissions. This is mainly true for components they buy from suppliers.

Combining different options and e.g. size or mileage weighting

Using lifetime GHG emissions rather than g/km emission may somewhat alleviate the leverage between the efficiency of ICEVs and the share of ZEVs, if the lifetime mileage of ZEVs is smaller than that of ICEVs, but this is only to be expected for EVs. In any case it will be difficult to predict lifetime mileage for technologies that are not yet applied in the market at large scale and in a mature way.

Inclusion of mileage weighting should mainly be considered an option for more cost-effectively dividing the applied CO_2 reduction technologies over different vehicle segments which may have different lifetime mileages.

Pros:

- Lifetime mileage-weighting corrects for fact that some technologies or size segments have longer vehicle lifetime and mileage than other, so that 1 g/km reduction in one segment has more/less impact on total GHG emissions than 1 g/km reduction in other segment.

Cons:

- Lifetime mileage figures need to be established. These are different per manufacturer, per country and vary over time. So difficult to reach consensus.
- As with WTT emissions some may argue that manufacturers have no control over how much is driven with the cars they sell.

Other considerations

- To increase acceptance the metric should be primarily linked to parameters that are influenced by the regulated entity.
  - By some stakeholders WTT based approaches are considered problematic for OEMs, who would be regulated (and potentially penalised) on the basis of a metric that is considered be partly out of their control due to the WTT factor. This, however, is a matter of interpretation. In a WTW-based metric manufacturers are not made responsible for the WTT emissions, but in the planning of their product portfolio they are made responsible for taking account of the fact that (different) energy carriers have (different) WTT emissions.
- For the automotive industry predictability of specific targets for individual OEMs is extremely important.
  - Including WTT emissions or energy consumption may reduce predictability of the target, especially if WTT factors are based on monitoring of actual emissions. WTT factors need to be updated regularly to match trends in the energy system, but the frequency of the updates is crucial for the predictability of the targets.
  - Predictability is improved if those elements in the legislation that OEMs cannot influence (specifically WTT emission factors for fuels/electricity in the EU or a certain country) are the same for all manufacturers and determined well in advance to allow product portfolio planning by OEMs in response to periodic changes in these elements.
- The acceptability of WTT factors included in the legislation strongly depends on the methodology used to determine these factors. Agreement on the monitoring mechanisms implemented to assess WTT factors is thus an important factor in increasing acceptance of WTW-based metrics.
  - This aspect is especially relevant if LCA aspects (embedded emissions from the production and decommissioning phases) would be included in the metric.

Other relevant issues for post 2020 regulation

Combining different options and inclusion of additional modalities

The CO_2 regulation for passenger cars is part of a broader package of climate-related policies in transport. The EU-ETS, FQD and RED are the main EU-policies with which this regulation interacts. The recent Commission proposal for a directive on the deployment of alternative fuels infrastructure also has the potential to be an important addition to this package. On a national and even regional/local policy level there is a relationship with vehicle and fuel taxation, and in some cases with road charging, city access or parking policies.

Looking at the decarbonisation of transport, various reasons can be identified to have various related policies in place, rather than one overarching policy or several separate, unrelated policy measures. There are quite a number of stakeholders involved in this transition, and these all have to move towards the same direction, in a coordinated way. Some actions, for example R&D of batteries for electric or hybrid electric vehicles and biofuels production processes for woody biomass streams need to be carried out first, before an option is mature enough for large scale market take-up. Car manufacturers need to develop and market vehicles that run on these low-carbon energy carriers. The power sector (or local governments) will need to provide charging points, oil companies need to put new fuels on the market. Consumers will have to get used to the new technology. Governments (partly EU, partly national) will have to develop the necessary technical standards, and provide effective incentives to support these developments and a robust policy framework to provide the right boundary conditions for the market.

Vehicle emissions regulations specifically target the car manufacturers, and can thus be an effective means to drive developments in that sector and to make sure that efficient vehicles are offered. Combining this with a range of other policies, directed at other stakeholders and promoting the longer-term R&D efforts, can then make sure that required infrastructures are implemented in time and that customer demand is stimulated, thus increasing the longer term effectiveness of the emission regulations.

Interaction between CO_2 regulation and the FQD and EU-ETS

There is an interaction between the CO_2 regulation for cars and vans and other EU policies, and this interaction is likely to increase if WTW emissions of the fuels and other energy carriers are to be

included in the regulation. Especially the FQD, RED and EU ETS are relevant policies in this respect. First of all, these policies have an impact on the WTW emissions of the various energy carriers, as they can be expected to reduce these emissions over time. In addition, the FQD and RED both provide additional incentives for electric cars, although this impact is currently considered to be very limited. The ETS may hamper the uptake of electric cars to some extent, as it adds a CO_2 price on electricity production. If electricity demand of the transport sector increases, there is a risk that this will increase the CO2-price if the emission cap of the ETS is not adapted accordingly. This impact is, however, considered to be limited.

Alternatively the emission regulation will also impact these policies, as it may help to bring the vehicles on the market that use low-carbon energy carriers such as electric cars. This will contribute to both the FQD and the RED targets. It will also impact the ETS, as it may increase the price of CO_2 emission allowances once the electricity demand increases, unless the ETS cap is increased accordingly over time. In the short to medium term, these impacts are expected to remain very limited.

In addition, it is worth noting that if the metric in the vehicle regulation is changed, a number of national policies can be adapted as well. For example, vehicle taxation is often based on the CO_2 emissions of cars as measured during type approval. If these would be based on WTW emissions of the energy carriers, their effectiveness would improve.

Regarding potential issues of double counting or double regulations, it is concluded that a WTW approach of the CO_2 regulation would not create significant risks or negative side effects. This policy would affect car manufacturers only and does not interact with other policies that affect this group of stakeholders. Care should be taken, though, that in national and EU statistics, the well-to-tank emissions and energy use of the transport fuels and energy carriers are not counted towards more than one sector.

Greenhouse gases to be included

The importance of including TTW emissions of GHGs other than CO_2 in the regulatory approach

The principal focus of this part of the assessment is to identify and quantify the emissions of all GHGs that the IPCC recommend should be included in the GHG inventory, for a range of powertrains and energy carriers. From the ratio of the GHG emissions/CO_2 emissions it was assessed whether there is a need to include the GHGs other than CO_2 in the coverage of the regulatory approach.

The GHGs included in the study were:
* carbon dioxide (CO_2) because it is the metric for the current regulatory approach, and
* nitrous oxide (N_2O) and methane (CH_4) because the IPCC guidelines for national GHG inventories specify that these are the species that are important and should be included.

The emissions of the non-CO_2 GHGs generally occurs together with CO_2 emissions. Their ratio remains virtually constant for a given vehicle principal powertrain technology and exhaust clean-up combination. Consequently, improvements in the efficiency of the ICE, or the addition of hybrid technology, is to first order expected to lead to equivalent reductions in both the CO_2 emissions and the non-CO_2 emissions.

The main conclusions from this analysis can be summarized as follows:

* There is no need for the coverage of the regulatory approach post 2020 to include the GHGs used in MACS unless it is found that changes to the powertrain / primary energy carrier technology mix would change the MAC systems used or their performance.
* There is no need for the coverage of the regulatory approach post 2020 to include TTW emissions of non-CO_2 GHGs from ICEVs using carbon-based liquid fuels because they are a small fraction of CO_2 emissions (<2% for Euro 4) and are potentially going to reduce further following the introduction of the Euro 6 emission standards.
* An exception may be necessary for natural gas (methane) fuelled vehicles if the technology becomes more widespread, to ensure that the additional potential GHG emissions of methane are not a significant proportion of the CO_2 emissions. Methane emissions are already measured and regulated in the most recent type approval regulation.

- The need to extend the regulatory approach post 2020 to include non-CO_2 GHGs from vehicles using either HCCI or high levels of SCR should be reviewed if, or when, the technology becomes more widespread.

WTW GHG emissions for different vehicle technologies and energy carriers

The above considerations relate to the TTW emissions of vehicles. If the metric for future CO_2 regulation would be changed to cover WTW CO_2 emissions, the inclusion of non-CO_2 is definitely necessary, as for some fuels (e.g. biofuels) these constitute a significant share of the WTT GHG emissions. In energy chain analyses (WTT or WTW analyses) it is, however, already common practice to include all relevant GHGs.

Implications with regard to vehicle testing and certification procedures

For most of the potential future metrics covered in this study, no changes in the vehicle testing procedure are required as long as certain key parameters are measured. These measurement parameters are then combined with other external input data into the relevant calculation. This 'post test' calculation can be dealt with separately to the test procedure itself. Nevertheless it could make sense to have the additional WTT and other information also on the TA certificate as this better allows vehicle to vehicle comparisons, e.g. for the purpose of labelling.

The key test-related measurement parameters are:

1. Tailpipe CO_2
2. Fuel consumption
3. Battery electrical balance (from measuring battery electrical current during test)
4. Electrical energy consumption

Choice of utility Parameter

The survey of the impacts of new technologies on the value of possible utility parameters concluded:

- The vast majority of CO_2 emissions reduction technologies lead to increases in mass in running order, the exceptions being light-weighting and improved aerodynamics;
- The combined effects of measures is to lead to a net increases in mass in running order because the mass increase due to EVs / HEVs / PHEVs is larger than the max reduction due to light-weighting (the BEV or PHEV + strong light weighting leads to a net mass increase of around 180 kg);
- Also, mass in running order as the utility parameter disincentives the use of light weighting because it reduces the cost effectiveness of applying weight reduction;
- The vast majority of CO_2 emissions reduction technologies lead to no change in footprint;
- Whilst there is very little evidence it is most likely that height too will be unaffected by the vast majority of CO_2 emissions reduction technologies. This when combined with the above conclusion that footprint too will broadly remain constant, leads to the conclusion that internal vehicle volume, or footprint x height, is also anticipated to remain constant.

Overall it is expected that the choice of utility parameter, whether mass in running order or footprint could influence the choice of vehicle technologies that might be used. Mass in running order, is an incentive for the adoption of electric vehicles, because they are heavier and have a higher CO_2 emissions target than their ICE counterparts, and is a disincentive for strong light-weighting. In part, this could be mitigated with adjustments to the value of M_0 in the target function, but care needs to be taken regarding how equable this is for different manufacturers, particularly those not producing electric vehicles. Having footprint as the utility parameter, on the evidence currently available, generally circumvents these distortions, and appears to be more technology neutral.

In view of the above the following reasoning could be developed: The use of an adjustable M_0 in the target function is intended to correct for autonomous mass increase resulting from market trends or OEMs adding luxury features to vehicles. It was not introduced in view of mass effects of new technologies. Selecting a utility parameter U that is not affected by new technologies makes that U_0 only has to be changed to compensate for autonomous market effects. This reduces the chance that it will have to be changed and as such increases planning certainty for OEMs regarding their target.

Moreover, it avoids undesired "distributional" impacts on OEMs with different technology strategies. This could be a powerful argument in favour of moving away from mass in the longer term.

Border between van and car legislation

Four approaches have been evaluated as options for combining the regulation for passenger cars and vans:

- Approach 1: Having a different approach for Class I & II vans and Class III vans, and a combined target for passenger cars and the smaller vans;
- Approach 2: Allowing manufacturers to pool their targets for passenger cars and vans, whereby over- or underachievement in one market can be compensated by under- or overachievement in the other market;
- Approach 3: Setting a single target for the combined sales of passenger cars and vans in combination with a single utility-based limit function that is applied to both passenger cars and vans;
- Approach 4: Bringing vehicles / vehicle platforms that are designed to be both cars and vans at the same time under the passenger car legislation.

Approach 1) is considered feasible for mass as utility parameter. However, due to the large difference in sales volumes between passenger cars and Class I & II vans, combined target function will be dominated by the passenger car data. A target function derived for passenger cars and Class I & II vans together based on a constant reduction compared to the fit through the combined data, leads to targets for the Class II vans that are tougher than for the lighter Class I vans. A flattened slope of the target line, as is applied to the present target for passenger cars, would further enhance this unbalance. Depending on their division of sales over class I and class II vans, this could lead to uneven burden sharing among manufacturers of these LCVs. When footprint would be used the target function describing the combined target would lead to distances to target for large passenger cars that cannot be overcome with the available reduction potential, while for small passenger cars hardly any or no reductions would be required.

Approach 2) is technically feasible for the 2020 targets and does not appear to have major drawbacks in principle. The viability, however, needs to be determined by detailed impacts that go beyond generic arguments. An important condition for avoiding undesired consequences is that the marginal costs for meeting the separate targets for passenger cars and vans are about the same. This condition is not satisfied for the existing cars and vans targets for 2020. The marginal costs for vans are much lower than for cars. Allowing pooling of the cars and vans targets would thus lead to average CO_2 emissions for vans in 2020 that are significantly below the currently established 2020 target of 147 g/km, while the average for passenger cars would only be slightly increased above 95 g/km. Pooling on the basis of sales and mileage weighted CO_2 emissions, instead of sales weighted emissions, is preferred to avoid that shifting reductions from vans to passenger cars leads to a lower net GHG emission reduction at the overall fleet level.

The impacts of approach 3) strongly depend on the choice of utility parameter. Setting a combined utility-based limit function is likely to lead to unattainable targets for either vans (mass) or passenger cars (footprint). The risk of undesirable distributional impacts (disproportionate impacts on a limited number of manufacturers) is considerable, especially given the fact that for reaching the 2020 target manufacturers will have to use a substantial part of the available reduction potential and are thus more likely to "hit the ceiling" of the cost curves.

The main problem with approach 4) is the legal definition of which vans would qualify for inclusion in the (possibly adapted) passenger car target. Also, this option reduces the room for internal averaging which manufacturers have available to meet the specific targets that are set for the remaining light commercial vehicles that do not fall under the passenger car target.

Important factors that hinder the establishment of a combined target without undesired impacts are that:

- the EU27 passenger car sales are 9 to 10 times larger than the sales of light commercial vehicles;
- the new van sales consist almost entirely of diesel vehicles. which have a more limited reduction potential and offer that reduction at a higher cost than petrol vehicles;

- not all manufacturers sell both passenger cars and vans. and even among those that do the proportions are very different.

All in all approaches 1) and 2) appear the most feasible, provided that mass is used as utility parameter. However, overall the evaluation of existing evidence with respect to the different approaches does not seem to create a convincing motivation to strive for a combined target for passenger cars and vans.

Impacts of changes in operating cost on overall use and total GHG emissions

The introduction of new (fuel-efficient) technologies could change the cost and cost structure of passenger cars. It seems likely that usage cost will then reduce and car purchase cost increase. The impact of these changes in the cost structure of passenger cars on transport demand and overall GHG emissions are rather uncertain. On the one hand, decreased usage cost may increase the usage per vehicle. But the increased purchase cost, on the other hand, may reduce car ownership which reduces total transport demand. Particularly the evidence on the latter impact is scarce, as a consequence of which it is difficult to determine the net impact on transport demand and overall GHG emissions. A first expert guess provided by [Smokers et al. 2012] indicates that on the longer term (2020 and beyond) the impact of decreased car ownership on total transport demand is larger than the increased usage per vehicle, resulting in a net decrease of car usage and overall GHG emissions. This would imply that these indirect (knock-on) effects would strengthen the direct GHG effects of vehicle CO_2 regulation.

As is shown in this chapter, the choice of metric may affect the likelihood and size of the impact on transport demand. Most alternative metrics result in smaller (or maybe even negative) reductions in total transport demand and hence less positive knock-on effects in terms of GHG emissions. An exception is the mileage weighting which may result in a more GHG emission reduction.

Although the likelihood and size of the impacts of vehicle regulation on transport demand are still rather uncertain, it is important to consider them from the start of developments, as these may largely affect the effectiveness of this policy option. In that case potential supporting policy instruments could be considered, like for example economic instruments.

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1 Introduction

1.1 Background

A very important and challenging goal of the European Union is to reduce greenhouse gas emissions until 2050 by 80% relative to 1990. In order to achieve this goal, increasing GHG constraints are required in every sector of the economy. Transport is one of the main CO_2 emitting sectors in Europe, and the only one that continues to grow substantially. Since road transport is responsible for the majority of the overall transport emissions, regulations have been adopted for the purpose of reducing CO_2 emissions from passenger cars and light commercial vehicles.

In December 2008 the European Parliament and Council reached an agreement through a co-decision procedure on the details of the CO_2 legislation for passenger cars, laid down in Regulation (EC) 443/2009[1]. Besides the target of 130 g/km for 2015 and details of the way it is implemented, Regulation No 443/2009 also specifies a target for the new car fleet of 95 g/km for the year 2020. A similar regulation has been implemented for light commercial vehicles (Regulation (EU) 510/2011), setting a target of 175 g/km for 2017 and of 147 g/km for the year 2020. Both regulations are currently undergoing amendment in order to implement the 2020 targets. In July 2012 the European Commission published their proposals for the modalities for implementation of these targets for passenger cars (COM(2012) 393) and vans (COM(2012) 394). Implementation of new technologies and improvements of existing technologies are the main instruments for a manufacturer to achieve these CO_2 emission goals.

In terms of technological decisions and pathways chosen to meet the targets set in such GHG constraining regulations for motorised road vehicles, it is important that these should have a positive effect on the total amount of CO_2 emissions over the total energy chain. Also choices made by manufacturers to meet short term legislative targets should as much as possible contribute to the transition towards a sustainable mobility system meeting long term GHG emission targets. Current CO_2 legislation for road vehicles is regulating only tank-to-wheel (TTW) emissions and is therefore ignoring the effect of upstream emissions from the point of view of transport technology choices, and is therefore likely to be sub-optimal from an overall CO_2 emission perspective.

Specifically for transportation, the European Commission has stated the objective to cut Europe's carbon emissions in transport by 60% by 2050 [EC 2011]. While this ambition is defined on the level of 'total sectoral emissions' according to IPCC definitions (Figure 1a, with the direct emissions of biofuels counting as zero), the current vehicle emissions regulations as referred to above, are defined on the level of 'Type approval TTW' (where CO_2 emissions of biofuels are about the same as of petrol and diesel). This is causing a divergence between the regulatory approach and the sectoral target definition as well as between the regulatory approach and the overall GHG emissions that can be directly or indirectly attributed to road vehicles ('Total climate impact' and 'Total GHG emitted WTW' in Figure 1b). Since manufacturers cannot directly influence driving behaviour and distance driven, the discrepancy between absolute emissions and type approval emissions in g/km cannot easily be overcome. Even though manufacturers can also not directly influence the well-to-tank (WTT) emissions, they do have a direct influence on the implemented type of drivetrain and associated energy carrier used on which the WTT emissions to large extent depend. An appropriate choice of metric might help to promote technology choices that optimally contribute to the overall GHG emission reduction target for transport.

Vehicles with very low or no direct CO_2 emissions (e.g. electric vehicles or hydrogen fuelled vehicles, further on referred to as ZEVs or zero tailpipe emission vehicles) are expected to make up a significant part of the new registrations before 2050. In the current CO_2 regulation, based on the TTW emissions, ZEVs count as 0 gCO_2/km because GHGs emitted during generation of electricity or hydrogen are not taken into account. In reality however, GHGs are emitted in these processes.

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[1] Regulation (EC) No 443/2009 for passenger cars and Regulation (EU) No 510/2011 for light commercial vehicles. See: http://ec.europa.eu/clima/policies/transport/vehicles/index_en.htm

a) From TTW emissions per kilometre to total direct emissions of the transport sector according to IPCC definition, with direct emissions of biofuels counting as zero and indirect emissions of energy carriers attributed to power sector and agricultural sector (in case of biofuels)

= Total sectoral emissions (IPCC)
 = Real World IPCC [g/km]
  = Real World TTW [g/km]
   = Type approval TTW [g/km]
    Vehicle
   + Test cycle
  + Driving behaviour
 - direct emissions of biofuels count as zero
+ Distance driven
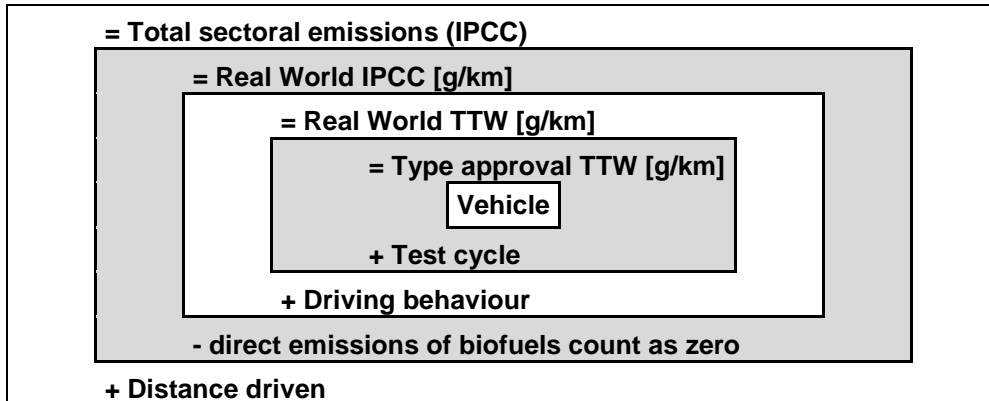
b) From TTW emissions per kilometre to total GHG emissions attributable to transport sector, including WTT emissions from the energy chain and GHG emissions from the product life cycle (production, decommission, recycling)

= Total climate impact
 = Total GHG emitted WTW
  = Real World WTW [g/km]
   = Real World TTW [g/km]
    = Type approval TTW [g/km]
     Vehicle
    + Test cycle
   + Driving behaviour
  + WTT
 + Distance driven
+ Embedded emissions
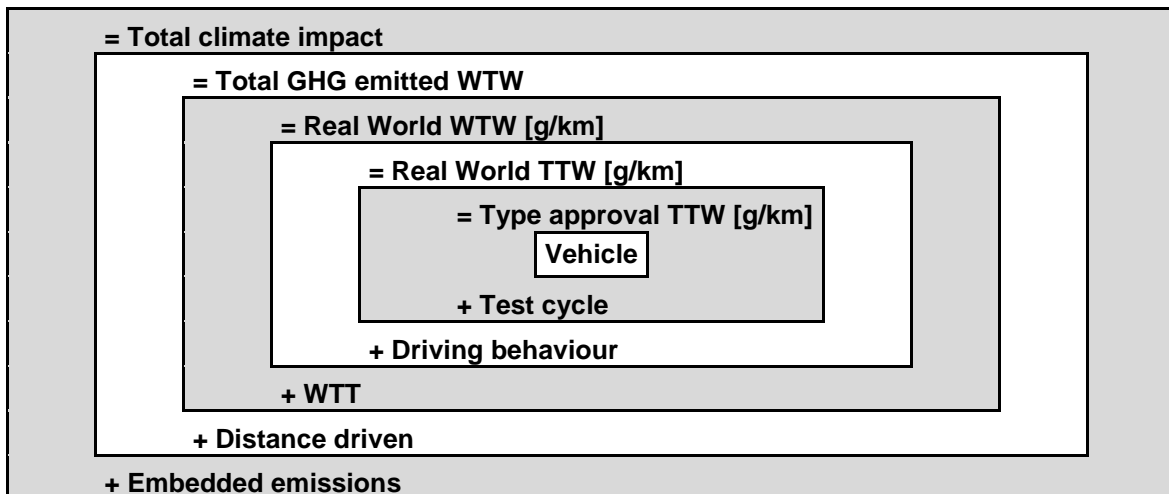
Figure 1   Schematic overview of various levels on which CO_2 emission targets can be defined.

When a share of a manufacturer's sales consists of these ZEVs, the effort that the manufacturer has to put into reducing CO_2 emissions from ICEVs (in order to meet its sales average TTW CO_2 target) decreases. As a result, the sales average TTW and WTW CO_2 emissions of ICEVs may increase with increasing ZEV sales of a certain manufacturer. Since in reality CO_2 is emitted to generate electricity or hydrogen, these increased WTW CO_2 emissions by ICEVs are not (fully) compensated by ZEVs, potentially resulting in higher overall WTW CO_2 emissions.

Impact of zero tailpipe emission vehicles (ZEVs) on climate integrity of the policy

The CO_2 regulations for cars and vans, being based upon tailpipe emissions, consider vehicles that are electric or hydrogen propelled to have zero GHG emissions. Therefore, in terms of compliance with the requirements of the Regulations, a manufacturer is permitted to have higher tailpipe emissions for the non ZEVs that they sell in relation to the proportion of ZEVs they sell. For example, if 5% of a manufacturer's sales are ZEVs, to achieve a new-car average of 95 gCO_2/km its non-ZEV vehicles will only need to achieve 100 gCO_2/km. The higher the ZEV share, the higher the non-ZEV emissions can be. If, as was permitted in the early years of the car regulation, these vehicles are given a multiplier ("super credits"), the effect is to allow even higher GHG emissions from the remaining non-ZEVs. Given the fact that for the next decades the energy generation for ZEVs will not be CO_2-free, a TTW

CO_2-based target therefore leads to a net increase in the WTW GHG emissions of new vehicles with increasing share of ZEVs.

Under the currently active EU Emissions Trading Scheme (ETS), CO_2 emissions of large emitters, e.g. the vast majority of the electricity and hydrogen production, are capped on a national level. However as the share of CO_2 emissions from electricity and hydrogen production for transportation purposes is small relative to the total CO_2 emissions from these industries, the marginal CO_2 emissions (and therefore also the costs) of these industries resulting from the increased use of these energy carriers in transportation is expected to be small. As a result, this extra demand may not be a sufficient incentive for these industries to reduce CO_2 intensities. A way to account for WTT emissions may therefore be an important instrument to effectively reduce the total CO_2 emissions from transportation.

Assessment of alternative metrics and regulatory approaches

In order to determine the optimal approach for post-2020 regulation of CO_2 emissions from road vehicles, in terms of avoiding possible negative consequences of the current TTW GHG based metric and promoting technological transitions that effectively contribute to meeting long term GHG emission targets, this study evaluates a range of alternative metrics and alternative regulatory approaches against a set of criteria. Alternative metrics include WTW GHG emissions and TTW and WTW energy consumption of vehicles. For each metric this assessment provides insight into the way in which variations in the share of ZEVs or in the WTT emissions associated with production of their energy carriers affects the average WTW emissions of vehicles sold. Also other pros and cons of the various options will be identified.

1.2 Other factors to be taken into consideration

In addition to what is already explained above the following more detailed considerations were requested by the Commission to be taken into account in the analysis.

Energy efficiency differs if measured for the vehicle or the whole well to wheel chain

While at the vehicle level electrified powertrains offer substantially higher energy efficiency than internal combustion engines, the energy generating sector has substantial inefficiencies. The result is that comparing the energy input to electricity generation required for an electric vehicle-km driven is not likely to be very different from the energy input to a refinery for an ICE vehicle-km driven. In view of this it is not self-evident that using energy as the metric offers any benefit over CO_2.

Vehicles with zero tailpipe emissions can have different energy consumption

Hydrogen fuelled vehicles (whether using fuel cell or ICE-based power trains) and battery electric vehicles have zero tailpipe emissions. These are often considered to be competing technologies over the longer term for light duty road vehicles. Due to the fact that the fuel cell or ICE for converting the hydrogen to usable energy is less efficient than the purely electric drive train in a battery electric vehicle a hydrogen fuelled vehicle will require more energy per vehicle-km. And besides that it can be argued that a TTW CO_2 based regulation does not promote improvements in energy efficiency of any of these ZEV technologies.

The evolving technologies for light duty vehicles

There is much speculation over how light duty vehicle technology will evolve in the future. There was a wave of enthusiasm for hydrogen technologies around the end of the 1990s and early in the 2000s. Some manufacturers foresaw hundreds of thousands of hydrogen fuel cell vehicles being sold by 2010. By the mid years of that decade, enthusiasm had shifted markedly to the potential offered by biofuels. Now following the end of that decade, there is much talk of the potential for pure electric vehicles and plug-in hybrids.

It is presently unknown which will be the winning technology or whether in fact none will win and different technologies will be important for different market segments. As a consequence, most major vehicle manufacturers are researching or even starting to market a number of different alternative fuel and powertrain options. In the light of this uncertainty it is particularly important that regulations affecting the industry do not influence it to move into one or another direction because of any in-built

bias in them, but that instead the technological choices should flow from which alternative is best able to achieve society's objectives.

Impact of mileage of different types/classes of vehicles

Different classes of the same type of vehicles are on average driven different distances. In general for cars, smaller vehicles are driven less distance annually than larger vehicles and diesel vehicles are driven a greater distance than petrol vehicles. Task 2.5.3 of [TNO 2011] investigated this aspect for the period to 2020. Consideration is required as to whether the situation beyond 2020 is likely to differ and whether there is a need for the legislation to reflect this.

It is currently the case that vehicles that are larger and heavier are expected to use more energy and emit more CO_2 underlying the utility curve in the current legislation. Changes in vehicle powertrains could potentially result in changes to this linkage.

It would be useful to consider the mileage aspect not only for gasoline vs. diesel powered vehicles but also for also for LPG, CNG, plug-in hybrid and pure electric vehicles.

In this report the impact of different mileages for different vehicle segments and technologies is briefly assessed in relation to the option of including mileage weighting in the CO_2 or energy regulation of cars.

Wide variation in proportion of well to tank GHG emissions

The split of GHG emissions between the use phase in the vehicle and the energy supply processes prior to that (here referred to as "well to tank") vary substantially. For conventional oil-derived fuels the well to tank emissions are around 15% of the total lifecycle emissions, but this proportion can reach 100% for zero emission vehicles such as battery electric or fuel cell vehicles. Other fuels have proportions in-between.

While the divergences are relatively small between conventional diesel, petrol, natural gas and LPG, and could therefore be ignored in the present vehicle CO_2 regulation, these divergences increase as other types of fuel or energy carriers are considered. Even with the retention of internal combustion engines, there is potential for tail pipe emissions to represent substantially different proportions of life cycle emissions. This situation is greatly exacerbated when different powertrains are considered.

Biofuels emit as much GHG when combusted as any other fuel, but under IPCC guidelines this is considered to be reabsorbed with cultivation of the crop. As a result, for accounting purpose, 100% of the GHG emissions occur well to tank. For a biofuel to be considered sustainable it needs to have lifecycle GHG emissions which are significantly lower than those of conventional fuel. In consequence, tailpipe emissions for biofuels will actually be a multiple of life cycle emissions, the value depending on the biofuel GHG intensity.

This issue is explored in detail by including vehicles with alternative energy carriers in the quantitative assessment of different metrics and exploring sensitivity of the outcomes to varying assumptions on the WTT emission and energy consumption factors.

How to ensure incentives where action is needed both on vehicles and energy supply?

It may be the case that a technology with low energy use or tail pipe emissions but high upstream emissions becomes very attractive for vehicle manufacturers. It seems desirable for incentives to be aligned so that vehicle manufacturers placing vehicles on the market take into account the overall lifecycle GHG emissions of the energy that those vehicles will be using.

At present there is a strong incentive to market ZEVs regardless of the likely GHG emissions of the energy supply to them. However, ZEVs are likely to remain expensive for some time to come and therefore it is also important to continue improving ICE technology .

The Commission has already carried out some preliminary assessment of desirable attributes of vehicle CO_2 regulation in the long term. In the *EU Transport GHG: Routes to 2050* study report paper 6

carried out some preliminary exploration of the relevant issues[2]. The NGO Transport and Environment has initiated some brainstorming on possible approaches to vehicle CO_2 regulations. In 2011 the International Council for Clean Transportation has organised a workshop to carry out reflection on appropriate future approaches to vehicle regulation. Results from these activities are taken into account.

Desirability of ensuring that all possible GHG reduction measures are available

The existing van and car regulations are based upon vehicle mass as utility parameter for differentiating the target. As part of the analytical work carried out to assess the 2020 targets, consideration has been given to whether it is desirable to consider an alternative parameter such as vehicle footprint. The analysis shows that were the parameter based on footprint, compliance costs would be slightly lower since mass reduction would become more attractive as a compliance option. In the long term, vehicle CO_2 reduction will become increasingly challenging and it is therefore important for the future regulatory approach to enable all appropriate compliance approaches.

1.3   Objectives

In follow up to previous work [AEA 2008], the European Commission's DG CLIMA has requested assistance in preparing the strategy for post-2020 light duty vehicle GHG emissions reductions. A crucial aspect in this strategy is the way in which GHGs, emitted for the purpose of driving vehicles, are regulated.

The main goal of this study is therefore to develop a framework for analysis of impacts of different regulatory options, and to use this framework for a first indicative analysis of how the efficiency and effectiveness of vehicle GHG regulation is affected. It will also indicate how total GHG emissions from road transport activities will be affected by a range of different penetration scenarios for alternative vehicle propulsion system and the use of alternative energy carriers. The framework consists of the following elements:

*   identification of relevant criteria for evaluating different options and qualitative evaluation of different options against these criteria;
*   use of a simplified model to assess impacts of varying ZEV shares and WTT emissions of alternative energy carriers on the average WTW GHG emissions of new vehicles;
*   use of a simplified fleet model to assess fleet wide TTW and WTW GHG emissions over a longer time period for scenarios with varying ZEV shares and WTT emissions of alternative energy carriers for the period 2020-2050.

The impact of various technological options on overall well-to-wheel GHG emissions is determined by:

*   the efficiency of vehicles
*   the TTW emissions of these vehicles
*   the WTT emissions of the energy carrier used
*   the penetration rate of the technological option.

Scenarios will focus on the dominant uptake of different technologies and the impacts of variations in assumptions on the above-mentioned characteristics of vehicles and energy carriers. A limited number of scenario variants will be constructed based on different assumptions with respect to the characteristics of these technologies. Technological options included in the scenarios are:

*   improved internal combustion engine vehicles (ICEVs)
*   battery-electric vehicles (BEVs)
*   plug-in hybrid electric vehicles (PHEVs)
*   fuel cell electric vehicles (FCEVs)
*   biofuels (assumed to be blended into petrol and diesel)

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[2] See: http://www.eutransportghg2050.eu

For the purpose of this exploratory exercise to evaluate alternative metrics for CO_2 regulation the model calculations will assume that these metrics are applied from 2020 onwards. Impacts over the 2020-2050 period will be assessed, on the EU level. Making this assumption in the assessment allows for an evaluation of the impacts over a sufficiently long period.

In addition to the above evaluation of alternative metrics this study also provides evaluations with respect to the following issues:

- Possibilities for and impacts of combining different options and inclusion of additional modalities;
- Interaction between vehicle regulation and the FQD and EU-ETS;
- Evaluation of relevant greenhouse gases to be included in a vehicle regulation, depending on the metric chosen;
- Implications of alternative metrics with regard to vehicle testing and certification procedures;
- The choice of utility parameter;
- The border between van and car legislation, and options for integration of these regulations;
- Impacts of changes in operating cost on overall vehicle use and total GHG emissions.

1.4 Relation with modelling performed in Service Request 8

In parallel to this Service Request 4, in which a wide range of aspects of different metrics for post 2020 CO_2 regulation are assessed, another project (Service Request 8) has been carried out which focusses more specifically on an analysis of the influence of metrics for future CO_2 legislation for light duty vehicles on the choices manufacturers may make with respect to deployment of technologies and the resulting GHG abatement costs. Results of Service Request 8 are reported in [TNO 2013].

1.5 Report structure

Chapters 2 to 5 of this report provide a detailed description of the various considered metrics and regulatory options, a set of relevant evaluation criteria, and detailed comparative analyses of the different options largely based on quantitative modelling. The results of these chapters are used to formulate pros and cons of the different options in chapter 6.

The second part of the report, chapters 0 to 13, contain further evaluations of issues not directly related to metrics but more generally relevant for post 2020 regulation of CO_2 emissions and or energy consumption of light duty vehicles.

2 Options for alternative metrics and regulatory approaches

2.1 Introduction

The main options for metrics and approaches for regulating CO_2 emissions from light duty vehicles beyond 2020, as identified by the Commission and required to be analysed in this study, are:

a. regulating vehicle CO_2 emissions

- tailpipe CO_2 emissions as in existing Regulation (= TTW CO_2 emissions)
- tailpipe CO_2 emissions for ICEs with exclusion of Zero Emission Vehicles
- tailpipe CO_2 emissions with notional GHG intensity for Zero Emission Vehicles
- tailpipe CO_2 emissions adjusted to take account of WTW emissions (= WTW GHG emissions)

b. regulating vehicle energy use

- energy used in the vehicle per vehicle-km (= TTW energy consumption)
- energy use per vehicle-km adjusted for WTW consumption (= WTW energy consumption)

c. inclusion of road fuel use in the EU ETS

d. a vehicle manufacturer based trading scheme based on lifetime vehicle GHG emissions.

Additional options that can be defined on the basis of other elements of the terms of reference for this project are:

e. a cap and trade system for vehicle manufacturers, of total CO_2 emissions of vehicles sold (expressed in g/km)

f. inclusion of embedded emissions in the WTW approaches listed above

g. combining different options with e.g. size dependent mileage weighting

All these alternatives are defined in more detail in sections 2.2 to 2.4. In chapters 4 to 8 many of these options are evaluated from different perspectives. In chapter 6 the options are further compared in terms of overall pros and cons.

2.2 GHG emission based metrics

2.2.1 Tailpipe CO_2 emissions as in existing Regulation

a.1 Tailpipe CO_2 emissions as in existing Regulation (TTW gCO_2/km)

Definition:
- based on g/km TTW CO_2 emissions

$$G_{target}^{TTW} = \sum_{i=1}^{m} \eta_i \cdot G_i^{TTW}$$

with:

G_{target}^{TTW} the TTW GHG emission target in g/km

G_i^{TTW} the sales-weighted average TTW GHG emissions in g/km of vehicles with technology i

η_i the share of vehicles with technology i in the total new vehicle sales ($\eta_i = n_i/N$ with n_i the number of vehicles with technology i and N the total new vehicle sales)

- CO_2 emissions as measured in the type approval test.
  - Currently based on NEDC, may in future change to WLTP.

- UN-ECE R101 caters for measurement of CO_2 emissions from plug-in hybrids[3].
- Electric driving and use of hydrogen count as zero emissions.
- Share of biofuels in conventional fuel has no impact on TA CO_2 emissions[4].

Other remarks
- This option is tested in the model developed and used in chapter 4 and 5.

2.2.2 Tailpipe CO₂ emissions for ICEVs with exclusion of Zero Emission Vehicles

a.2   *Tailpipe CO₂ emissions for ICEVs with exclusion of Zero Emission Vehicles*

Definition:
- based on g/km TTW CO_2 emissions

$$G_{target-ICEV}^{TTW} = G_{ICEV}^{TTW}$$

with:

$G_{target-ICEV}^{TTW}$ the TTW GHG emission target in g/km

G_{ICEV}^{TTW} the sales-weighted average TTW GHG emissions in g/km of internal combustion engine vehicles (ICEVs)

- CO_2 emissions as measured in the type approval test.
  - Currently based on NEDC, may in future change to WLTP.
  - Share of biofuels in conventional fuel has no impact on TA CO_2 emissions.

- ICEVs include HEVs.
  - Charge-sustaining (or not off-vehicle charging) hybrid powertrains are a technology for making ICEVs more fuel efficient, not a separate category.
- PHEVs need to be treated separately.
  - A target for PHEVs could be defined on the basis of the ICEV target and the electric range.

Other remarks
- No need to account for the biofuels share in conventional fuels as ICEVs are not compared to alternative energy carrier technologies.
- In this metric TTW CO_2 emissions are a very good proxy for TTW energy consumption (or vehicle efficiency).
- Can be tested in the models of chapter 4 and 5, but the result is trivial as introduction of alternatives does not affect target for ICEVs.

2.2.3 Tailpipe CO₂ emissions with notional GHG intensity for Zero Emission Vehicles

a.3   *Tailpipe CO₂ emissions with notional GHG intensity for Zero Emission Vehicles*

Definition:
- Based on g/km TTW emissions for ICEVs.
- GHG emissions for ZEVs accounted for on the basis of MJ/km TTW energy consumption times a notional g/MJ WTT factor.
  - Notional g/MJ WTT factor does not need to be exact: any value > 0 helps to reduce the leverage of ZEVs on the target for ICEVs.
- In its simplest form (disregarding PHEVs and possible alternatives with low TTW

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[3] Off-Vehicle Charging (OVC) hybrids in R101 terminology, a category including both plug-in hybrids(PHEVs) and extended-range electric vehicles (EREVs).
[4] Note that this definition is different from the IPCC accounting approach in which biofuels are defined to have zero TTW emissions, and in which all WTW emissions are attributed to the WTT part of the energy chain. In the TTW definition used above WTT emissions can be negative (sum of uptake of CO_2 in the WTT chain by growth of biomass and GHG emissions occurring in various steps of the chain, such as crop cultivation, harvesting and transport of biomass, biomass conversion and distribution of biofuels).

emission but high WTT emissions) the definition could be as follows:

$$G_{target}^{TTW} = \eta_{ICEV} \cdot G_{ICEV}^{TTW} + \sum_{i=1}^{m} \eta_i \cdot a_i \cdot E_i^{TTW}$$

with:

G_{target}^{TTW}	the TTW GHG emission target in g/km
G_{ICEV}^{TTW}	the sales-weighted average TTW GHG emissions in g/km of ICEVs
η_{ICEV}	the share of ICEVs in the new vehicle sales
E_i^{TTW}	the sales-weighted average TTW energy consumption in MJ/km of vehicles with zero-emission technology i
η_i	the share of vehicles with zero-emission technology i
a_i	the notional WTT GHG intensity factor in g/MJ for vehicles with zero-emission technology i

- In general for this metric the target can be defined as:

$$G_{target}^{TTW} = \sum_{i=1}^{m} \eta_i \sum_{j=1}^{n} a_j \cdot E_{i,j}^{TTW}$$

with:

η_i	the share of vehicles with technology i
$E_{i,j}^{TTW}$	the sales-weighted average TTW consumption in MJ/km of energy carrier j by vehicles with technology i
a_j	the notional WTT GHG intensity factor in g/MJ for energy carrier j defined as: $a_j = g_j^{TTW}$ for all conventional fuels, with g_j^{TTW} the TTW emissions of energy carrier j and a_j = a notional WTT value for all energy carriers with zero TTW emissions.

In this definition plug-in hybrids are included as they consume both fuel and electricity.

- This option can be seen as 1st order correction to reduce the leverage of ZEVs (i.e. the problem of a TTW CO_2-based metric that WTW emissions increase with increasing ZEV-share).
- Notional factors can be declared values or can be calculated on the basis of WTW emission estimates.
  - See note below.
  - To be discussed whether notional factors need to be EU average or can be Member State specific.
- The above mathematical definition can be expanded to also explicitly include PHEVs and possible alternatives with low TTW emissions but WTT emissions that strongly deviate from those of petrol and diesel.
  - See note below.

Other remarks	- This option is tested in the models of chapter 4 and 5.

Options for defining the notional WTT factors

- The notional WTW GHG intensity factor for zero-emission vehicles can be approximated on the basis of WTW data as follows:

$$a_i = g_i^{WTT} \cdot (g_{ICEV}^{TTW} / g_{ICEV}^{WTW})$$

with:

g_i^{WTT}	the WTT GHG emission factor in g/MJ of energy carrier i
g_{ICEV}^{WTW}	the average WTW GHG emission factor in g/MJ of fuel for ICEVs
g_{ICEV}^{TTW}	the average TTW GHG emission factor in g/MJ of fuel for ICEVs

- In the above definition the WTT GHG intensity of energy carrier i is divided by the ratio between average WTW and TTW emissions of petrol and diesel to account for the fact that conventional fuels also have WTT emissions. Ignoring this, while using approximate WTT emission for alternative energy carriers, would be a disadvantage to the alternative energy carriers.

- Alternatively the notional WTT factors a_i can also be used to set scores for all technologies (powertrain / energy carrier combination) that do not necessarily reflect the actual WTT emission of ZEVs or of all different options. Instead they can be used as notional scores which reflect the value that is attributed to a technology in achieving long term GHG emission reductions and which can be tuned to promote specific technologies over other options.

How to include PHEVs and other alternatives into the definition?

- The definition for this option can be rewritten in a more explicit way to show how two additional categories of vehicles can be included:
  - PHEVs (incl. EREVs).
  - Vehicles using alternative energy carriers which have non-zero TTW emissions but WTT emissions that strongly deviate from those of petrol and diesel.

$$G_{target}^{TTW} = \eta_{ICEV} \cdot G_{ICEV}^{TTW} + \sum_{i=1}^{m} \eta_i \cdot a_i \cdot E_i^{TTW} + \eta_{PHEV} \cdot (G_{PHEV}^{TTW} + a_{elec} \cdot E_{PHEV}^{TTW}) + \sum_{j=1}^{k} \eta_j \cdot (G_j^{TTW} + b_j \cdot E_j^{TTW})$$

with (in addition to the simplified definition):

G_{PHEV}^{TTW}	the sales-weighted average TTW GHG emissions in g/km of PHEVs
E_{PHEV}^{TTW}	the sales-weighted average TTW electricity consumption in MJ/km of PHEVs
η_{PHEV}	the share of PHEVs in the new vehicle sales
a_{elec}	the notional WTW GHG intensity of electricity
G_j^{TTW}	the sales-weighted average TTW GHG emissions in g/km of vehicles with alternative non-ZEV technology j that have deviating WTT emissions
E_j^{TTW}	the sales-weighted average TTW energy consumption in MJ/km of vehicles with alternative non-ZEV technology j that have deviating WTT emissions
η_j	the share of vehicles with alternative non-ZEV technology j
b_j	the notional WTT GHG intensity factor in g/g for vehicles with alternative non-ZEV technology j

- The notional WTW GHG intensity factor for vehicles with alternative non-ZEV technology j that have deviating WTT emissions can be approximated on the basis of WTW data as follows:

$$b_j = g_j^{WTT} \cdot (g_{ICEV}^{TTW} / g_{ICEV}^{WTW})$$

with:

g_j^{WTT} the WTT GHG emission factor in g/MJ of energy carrier j

g_{ICEV}^{WTW} the average WTW GHG emission factor in g/MJ of fuel for ICEVs

g_{ICEV}^{TTW} the average TTW GHG emission factor in g/MJ of fuel for ICEVs

2.2.4   Tailpipe CO₂ emissions adjusted to take account of WTW emissions

a.4   *Tailpipe CO₂ emissions adjusted to take account of WTW emissions (WTW gCO₂/km)*

Definition:
- Based on g/km WTW emissions for all technologies / energy carriers.
- In general WTW emissions of vehicles can be written in different ways which are all equivalent:

$$G_i^{WTW} = g_i^{WTW} \cdot E_i^{TTW} = G_i^{TTW} + g_i^{WTT} \cdot E_i^{TTW} = (g_i^{WTT} + g_i^{TTW}) \cdot E_i^{TTW}$$

with:

G_i^{WTW} the WTW GHG emissions in g/km of vehicles with energy carrier i

g_i^{WTW} the WTW GHG emission factor in g/MJ of energy carrier i

g_i^{WTT} the WTT GHG emission factor in g/MJ of energy carrier i

g_i^{TTW} the TTW GHG emission factor in g/MJ of energy carrier i
E_i^{TTW} the TTW energy consumption in MJ/km of vehicles with energy carrier i

- WTW or WTT emission factors can be based on actual monitoring or can be set as default values which are regularly updated on the basis of less frequent monitoring.
  - Emission factors can be defined as EU averages, or per Member State (MS).
  - Emission factors cannot be manufacturer specific, unless based on weighted average of MS specific values.
  - Using actual data requires a complex and fast monitoring system to have up-to-date information of EU or MS averages.
  - The relation with monitoring of GHG intensity of energy carriers as foreseen under the FQD should be noted.
  - Main methodological issues relate to:
    - using average vs. marginal emissions;
    - impact of EU-ETS on emission values for e.g. electricity and hydrogen.
  - WTT emission factors may need to take into account estimated future progress to represent expected average values over vehicle lifetime, rather than values representative for the year in which the vehicle is sold.
- In general for this WTW GHG based metric the target can be defined as:

$$G_{target}^{WTW} = \sum_{i=1}^{m} \eta_i \sum_{j=1}^{n} g_j^{WTW} \cdot E_{i,j}^{TTW}$$

with:

G_{target}^{WTW} the WTW GHG emission target in g/km
η_i the share of vehicles with technology i in the new vehicle sales

g_j^{WTW} the WTW GHG emission factor in g/MJ of energy carrier j

$E_{i,j}^{TTW}$ the sales-weighted average TTW consumption of energy carrier j in MJ/km by vehicles with technology i

- Making an explicit distinction between conventional vehicles, plug-in hybrids and various ZEV technologies, the above equation can also be written as:

$$G_{target}^{WTW} = \sum_{i=1}^{l} \eta_{ICEV-i} \cdot (G_{ICEV-i}^{TTW} + g_i^{WTT} \cdot E_{ICEV-i}^{TTW})$$

$$+ \sum_{j=1}^{m} \eta_{PHEV-j} \cdot (G_{PHEV-j}^{TTW} + g_j^{WTT} \cdot E_{PHEV-j}^{TTW} + g_{elec}^{WTT} \cdot E_{PHEV-j-elec}^{TTW})$$

$$+ \sum_{k=1}^{n} \eta_{ZEV-k} \cdot g_{ZEV-k}^{WTT} \cdot E_{ZEV-k}^{TTW}$$

with:

η_{ICEV-i} the share of ICEVs with fuel i in the new vehicle sales

G_i^{TTW} the sales-weighted average TTW GHG emissions in g/km of ICEVs with fuel i

g_i^{WTT} the WTT GHG emission factor in g/MJ of fuel i

E_i^{TTW} the sales-weighted average TTW electricity consumption in MJ/km of ICEVs with fuel i

η_{PHEV-j} the share of PHEVs with fuel j in the new vehicle sales

G_{PHEV-j}^{TTW} the sales-weighted average TTW GHG emissions in g/km of PHEVs with fuel j

E_{PHEV-j}^{TTW} the sales-weighted average TTW fuel consumption in MJ/km of PHEVs with fuel j

g_{elec}^{WTT} the WTT GHG emission factor of electricity in g/MJ

$E_{PHEV-j-elec}^{TTW}$ the sales-weighted average TTW electricity consumption in MJ/km of PHEVs with fuel j

η_{ZEV-k} the share of ZEVs with energy carrier k in the new vehicle sales

g_{ZEV-k}^{WTT} the WTT GHG emission factor in g/MJ of energy carrier $ZEV-k$

E_{ZEV-k}^{TTW} the sales-weighted average TTW energy consumption in MJ/km of ZEVs with energy carrier $ZEV-k$

Other remarks

- This option is tested in the models of chapter 4 and 5.
- The option of having WTT emission factors taking into account estimated future progress to represent expected average value over vehicle lifetime might be helpful, though the risk of manipulation by "optimistic" forecasting should be noted.

2.3 Energy consumption based metrics

2.3.1 Energy used in the vehicle per vehicle-km

b.1 Energy used in the vehicle per vehicle-km (TTW MJ/km)

Definition:
- based on MJ/km TTW energy consumption

$$E_{target}^{TTW} = \sum_{i=1}^{m} \eta_i \cdot E_i^{TTW}$$

with:

E_{target}^{TTW}	the TTW energy consumption target in MJ/km
E_i^{TTW}	the sales-weighted average TTW energy consumption in MJ/km of vehicles with technology i
η_i	the share of vehicles with technology i in the total new vehicle sales ($\eta_i = n_i/N$ with n_i the number of vehicles with technology i and N the total new vehicle sales)

- Energy consumption as measured in the type approval test.
  - Currently based on NEDC, may in future change to WLTP.
  - UN-ECE R101 caters for measurement of fuel consumption and electricity consumption of plug-in hybrids[5]. For this metric the consumption of different energy carriers by the same vehicle is to be added.

Other remarks
- This option is tested in the models of chapter 4 and 5.

2.3.2 Separate efficiency targets for different classes of propulsion systems

b.2 Separate efficiency targets for different classes of propulsion systems

Definition:
- Based on g/km TTW energy consumption

$$E_{target-i}^{TTW} = E_i^{TTW}$$

with:

$E_{target-i}^{TTW}$	the TTW energy consumption target in MJ/km of vehicles with technology i
E_i^{TTW}	the sales-weighted average TTW energy consumption target in MJ/km of vehicles with technology i

- TTW energy consumption as measured in the type approval test.
  - Currently based on NEDC, may in future change to WLTP.
- Separate targets for ICEVs (including HEVs), BEVs, FCEVs, etc.
  - Charge-sustaining (or non off-vehicle charging) hybrid powertrains are a technology for making ICEVs more fuel efficient, not a separate category.
- PHEVs need to be treated separately.
  - A target for PHEVs might be defined on the basis of the targets for ICEVs and BEVs combined with the electric range.

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[5] Off-Vehicle Charging (OVC) hybrids in R101 terminology, a category including both plug-in hybrids(PHEVs) and extended-range electric vehicles (EREVs).

- – Simply adding energy content of fuel and electricity consumed creates leverage for vehicles with long electric range.
- • Per technology targets need to be based on evaluation of technical potential and cost effectiveness.
- • Some methodology needed to harmonize targets across technologies.
  - – Could be based on equal marginal costs for WTW GHG reduction

Other remarks	• This option can be tested in the models of chapter 4 and 5 but the result is trivial as introduction of alternatives does not affect the target for ICEVs.

2.3.3 Energy use per vehicle-km adjusted for WTW consumption

b.3   *Energy use per vehicle-km adjusted for WTW consumption (WTW MJ/km)*

Definition:
- • Based on g/km WTW energy consumption for all technologies / energy carriers.
- • Is equivalent to WTW primary energy use.
- • In general WTW energy consumption of vehicles can be written in different ways which are all equivalent:

$$E_i^{WTW} = e_i^{WTW} \cdot E_i^{TTW} = E_i^{TTW} + e_i^{WTT} \cdot E_i^{TTW} = (1 + e_i^{WTT}) \cdot E_i^{TTW}$$

with:

E_i^{WTW}	the WTW GHG emissions in MJ/km of vehicles with energy carrier i
e_i^{WTW}	the WTW energy consumption factor in MJ/MJ of energy carrier i
e_i^{WTT}	the WTT energy consumption factor in MJ/MJ of energy carrier i
e_i^{TTW}	the TTW energy consumption factor in MJ/MJ of energy carrier i
E_i^{TTW}	the TTW energy consumption in MJ/km of vehicles with energy carrier i

- • WTW or WTT energy consumption factors can be based on actual monitoring or can be set as default values which are regularly updated on the basis of less frequent monitoring.
  - – Energy consumption factors can be defined as EU averages, or per MS.
  - – Energy consumption factors cannot be manufacturer specific, unless based on weighted average of MS specific values.
  - – Using actual data requires complex and fast monitoring system to have up-to-date information of EU or MS averages.
  - – Main methodological issues relate to:
    - – using average vs. marginal energy consumption;
    - – indirect impact of EU-ETS on WTW energy consumption values for e.g. electricity and hydrogen.
  - – WTT energy consumption factors may need to take into account estimated future progress to represent expected average values over the vehicle lifetime, rather than values representative for the year in which vehicle is sold.
- • In general for this WTW energy-based metric the target can be defined as:

$$E_{target}^{WTW} = \sum_{i=1}^{m} \eta_i \sum_{j=1}^{n} e_j^{WTW} \cdot E_{i,j}^{TTW} = \sum_{i=1}^{m} \eta_i \sum_{j=1}^{n} (1 + e_j^{WTT}) \cdot E_{i,j}^{TTW}$$

with:

E_{target}^{WTW}	the WTW energy consumption target in MJ/km
η_i	the share of vehicles with technology i in the new vehicle sales
e_j^{WTW}	the WTW energy consumption factor in MJ/MJ of energy carrier j
e_j^{WTT}	the WTT energy consumption factor in MJ/MJ of energy carrier j
$E_{i,j}^{TTW}$	the sales-weighted average TTW consumption of energy carrier j in MJ/km by vehicles with technology i

- Making an explicit distinction between conventional vehicles, plug-in hybrids and various ZEV technologies, the above equation can also be written as:

$$E_{target}^{WTW} = \sum_{i=1}^{l} \eta_{ICEV-i} \cdot (1 + e_i^{WTT}) \cdot E_{ICEV-i}^{TTW}$$
$$+ \sum_{j=1}^{m} \eta_{PHEV-j} \cdot ((1 + e_j^{WTT}) \cdot E_{PHEV-j}^{TTW} + (1 + e_{elec}^{WTT}) \cdot E_{PHEV-j-elec}^{TTW})$$
$$+ \sum_{k=1}^{n} \eta_{ZEV-k} \cdot (1 + e_{ZEV-k}^{WTT}) \cdot E_{ZEV-k}^{TTW}$$

with:

η_{ICEV-i}	the share of ICEVs with fuel i in the new vehicle sales
E_i^{TTW}	the sales-weighted average TTW energy consumption in MJ/km of ICEVs with fuel i
e_i^{WTT}	the WTT energy consumption factor in MJ/MJ of fuel i
E_i^{TTW}	the sales-weighted average TTW electricity consumption in MJ/km of ICEVs with fuel i
η_{PHEV-j}	the share of PHEVs with fuel j in the new vehicle sales
E_{PHEV-j}^{TTW}	the sales-weighted average TTW energy consumption in MJ/km of PHEVs with fuel j
E_{PHEV-j}^{TTW}	the sales-weighted average TTW fuel consumption in MJ/km of PHEVs with fuel j
e_{elec}^{WTT}	the WTT GHG emission factor of electricity in g/MJ
$E_{PHEV-j-elec}^{TTW}$	the sales-weighted average TTW electricity consumption in MJ/km of PHEVs with fuel j
η_{ZEV-k}	the share of ZEVs with energy carrier k in the new vehicle sales
e_{ZEV-k}^{WTT}	the WTT GHG emission factor in g/MJ of energy carrier $ZEV-k$
E_{ZEV-k}^{TTW}	the sales-weighted average TTW energy consumption in MJ/km of ZEVs with energy carrier $ZEV-k$

Other remarks	- This option is tested in the models of chapter 4 and 5.

2.4   Alternative options

2.4.1   *Inclusion of road fuel use in EU ETS*

c	*Inclusion of road fuel use in the EU ETS*

Definition:
- This is not an alternative metric for regulation of vehicles or vehicle manufacturers, but an alternative policy option, i.e. an economic instruments targeted at fuel producers or vehicle users instead of a vehicle / manufacturer based regulation.
- As explained e.g. in [CE 2010] the inclusion of the transport sector in EU-ETS can be implemented by means of upstream or downstream trading. In a cap & trade system, an upstream trading system implies that the cap will be put on companies that sell transport fuels. They need emission allowances for the CO_2 emissions caused by the fuels sold by them, and these will be capped. In an upstream trading system, the fuel consumers that actually use the fuels and thus emit the CO_2, will be the trading parties.
- A cap & trade system for CO_2, such as the EU-ETS, sets a cap on absolute emissions of the participants. These buy (e.g. through auctioning) or receive (for free) CO_2 emission allowances. If a participant emits more than the allowances owned by the participant, the participant has to buy more allowances from other participants that have more allowances than emissions, or that invest in CO_2 mitigation measures. The choice between the first and the latter will depend on the price, so that, at least in theory, all CO_2 mitigation measures with cost (per ton CO_2 avoided) lower than the cost of the emission allowances will be implemented.

Other remarks
- This option cannot be tested in the models of chapter 4 and 5.
- As stated in [CE 2010], most studies on transport and EU-ETS conclude that road transport would require a more upstream approach, where transport fuel sellers are the trading parties. This would limit the number of actors and associated transaction costs, and it could make use of existing national fuel administrations already in place for excise duty and VAT.
- When the traders are petroleum companies and other fuel sellers, they will divert these cost to the fuel consumers, by increasing the cost of fuel accordingly. They can also increase the share of renewable fuels, for which no or fewer CO_2 emission allowances are necessary (this choice will depend on the cost of alternative fuels versus that of allowances). Consumers will react, as in other forms of fuel pricing, by taking measures that result in less cost, i.e., in less CO_2 emissions. In road transport, for example, they may drive less or more fuel efficient, buy more fuel efficient vehicles, adapt logistics (in case of goods transport), reduce commuting distance, etc.
- CE Delft is currently carrying out a study for DG CLIMA on inclusion of transport (and built environment) in EU ETS.

2.4.2   *A baseline & credit system for vehicle manufacturers*

d	*A vehicle manufacturer based trading scheme based on lifetime vehicle GHG emissions*

Definition:
- This is not just an alternative metric but also an alternative regulatory approach (as far as allowing trading is concerned).
  - Including lifetime mileage in the metric is also proposed under option g).
- In contrast to EU-ETS this is not a "cap & trade" system but just a "trading scheme" associated with a vehicle based target.
  - This is usually called a 'baseline and credit' trading scheme.
- The interpretation of this option is that it is:
  - in addition to a manufacturer based target using a lifetime mileage weighted

     o allowing manufacturers to trade excess emissions on the basis of lifetime GHG emissions = gCO_2/km x lifetime mileage, either on a TTW or WTW basis with default lifetime mileage values defined e.g. as function of the vehicle's utility value.

Other remarks	

	• This option cannot be tested in the models of chapter 4 and 5.
	  o Using the SR1 cost assessment model [TNO 2011] one could test whether such a trading scheme would lead to a different distribution of reduction efforts over manufacturers and different overall costs for meeting the target, but such modelling is not foreseen as part of SR4.
	  o For the 2015 target this approach was already assessed to some extent (i.e. allowing trading of TA g/km emissions instead of lifetime GHG emission) in [TNO 2006] and [IEEP 2007] which showed that costs for meeting the target were somewhat lower (due to increased scope for internal averaging compared to a manufacturer based target without trading). But cost reductions were considered not to be sufficient to justify the cost of the administrative system needed to facilitate trading. Also it was expected that manufacturers would be unwilling to trade as it discloses strategic information.
	  o For the stricter post 2020 targets this option could become more interesting as it would allow setting targets that not all manufacturers can meet within their own sales portfolio and technical capabilities.

2.4.3 Cap & trade system for vehicle manufacturers

e1	*A cap and trade system for vehicle manufacturers, of total CO_2 emissions of vehicles sold (expressed in g/km)*

Definition:	

	• This is not just a metric but also a regulatory approach.
	  o Target set for g/km x sales instead of sales-weighted average g/km.
	  o Metric is g/km x sales
	• Cap set as total g/km of all new vehicles sold in a given year.
	  o This needs to be based on projected vehicle sales times a vehicle based g/km target. This option therefore can be considered as adding the possibility of trading to a target set using a TTW or WTW CO_2 based metric.
	  o If vehicle sales increase more than expected, manufacturers have to produce vehicles with lower g/km emissions and vice versa.
	• Could be based on TTW or WTW emissions.
	• This approach can also be applied to a MJ/km target.

Other remarks	
	• This option cannot be tested in the models of chapter 4 and 5. o Using the SR1 cost assessment model [TNO 2011] one could test whether such a trading scheme would lead to a different distribution of reduction efforts over manufacturers and different overall costs for meeting the target, but such modelling is not foreseen under SR4.

e2	*A cap and trade system for vehicle manufacturers, of total energy consumption of vehicles sold (expressed in MJ/km)*

Definition:	

	• This is not just a metric but also a regulatory approach.
	  o Target set for MJ/km x sales instead of sales-weighted average MJ/km.
	  o Metric is MJ/km x sales
	• Cap set as total MJ/km of all new vehicles sold in a given year.
	  o This needs to be based on projected vehicle sales times a vehicle based MJ/km target. This option therefore can be considered as adding the possibility of trading to a target set using a TTW or WTW MJ based metric.
	  o If vehicle sales increase more than expected manufacturers have to produce

vehicles with lower MJ/km energy consumption and vice versa.
- Could be based on TTW or WTW energy consumption.

Other remarks	• This option cannot be tested in the models of chapter 4 and 5. o Using the SR1 cost assessment model one could test whether such a trading scheme would lead to a different distribution of reduction efforts over manufacturers and different overall costs for meeting the target, but such modelling is not foreseen in SR4 work plan.

2.4.4 Inclusion of embedded emissions in WTW approaches

f   *Inclusion of embedded emissions in the WTW approaches listed above*

Definition:	• Embedded GHG emissions (or life-cycle emissions) are emissions directly or indirectly originating from other phases of a product's life cycle than the use phase. In the production phase GHG emissions are associated with mining, production, and transport of materials, manufacturing of components and vehicles, and transport / distribution of products. In the decommissioning phase emissions are associated with scrappage of vehicles, recycling of materials and waste disposal.
	• Embedded emissions can be included in the metrics as developed under a), b), d) and e).
	• Embedded emissions are identified by means of a so-called Life Cycle Analysis (LCA). Scientific methods for this are well established, but the reliability of the results depends very much on the quality of the input data.
	• As manufacturers do have control over embedded emissions associated with vehicle production, LCA values could be based on actual performance of individual manufacturers.
	   o This would, however, require an agreed and accountable methodology for determining these actual emissions.
	• A 1st order approach with default values would suffice to cater for main differences in embedded emissions when moving from ICEVs to e.g. EVs or FCEVs.
	   o Default values would need to be updated regularly.

Other remarks	• This option could in principle be tested with models of chapter 4 and 5, but inclusion of embedded emissions has not been considered as part of the scope for these simplified models.

2.4.5 Combining different options with e.g. size-dependent mileage weighting

g   *Combining different options and inclusion of other aspects such as size-dependent mileage weighting.*

Definition:	• For a given vehicle lifetime GHG emissions = gCO_2/km x lifetime mileage, either on a TTW or WTW basis. • As actual mileages cannot be used, default lifetime mileage values must be defined. • Mileage weighting only affects the metric if the mileage is different for different vehicles. Mileage therefore needs to be correlated with one or more objectively identifiable vehicle attributes. • The utility parameter used in the legislation is an obvious candidate for a size dependent mileage weighting. o The most obvious implementations are in the form of a size- or mass-based mileage. The former is preferred as vehicle mass will be strongly affected by weight reduction measures in the next decades. Size could e.g. be parameterised as pan area (length x width) or footprint (wheelbase x track width).

- Besides size-dependent the mileage could also be technology dependent. EVs may be assumed to be used in applications with lower annual mileages, while e.g. diesel vehicles are and FCEVs on hydrogen may be used in applications with longer annual mileages.
- For mileage weighting the type approval emission value of every vehicle sold is multiplied by the lifetime mileage assume for that vehicle. Dividing the sum of all lifetime GHG emissions of all vehicle sold by the sum of the lifetime mileages of all vehicles sold, yields the lifetime-mileage weighted average emissions.
   - This can be applied per manufacturer as well as to all vehicles sold in Europe.
- Mileage weighting can be included in the metrics as developed under a), b), and e).
   - Mileage weighting is already included in option d).
- Mileage weighting has already been indicatively explored as part of Service Request 1 [TNO 2011]. The main options are clear.

Other remarks	• This option is not tested with the models of chapter 4 and 5, as it has been decided not to include mileage weighting in the structure of the simplified fleet model.

3 Relevant criteria and issues for comparing options

3.1 Introduction

In this section, a set of criteria is identified against which options can be evaluated. These include criteria related to:

- Net GHG emission impact of the metric
- Impact of the metric on technology development and implementation, including the metric's impact on the transition towards a future sustainable transport system
- Economic impacts of the metric, including cost effectiveness from a manufacturer, user and societal perspective
- Impact of the metric on energy dependence
- Compatibility with other policy instruments
- Ease of implementation
- Acceptability

Various criteria are described in more detail in section 3.2. As will become clear from their description, many criteria are interconnected. Impacts on costs e.g. depend on different technology choices which may be promoted by different metrics, and these in turn affect impacts on WTW emissions and the extent to which a metric fosters the transition towards a longer term sustainable transport system.

In the following chapters of this report, as well as in additional analyses which have been carried out in Service Request 8 and separately reported in [TNO 2013], evaluations are made that provide information on how different metrics score against several of the criteria listed below. A systematic analysis of all metrics against all criteria, however, is not possible within the context of this project.

3.2 Relevant criteria for describing pros and cons of options

3.2.1 Net GHG emission impact of the metric

- Control over the net contribution of the legislation to reaching overall goals with respect to reduction of GHG emissions and energy consumption
    - CO_2 legislation for vehicles does not automatically lead to a net reduction of WTW GHG emission of the transport sector. The latter are a product of the number of kilometres driven (transport volume), the emissions and energy consumption per km of vehicles and the WTT emissions per unit of energy from the production of fuels / energy carriers. As soon as other energy carriers than petrol and diesel come into play, a reduction in vehicle emissions no longer automatically leads to an overall reduction in emissions at a given level of transport volume. the same can be argued for primary energy consumption.
    - Including WTT emissions or energy consumption may improve control over the net impacts of vehicle legislation on overall GHG emissions and energy consumption.
    - Even in a situation without a significant share of alternative energy carriers including WTT aspects may be considered useful, as it can also help to make sure that improvements in conventional vehicle efficiency are not counteracted by increases in WTT emissions of fossil fuels due to e.g. the increased use of unconventional oil or synthetic fuels.
    - In this context also the following two aspects are relevant:
        - Relation between type approval values and real-world performance
        Fuel consumption and CO_2 emissions under real-world (RW) driving conditions are generally larger than on the type approval (TA) test. For conventional vehicles fuel consumption and CO_2 emissions are strictly correlated so that different metrics do not influence the RW/TA ratio directly. Indirect effects may occur if different metrics lead to different technology choices which may have different consequences for the RW/TA ratio. This becomes even more complex when

alternative technologies are introduced[6], where TTW CO_2 emissions and TTW energy consumption are no longer directly correlated.

- Knock-on consequences

  Changes in vehicle technology or other vehicle attributes in response to regulation may lead to changes in vehicle prices and in vehicle operation costs (incl. energy costs), as also mentioned in section 3.2.3. These changes in total cost of ownership may lead to positive or negative[7] knock-on consequences on vehicle ownership and usage which may amplify or dampen the effect of the regulation on overall GHG emissions from transport. The choice of metrics or regulatory approach affects technologies chosen to meet the targets and may thus affect the size of possible knock-on consequences.

- Sensitivity of the <u>WTW GHG emissions of newly sold vehicles</u> with respect to variation in the mix of technologies which is used to meet the target set by the CO_2 regulation
  - o In first order the legislation is aimed at reducing the GHG emissions of newly sold vehicles. This criterion reflects the desire that the future metric and regulatory approach in terms of net WTW GHG emission reduction should be insensitive to the mix of technical options chosen by manufacturers to meet the target.
  - o More specifically, the current TTW CO_2 based metric has the problem that WTW emissions of new vehicles go up when the share of electric, plug-in hybrid or fuel cell vehicles increases. The post-2020 metric should preferably not have this drawback.
  - o In this context it is relevant to gain insight in the expected WTW CO_2 emission reduction that is achieved for a technology mix that is cost-optimal from a manufacturers' and user perspective[8].

- Sensitivity of the achieved <u>fleet-wide WTW GHG emission reduction</u> with respect to variation in the mix of technologies which is used to meet the target set by the CO_2 regulation
  - o This criterion is directly related to the above. Evolution of WTT emission factors for e.g. electricity generation and hydrogen production affects the fleet-wide impacts of introducing alternative propulsion technologies.

- Sensitivity of the achieved <u>fleet wide GHG emissions, according to the IPCC definition of GHG emissions attributable to EU or Member States</u>, with respect to variation in the mix of technologies which is used to meet the target set by the CO_2 regulation
  - o This aspect could be politically relevant in international negotiations on GHG emission reduction targets, especially in relation to the use of (imported) biofuels. The latter count as zero-emission for an IPCC-based target set for the transport sector. Emissions of biofuel production are attributed to the agricultural sector or do not count at all (in case of imported biofuels).

3.2.2   Impact of the metric on technology development and implementation

The current CO_2 legislation for passenger cars and vans is intended to promote the development and application of technologies that reduce CO_2 emissions from cars. Which technologies are more or less strongly incentivised depends partly on the target level (e.g. as beyond some point lower levels can no longer be met with improvements in conventional ICEV technology alone) and partly on the details or modalities of the legislation. The metric is part of the latter.

- The degree to which the approach may <u>favour specific technologies</u> and thus depart from the accepted technological neutrality desired in EU legislation
  - o The criterion of "technology neutrality" is not unambiguously defined. Different definitions are possible, with different levels of "strictness, and several are relevant in the context of evaluating alternative metrics[9]:
    - Target can be met with multiple technologies;

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[6] For plug-in hybrid vehicles the direct CO_2 emissions in real-world driving are also affected by the share of electric driving. The RW/TA ratio for TTW CO_2 emissions is expected to be higher than for TTW energy consumption, where electric driving does not count as zero.
[7] Negative knock-on consequences are also known as rebound effects.
[8] This specific aspect is analysed in more detail in SR8 [TNO 2013]
[9] This specific aspect is analysed in more detail in SR8 [TNO 2013]

- Target can be met with multiple technologies at comparable additional manufacturer costs;
- Target can be with practically achievable shares of different technologies;
- The metric-target combination incentivises different technologies proportional to their contribution towards meeting agreed objectives. This is e.g. determined by whether different technologies contribute to meeting the target in a way that is proportionate to their contribution to the overall fleet-wide WTW GHG emission reduction or to their cost-effectiveness with regard to GHG emission reduction. The latter is affected by possible cost leverages through the reduced need for applying CO_2 emission reduction technology in ICEVs as a result of selling a significant share of alternative vehicles.

- The degree to which the metric <u>stimulates manufacturers to invest in technologies that may effectively contribute to the transition towards a sustainable transport</u> system in the long term
  - o Future regulation should preferably promote the transition from the current high carbon fossil-based system to the use of low-carbon energy sources (possibly including nuclear of fossil-based energy combined with carbon capture and storage) and ultimately to renewable primary energy for the transport sector.
  - o Given that a large share of alternative technologies is likely to be necessary for meeting longer-term (2050) GHG reduction goals for the transport sector, and knowing that implementation of these alternatives is a complex and time-consuming transition process, it may be considered beneficial for a metric if it somehow promotes innovation and early action by manufacturers in marketing these alternatives. Obviously such an incentive is not only determined by the choice of metric but by the combination of metric and target level.

- <u>Alignment</u> of technology mix that leads to lowest costs for manufacturers or users with the technology mix that leads to lowest GHG abatement costs from a societal perspective[10]
  - o It is to be expected that manufacturers will optimise the mix of technologies that they choose to meet a given target under a given metric in such a way that their costs are minimised. As long as only conventional vehicles are sold minimizing additional manufacturer costs for meeting a given target also leads to minimal costs to the user, as the fuel cost savings are to first order determined by the target to be met. When alternative technologies come into play the situation becomes more complex, and the optimum from a manufacturer cost point of view may no longer be aligned with the optimum from a user point of view. In turn the lowest cost solutions from a manufacturer and / or user perspective may not be aligned with the lowest cost solution from a societal perspective.
  - o Ideally the metric works in such a way that it incentivises manufacturers and users to choose technologies that contribute to meeting the overall GHG emission reduction targets at optimal societal costs.

- <u>Promoting improvements in energy efficiency in all powertrain technologies</u>, incl. those with zero TTW emissions
  - o Including WTT emissions into the metric is not only relevant to make sure that vehicles with zero TTW emissions on the type approval test -but non-zero WTT emissions- are appropriately valued relative to conventional vehicles. It will also make sure that there is an incentive to keep increasing the efficiency of these alternative technologies. The same argument holds for moving to a TTW or WTW energy based metric. Such an incentive is not present in a TTW CO_2 based metric.

3.2.3 Economic impacts of the metric

- <u>First order economic impacts</u> include:
  - o Impacts on costs at the <u>manufacturer</u> level
    - In first order determined by the additional manufacturer costs associated with implementing incremental improvements or alternative technologies for meeting the target.
  - o Impacts on costs at the <u>user</u> level

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[10] Analysis of this criterion is one the core assessments carried out in SR8 [TNO 2013]

- Impact on total cost of ownership, influenced by increased vehicle costs on the one hand and changes (in most cases a reduction) in energy costs on the other hand.
- Due to taxation on vehicles and energy carriers, in the transport sector the cost-effectiveness of reduction options from a societal point of view generally differs from the cost-effectiveness from the user's perspective.
    - o Impacts on costs at the <u>societal</u> level
        - Impact on total societal costs
        - Impact on CO_2 abatement costs, i.e. on the cost effectiveness of vehicle GHG emission reduction

- <u>Resilience</u>, or sensitivity of the costs to variations in compliance strategies[11]
    - o In relation to the above cost criteria and the criteria related to the choice of technologies also the sensitivity of costs with respect to technology choices, more specifically the realised shares of alternative technologies, is a relevant criterion.
    - o When significant shares of alternatives are necessary to meet a given target, this involves a certain level of uncertainty for manufacturers as selling a certain amount of alternative vehicles requires users buying these vehicles. If the costs for meeting the target are very sensitive to the share of alternatives, e.g. due to high marginal costs for compensating emission reductions not realised by these alternative with increased efficiency of conventional vehicles, this involves a risk for manufacturers.

- <u>Wider economic impacts</u> would include:
    - o impacts on the competitiveness of the European car industry;
    - o impacts on competitiveness of businesses using vehicles;
    - o impacts on employment and economic growth in the EU;
    - o effects on mobility volumes and modal choice and indirect impacts of that on other parts of the economy.

3.2.4   Impact of the metric on energy dependence

- Impact of different scenarios on the <u>total primary energy consumption</u>
    - o From a GHG emissions point of view it is not necessarily desired to make the net WTW primary energy consumption insensitive to the mix of technical options chosen by manufacturers to meet the target. 1 MJ of primary fossil energy is not equivalent to 1 MJ of renewable energy.
    - o But given the scarcity and costs of renewable energy a target that would easily allow the WTW primary energy consumption to increase with the increased use of low carbon energy carriers would make it more difficult to make sure that the required amounts of such energy carriers can be delivered at acceptable costs.

- Impact of different scenarios on the <u>primary energy consumption from different sources</u>
    - o The impact on the metric on the future energy mix for transport is relevant from an energy dependence or energy security point of view.

- <u>Degree to which energy efficiency is promoted</u>, also for vehicles with zero or low WTW GHG emissions
    - o The current TTW CO_2-based metric does not provide an incentive for BEVs and FCEVs to become more efficient. For the longer term such incentives could be desirable.
    - o There are intrinsic drivers to improve efficiency of zero-emission vehicles. In case of BEVs a higher efficiency allows longer range with the same battery or the same range with a smaller battery (and thus lower costs). Also energy costs are reduced. In FCEVs higher efficiency also allows longer driving range on a tank of hydrogen and lower fuel costs.

3.2.5   Compatibility with other policy instruments

- *Suitability* of the values based on a given metric <u>for application in labelling or in vehicle taxation</u> differentiated by CO_2 emissions or energy consumption

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[11] This specific aspect is analysed in more detail in SR8 [TNO 2013]

- o Where e.g. a WTW-based regulation at the European level is likely to work with EU-average WTT emission factors, Member States may value different technologies differently based on MS-specific WTT emission factors that may differ significantly from EU-averages.
    - If the metric is also to serve as a basis for policy instruments in Member States (e.g. CO_2-based taxation) the values used at the EU level may not be acceptable to Member States.

- Interaction with the RED and FQD, specifically the parts of these policy instruments related to reducing the carbon intensity of energy used for transport.
    - o This issue is part of a broader evaluation carried out in chapter 8 of this report.

3.2.6   Ease of implementation

- Administrative burden
    - o Monitoring of type approval test results of newly sold vehicles is already part of the present regulation. The monitoring mechanism may need some modifications to cater for a new metric, but does not have to be developed and implemented from scratch.
    - o If WTT or life-cycle impacts are to be included these need to be monitored or at least assessed at regular intervals. A mechanism for this would need to be developed and implemented.

- "Measurability" of required input parameters with respect to vehicles and energy carriers
    - o Possible need to develop new vehicle test procedures
        - UN-ECE R101 caters for measurement of CO_2 emissions and energy consumption of plug-in hybrids[12]. This procedure may need to be updated to generate more representative results for the TTW CO_2 emissions and the combined consumption of fuel and electricity by plug-in hybrids.

3.2.7   Acceptability

- Acceptance by stakeholders, incl. industry and Member States
    - o To increase acceptance the metric should be primarily linked to parameters that are influenced by the regulated entity.
        - According to some stakeholders WTT based approaches are considered problematic for OEMs, who would be regulated (and potentially penalised) on the basis of a metric that is considered be partly out of their control due to the WTT factor. This, however, is a matter of interpretation. In a WTW-based metric manufacturers are not made responsible for the WTT emissions, but in the planning of their product portfolio they are made responsible for taking account of the fact that (different) energy carriers have (different) WTT emissions.
    - o For the automotive industry predictability of specific targets for individual OEMs is extremely important.
        - Including WTT emissions or energy consumption may reduce predictability of the target, especially if WTT factors are based on monitoring of actual emissions. WTT factors need to be updated regularly to match trends in the energy system, but the frequency of the updates is crucial for the predictability of the targets.
        - Predictability is improved if those elements in the legislation that OEMs cannot influence (specifically WTT emission factors for fuels/electricity in the EU or a certain country) are the same for all manufacturers and determined well in advance to allow product portfolio planning by OEMs in response to periodic changes in these elements.
    - o The acceptability of WTT factors included in the legislation strongly depends on the methodology used to determine these factors. Agreement on the monitoring mechanisms implemented to assess WTT factors is thus an important factor in increasing acceptance of WTW-based metrics.
        - This aspect is especially relevant if LCA aspects (embedded emissions from the production and decommissioning phases) would be included in the metric.

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[12] Off-Vehicle Charging (OVC) hybrids in R101 terminology, a category including both plug-in hybrids(PHEVs) and extended-range electric vehicles (EREVs).

- <u>Representativeness</u> of the values based on a given metric for the impacts in specific countries
    - o This criterion is related to the above criteria on WTW impacts of the metric.
    - o Where e.g. a WTW-based regulation at the European level is likely to work with EU-average WTT emission factors, Member States may value different technologies differently based on Member State specific WTT emission factors that may differ significantly from EU-averages.
        - If the metric is also to serve as a basis for policy instruments in Member States (e.g. CO_2-based taxation) the values used at the EU level may not be acceptable to Member States.
        - Also there may be a conflict of interest between the optimal way of meeting an EU level WTW target for cars and the optimal solution at the MS level for meeting GHG emission targets based on IPCC accounting rules.

- <u>Transparency</u>, intelligibility, simplicity
    - o Alternative metrics may lead to more complex legislation. In general increased complexity tends to reduce acceptance.

3.2.8   Other criteria to be considered

In addition to the above criteria, which largely focus on the legislation's effectiveness for reducing energy consumption and CO_2 emissions of vehicles, also other aspects could be considered. These are e.g. specified in the guidelines for Impact Assessments that the European Commission has to make of proposed legislation. The most relevant aspect to be listed here could be:

- <u>Potential effects on air pollution, noise, and safety</u>, etc.
    - o These impacts are directly related to changes in the (propulsion) technologies applied to vehicles. CO_2 legislation may lead to a shift in sales between petrol and diesel or may at some point require alternative technologies such as battery-electric and fuel cell vehicles with zero local exhaust emissions and low noise emissions especially in urban driving.
    - o These impacts could especially be relevant if also life-cycle impacts (from production, decommissioning / recycling) would be included.
    - o Indirectly air pollution, noise, and safety may be affected by the knock-on consequences of the legislation. If CO_2 legislation affects the purchase price of vehicles or the costs per kilometre, this will have impacts on the transport volume as well as the modal split, which in turn have impacts on air pollution, noise, and safety, but also on e.g. congestion.

3.3   Methodological issues related to metrics and regulatory options

3.3.1   How to account for GHG intensity of energy carriers such as electricity and hydrogen?

Including WTT emissions into the CO_2 regulation for vehicles requires a specific and accountable methodology that defines how upstream emissions are to be attributed to energy carriers such as electricity and hydrogen. A detailed discussion as well as a determination of WTT factors for use in the assessments carried out in this study can be found in Annex A.

At this point in time there is no scientific consensus on the method for attributing GHG emissions from production of electricity or hydrogen to electric and hydrogen vehicles. Attribution of upstream emissions from electricity production can e.g. be based on average emission factors for the national generation system or marginal emissions determined at different system levels. Also average emission factors can be defined in different ways, e.g. based on the national production mix or the national consumption mix (including imports and excluding exports) or more specifically on the mix of sources from which electricity is supplied to consumers.

The issue is furthermore complicated by the interaction with the EU-ETS. Formally it could be argued that the marginal emissions of additional electricity production are zero due to the emission cap imposed by the EU-ETS. In practice this is not likely to be the case due to various forms of carbon leakage in the EU-ETS, e.g. related to JI/CDM which allows the purchase of emission credits from

projects outside the EU. However, even without this, it is difficult to see how and why in practice the "last" electricity used should be given a different GHG intensity from the rest of the electricity consumption. From a system point of view the marginal emissions approach makes sense, as it assesses what the net impact on the CO_2 emissions of the system is of a given change in the system, all else remaining equal. The situation of one change in the system, however, is rather academic. In reality there is always more than one thing changing. It then becomes difficult / impossible to say which kWh (with which marginal emissions) is to be attributed to which change. This would be the main argument to go for average emissions rather than a marginal emissions approach.

Overall some approach based on average emissions seems most fair, as it attributes emissions to all users of electricity, so that also all electricity consumers benefit from greening of the electricity production. Similar considerations apply to hydrogen.
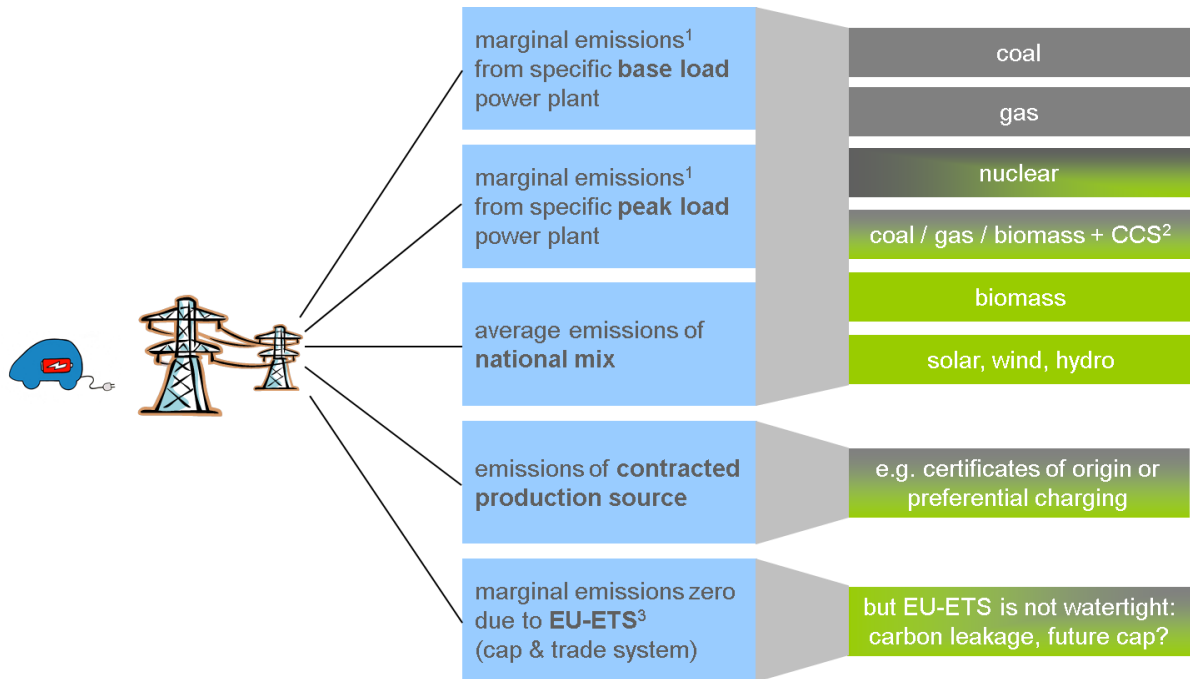
1) "marginal emissions" are emissions produced by power plant that is switched on, or from which output is increased, when EV is plugged into the grid and starts to charge
2) CCS = Carbon Capture and Storage
3) ETS = Emission Trading System

Figure 2   Different ways of attributing upstream emissions of electricity production to consumed kWhs

In case of biofuels WTT emissions often occur outside the country or even outside the EU. Proper monitoring and certification of these emissions, and appropriate means of accounting for Indirect Land-Use Change (ILUC) effects, are the main challenges.

3.3.2   Challenges for CO_2 regulation and FQD with respect to accounting for effects in the entire energy chain

The Fuel Quality Directive[13] contains elements aiming at decarbonisation of energy carriers for transport. Together with the vehicle-based CO_2 or energy regulation, aimed at improving the energy efficiency of vehicles, this is intended as a kind of integrated approach to achieve sustainable mobility (see Figure 3). But whether the combination secures that the right technologies are chosen and the desired reductions are achieved depends on details of their implementation. With the vehicle regulation it is now considered to include WTT aspects. At the same time development of a metric for

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[13] DIRECTIVE 2009/30/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC

effectuating the FQD policy seems to require inclusion of factors that account for the TTW efficiency of vehicles. This constitutes a risk for double counting or for creating flaws and loopholes.

The FQD states that "Suppliers should, by 31 December 2020, gradually reduce life cycle greenhouse gas emissions by up to 10 % per unit of energy from fuel and energy supplied. This reduction should amount to at least 6 % by 31 December 2020, compared to the EU-average level of life cycle greenhouse gas emissions per unit of energy from fossil fuels in 2010, obtained through the use of biofuels, alternative fuels and reductions in flaring and venting at production sites. Subject to a review, it should comprise a further 2 % reduction obtained through the use of environmentally friendly carbon capture and storage technologies and electric vehicles and an additional further 2 % reduction obtained through the purchase of credits under the Clean Development Mechanism of the Kyoto Protocol." The methodology to calculate the contribution of electric road vehicles towards this target is currently being developed. Such methodology is in first instance necessary to enable energy suppliers to report annually to the authority designated by the Member State on the greenhouse gas intensity and amount of different energy carriers supplied to the transport sector within that Member State. The way the methodology is defined will largely determine the net incentive provided by the FQD for energy suppliers to invest in promoting the use of electric vehicles.
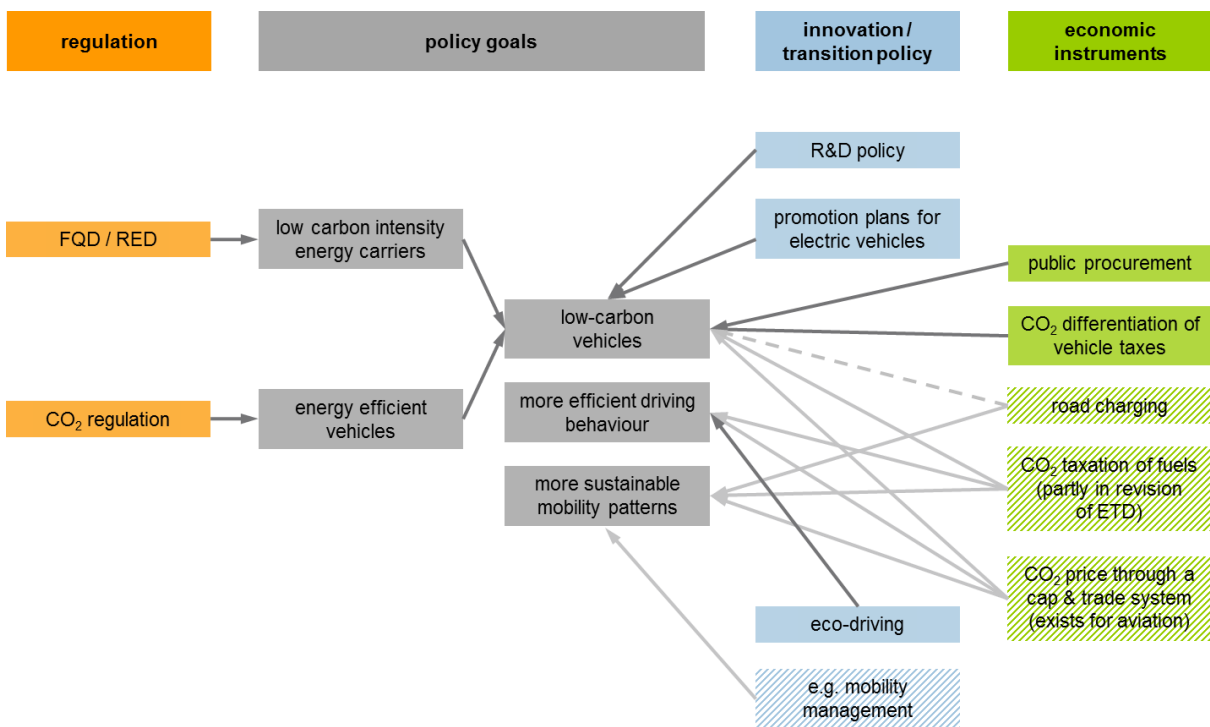
Figure 3   Interaction between FQD/RED and CO$_2$ regulation in promoting low-carbon vehicles and role of these measures in a wider policy context aimed at sustainable mobility

The case of the FQD already reveals some complexities. The first one concerns e.g. the way in which one can determine the amount of electricity that is supplied to electric vehicles. Electricity supplied through charging poles can be monitored, but the amount of electricity taken up by electric vehicles through home charging is more difficult to measure. The second issue relates to monitoring the carbon intensity. The formal definition of carbon intensity (in gCO$_2$-equiv./MJ) of all energy carriers used for transport in a country is:

$$GHG\ intensity = \frac{\sum_i GHG_i \times E_i}{\sum_i E_i}$$

In the above formula GHG_i is the carbon intensity of energy carrier i (in gCO$_2$-equiv./MJ) and E_i the amount of energy of type i used in transport (in MJ).

In this definition the replacement of fossil fuels by electricity may lead to an increase in the GHG emissions per MJ, even when the assumed gCO_2/MJ for electricity is such that electric vehicles would provide a net gCO_2/km reduction compared to conventional vehicles. This is due to the fact that electric vehicles are much more energy efficient on a tank-to-wheel basis than conventional vehicles. In order for the FQD to provide a net incentive for promoting the use of electric vehicles, the above formula thus needs to be adjusted to correct for the difference in energy efficiency of conventional and electric vehicles. In the provisions for the FQD that are currently being developed this is done in the following way:

$$GHG\ intensity = \frac{\sum_i GHG_i \times AF_i \times E_i}{\sum_i E_i}$$

In this equation AF_i is an adjustment factor that accounts for the difference in efficiency between conventional vehicles and vehicles with alternative energy carrier i. In the current proposal AF_i equals 1 for all conventional fuels and 0.4 for electric vehicles. For other energy carriers no specifications are proposed. Apart from the apparent lack of generalisation, it is most of all clear that this correction moves the formula away from a formal definition of carbon intensity, and requires introduction of correction factors of which the value is debatable and affects the impact of the policy instrument.

The GHG intensity targets of the FQD and the CO_2 legislation for cars and vans are intended as complementary measures that together induce a net reduction of GHG emissions from transport by on the one hand decarbonising the energy used by transport and on the other hand reducing energy demand by making vehicles more efficient. Both instruments not only reduce emissions from vehicles running on fossil fuels, but also provide incentives for the increased use of electricity and hydrogen in the transport sector. Proper tuning of the metrics and target settings used in both instruments is necessary to avoid loopholes or conflicting incentives. To fully manage achievement of a net reduction in GHG emissions from transport also additional policy is needed to control the growth of vehicle kilometres.

More detailed considerations on interaction between CO_2 regulation and the FQD / RES are given in chapter 8.

3.3.3 CO_2 emissions and energy consumption of plug-in hybrids

Plug-in hybrids and range-extender electric vehicles are vehicles that are able to run on fuel, e.g. petrol or diesel burnt in an ICE, and electricity charged from the grid. As defined in UNECE R101, fuel consumption and CO_2 emissions of such plug-in hybrids and range-extender electric vehicles are determined by combining the results of two tests, one starting with a fully charged battery and one starting with a depleted battery. These test results are combined as follows:

$$M = \frac{D_e \cdot M_1 + D_{av} \cdot M_2}{D_e + D_{av}}$$

where:

M = mass emission of CO_2 in grams per kilometre;

M_1 = mass emission of CO_2 in grams per kilometre with a fully charged electrical energy/power storage device;

M_2 = mass emission of CO_2 in grams per kilometre with an electrical energy/power storage device in minimum state of charge (maximum discharge of capacity);

D_e = vehicle's electric range, according to the procedure described in Annex 9 to this Regulation, where the manufacturer must provide the means for performing the measurement with the vehicle running in pure electric operating state;

D_{av} = 25 km (assumed average distance between two battery recharges).

Similar formulae are used to calculate type approval fuel consumption, electricity consumption and pollutant emissions on the basis of the two separate tests.

Plug-in vehicles (PHEVs) with an electric range exceeding 11 km (the length of the NEDC cycle), and with sufficient electric power, are able to run the first test without use of the ICE, and thus without

consuming fuel. For those vehicles the combined test result can be seen as representing the CO_2 emissions over a trip with a length equalling the vehicle's electric range (driven purely electric) plus 25 km driven on the ICE.

For current PHEVs on the market typical electric ranges, as measured in type approval testing, vary from 25 km (Toyota Prius plug-in) to 87 km (Opel Ampera and Chevrolet Volt). This means that the share of electrically driven kilometres, as implicitly assumed in the above formula, ranges from some 50% to about 80%. How PHEVs compare to other propulsion systems in the various metrics is heavily determined by this share of electrically driven kilometres and thus by the choice of the value for D_{av}. If these shares do not correspond adequately to average shares of electrically driven kilometres under real world driving conditions, the metrics may not treat PHEVs in a fair way compared to other options.

As PHEVs only entered the market recently it could be advisable to monitor actual shares of electric driving and to adjust the value of D_{av} to the observed average as soon as this has been established with a sufficient degree of reliability and representativeness.

4 Impact of various metrics on WTW emissions of new vehicles in the target year and interaction of technologies

4.1 Introduction

In this chapter the "internal logic" of various alternative metric options is analysed by means of example calculations that illustrate:

a) the impact on the average new vehicle WTW GHG emissions of varying shares of alternative technology vehicles in the new vehicle sales and of varying WTT emissions of the associated energy carriers;
b) the impact of changes in the share and energy efficiency of alternatively powered vehicles such as EVs on the required energy efficiency and CO_2 emissions of ICEVs (or vice versa) for meeting a given target.

The former (aspect a) is a check on whether the introduction of alternative technologies may lead to "WTW CO_2 leakage" under a given metric. Such leakage occurs under the current TTW-based CO_2 target, but it needs to be checked whether and to what extent alternative metrics solve this problem.

Aspect b) illustrates what we call the "leverage" or "waterbed function" that is inherent to targets that cover the average emissions or energy consumption of a group of vehicles. Such a leverage is already present without alternatively powered vehicles, as under the present regulation selling one very efficient vehicle allows all other vehicles in the sales of a manufacturer to emit a fraction more. This leverage is amplified when certain vehicle types have a very different performance from others under a given metric, as is the case for EVs and FCEVs which count as zero emission under the present TTW-based CO_2 target.

The analysis also explores the amount of flexibility that exists under a given target / metric combination in terms of variation in the shares of different technologies that allow the target to be met.

4.2 Methodology for modelling the impact of various metrics on TTW and WTW emissions and energy consumption of new vehicles in the target year

4.2.1 A simplified modelling approach

A spreadsheet tool has been developed to assess the allowed energy consumption and CO_2 emissions of average conventional vehicles (a mix of petrol and diesel vehicles) under targets set on the basis of different metrics as function of the share of alternative zero-emission vehicles (ZEVs), their energy efficiency, and the WTT GHG emissions in the various energy chains, and to assess the average WTW CO_2 emissions of new vehicles as function of the aforementioned aspects.

As the intention of the assessment is to illustrate the inherent logic and basic sensitivities of various metrics, the model only includes battery electric vehicles (EVs) as alternative technology. Similarly, for conventional vehicles no distinction is made between petrol and diesel or between different size classes. While this simplifies the analysis, it may cause the sensitivity to be somewhat exaggerated compared to a situation with more types of powertrains available for some of the metrics, as the impact of changes in the assumptions for one of the technologies (in this case EVs) could then be compensated not only by changes in the characteristics of ICEVs but also of other alternatives in the new vehicle fleet (e.g. FCEVs). For the TTW CO_2 based metric, however, all ZEV count as zero emission (with the effect of a given share of PHEVs roughly equivalent to that of a smaller share of EVs), so that conclusions do not depend on the ZEV chosen as in the example calculations.

Especially in the medium term it may be more likely for PHEVs to achieve a large share in the new vehicle sales than for EVs. The above described simplification of the modelling can be considered to

cater for that as well, as the impact of an assumed share of EVs to first order can be considered roughly equal to that of a twice as large share of PHEVs.

The steps followed in this assessment are shown in the flow chart depicted in Figure 4.
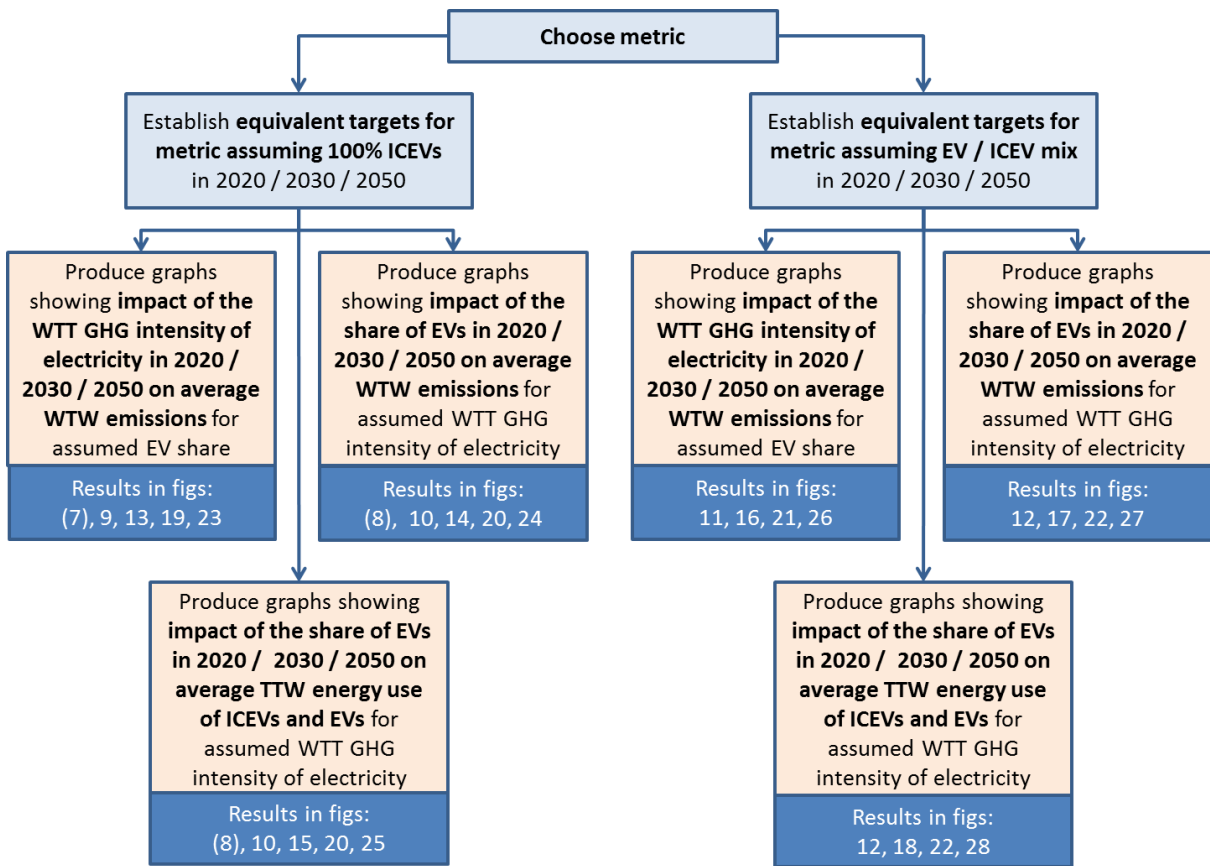
Figure 4   Flow chart showing the steps followed in the assessment presented in this chapter

4.2.2   Setting equivalent targets for different metrics

Comparison of the sensitivity of different metrics with respect to variations in the share of alternative vehicles, their energy efficiency, and the WTT GHG emissions in the various energy chains requires definition of equivalent targets under the different metrics in order to separate the impact of the stringency of the target from that of the choice of metric. This approach is necessary for the purpose of this comparison but would cease to be of concern if a choice was made to use any of the options available. The method for determining equivalent targets could then be applied to assure that the first target defined on the basis of a new metric, e.g. in year $x + 5$ is of a stringency that is compatible with what would be expected on the basis of the TTW CO_2 based target existing for year x.

If the starting point is a TTW CO_2 based target, as in the current legislation, the calculation of equivalent targets for alternative metrics such as WTW CO_2 emission or TTW or WTW energy consumption, depends on the technologies that are assumed to be deployed in order to reach the TTW CO_2 based target.

Assuming the target is met by ICEVs only, the TTW CO_2 based target can be translated to the other metrics using the TTW and WTT CO_2 emission values (in g/MJ) for conventional fuels. WTT CO_2 emissions may change over time as function of changes in the fossil energy chains and an increasing share of blended biofuels.

Assuming that the target is met by a mix of ICEVs and EVs, the new vehicles sales average WTW CO_2 emissions or TTW or WTW energy consumption is calculated using the TTW and WTT CO_2 emission

values (in g/MJ) for conventional fuels, combined with the WTT emissions from the production of alternative energy carriers and the assumed energy consumption of alternative vehicles using these energy carriers (in this simplified case: electricity generation and EVs). These values are used as equivalent targets for the different metrics.

For short term targets (up to 2025 or 2030) both options are generally feasible in the light of current knowledge. For longer term targets on a trajectory that is compatible with the Commission's ambition to reduce CO_2 emissions from transport by 60% the target values can in principle not be met by ICEVs only, unless one assumes currently unknown technologies to be available or drastic changes in the size and performance of vehicles. Also equivalent targets based on the 100% ICEV assumption may lead to unrealistic values for the TTW energy consumption of ICEVs if the target is assumed to be met with a finite share of EVs in the new vehicle fleet. This will be illustrated further on in this chapter. For all options assessments are presented for both ways of identifying equivalent targets.

4.2.3   Example calculations

Example calculations are performed for three different target years: 2020, 2030 and 2050. The starting point for the 2020 situation is the existing 95 g/km target based on TTW CO_2 emissions. For 2030 and 2050 TTW CO_2 targets have been derived from the reconstruction of the reference scenario underlying the European Commission's White Paper as described in chapter 5. These assumptions are therefore consistent with the reference scenario used for the assessment at the fleet level presented in that chapter. Vehicle and energy carrier specifications and equivalent targets for the different metric and target years are listed in Table 2. The precise value of the targets is not crucial since the purpose of the analysis is to understand what the implications of different approaches would be.

The WTT emissions from electricity generation in Table 2 correspond to the "decarbonisation scenario" as described in Annex A.2.3. Similarly the WTW emission factors for biofuels, which have been used to calculate the WTW emission factors of conventional fuel with increasing biofuel share between 2020 and 2050, are based on the "decarbonisation scenario" as described in Annex A.2.2.

It is to be noted that these calculations use only one set of assumptions for the three years and are for illustrative purposes only, to demonstrate the behaviour and challenges relating to different options. A much more detailed investigation with multiple scenarios and sensitivity tests has subsequently been performed for the 4 TTW and WTW based metrics in Service Request 8 [TNO 2013].

From Table 2 we can see that equivalent targets for alternative metrics are always higher when the target is based on the assumption that the TTW GHG target is met by a mix of ICEVs and EVs instead of on the 100% ICEVs assumption. Target values for the 100% ICEVs assumption may become unrealistically low, as is illustrated in the analyses below. Under this equivalent target setting the required energy consumption of ICEVs may even become negative if a high share of ZEVs is assumed, as the target may be lower than the energy consumption of these ZEVs. This means that for the short term there may be a choice regarding the assumption on which the equivalent target is based, if it is decided to move from the present TTW GHG based metric to an alternative metric. However, in the longer term targets would be set taking account of technological development and deployment as well as the shares of different ZEVs that would have been experienced and would be expected or considered feasible for meeting the target.

The figures shown in Table 2 form the basis for all the subsequent graphs and analysis in this section of the report.

Table 2   Assumptions with respect to specifications of vehicles and energy carriers and equivalent targets for different metrics and target years

		2020	2030	2050	
vehicle and energy specs	energy consumption EVs	0.160	0.160	0.160	kWh/km
	energy consumption EVs	0.574	0.574	0.574	MJ/km
	share of EVs in baseline scenario	1%	34%	69%	
	energy consumption of ICEVs in baseline with TTW CO2 target	1.309	1.137	0.924	MJ/km
	TTW CO2 emission of ICEVs in baseline with TTW CO2 target	96.0	83.3	67.7	g/km
	assumed minimum TTW CO2 emissions of ICEVs	95.0	55.0	55.0	g/km
	EU average WTT emissions of electricity production	205.5	100.6	3.6	g/kWh
	EU average WTT emissions of electricity production	57.1	27.9	1.0	g/MJ
	biofuel share in petrol/diesel	9.1%	10.4%	39.8%	
	WTW/TTW emissions of petrol/diesel with biofuels	1.13	1.10	0.80	g/g
	WTT energy consumption of fuel production	0.28	0.32	0.66	MJ/MJ
equivalent targets	TTW CO2 target	95.0	55.0	21.0	g/km
	WTW CO2 (based on 100% ICEV)	107.4	60.5	16.8	g/km
	WTW CO2 (based on ICEV / EV mix)	107.7	66.0	17.2	g/km
	TTW MJ (based on 100% ICEVs)	1.30	0.75	0.29	MJ/km
	TTW MJ (based on ICEV / EV mix)	1.30	0.95	0.68	MJ/km
	WTW MJ (based on 100% ICEV)	1.66	0.99	0.48	MJ/km
	WTW MJ (based on ICEV / EV mix)	1.67	1.45	1.20	MJ/km
	TTW CO2 with notional WTT factor a1 for ZEVs (based on 100% ICEVs)	95.0	55.0	21.0	g/km
	TTW CO2 with notional WTT factor a2 for ZEVs (based on 100% ICEVs)	95.0	55.0	21.0	g/km
	TTW CO2 with notional WTT factor a3 for ZEVs (based on 100% ICEVs)	95.0	55.0	21.0	g/km
	TTW CO2 with notional WTT factor a1 for ZEVs (based on ICEV / EV mix)	95.1	57.5	21.0	g/km
	TTW CO2 with notional WTT factor a2 for ZEVs (based on ICEV / EV mix)	95.3	59.9	21.7	g/km
	TTW CO2 with notional WTT factor a3 for ZEVs (based on ICEV / EV mix)	95.4	64.9	23.8	g/km

4.2.4   How to read the following graphs?

If only two technologies are considered, all metrics have the same basic structure:

$$a_1 \cdot x_1 + a_2 \cdot x_2 = target$$

with a_i and x_i respectively the share and average emission or energy consumption of technology i. If the average emission or energy consumption of one technology is fixed the average emission or energy consumption of the other technology becomes inversely proportional to the share of the first technology:

$$x_1 = \frac{target - a_2 \cdot x_2}{(1 - a_2)}$$

We assume a situation in which only ICEVs (with a range of options to reduce CO_2 emissions) and electric vehicles (EVs) are marketed. If in that case a fixed TTW energy consumption of EVs is assumed, the TTW and WTW CO_2 emissions of ICEVs depend non-linearly on the share of EVs as shown in Figure 5. The average TTW emissions of new vehicles remain constant, as required by the TTW CO_2 based legislation, so the TTW emissions of ICEVs are expected to vary in response to the share of 0 g/km EVs in the new vehicle sales. This figure also shows that the average WTW CO_2 emissions of new vehicles linearly increase with the share of EVs. Comparing graph a), which assumes WTT emissions for EVs to be 100 g/kWh, to graph b), which assumes 250 g/kWh, it can be seen that this increase is stronger if the WTT emissions of electricity production are higher. The TTW emissions of ICEVs are not affected by the WTT emissions of EVs.

The latter is further illustrated in graph a) of Figure 6. This graph also illustrates how an equivalent target can be defined if the TTW CO_2 based legislation is to be replaced by legislation using a WTW CO_2 based metric. As mentioned in section 4.2.2, definition of an equivalent target requires assumptions on the technologies with which the original target is met. If one assumes that a TTW target of 55 g/km is met by selling 75% ICEVs and 25% EVs, with the EVs having WTT emissions of 250 g/kWh and the ICEVs having a WTW/TTW ration of 1.1 (i.e. 0.1 g/km WTT emissions per 1 g/km TTW emissions), the equivalent WTW CO_2 based target is 70.4 g/km.

Graphs b) and c) of Figure 6 show how the TTW and WTW emissions of ICEVs, EVs and the average for all new vehicles depend on the share of EVs in the new vehicle sales and on the WTT emissions of EVs for a legislation that applies this equivalent target of 70.4 g/km on the basis of a WTW CO_2 metric. Under this metric the average WTW emissions remain constant. Again the emissions of ICEVs vary as function of the share of EVs, but the sensitivity is less pronounced as EVs are not zero-emission under a WTW CO_2 based metric. In this case the TTW emissions of ICEVs do depend on the WTT emissions of EVs, though, going down with increasing WTT emissions from electricity production.

How to read the graphs?
Dependence of the TTW and WTW emissions of ICEVs and of the averages for all new vehicles on the share of EVs under a TTW CO_2 based metric

TTW CO_2 target with $WTT_{electricity}$ = 100 g/kWh

a)

$$\eta_{ICEV} \cdot G_{ICEV}^{TTW} + \eta_{EV} \cdot G_{EV}^{TTW} = G_{target}^{TTW}$$

$$G_{ICEV}^{TTW} = \frac{G_{target}^{TTW}}{(1 - \eta_{EV})}$$

TTW CO_2 target = 55 g/km

TTW CO_2 target with $WTT_{electricity}$ = 250 g/kWh

b)

$$\eta_{ICEV} \cdot G_{ICEV}^{TTW} + \eta_{EV} \cdot G_{EV}^{TTW} = G_{target}^{TTW}$$

$$G_{ICEV}^{TTW} = \frac{G_{target}^{TTW}}{(1 - \eta_{EV})}$$

TTW CO_2 target = 55 g/km
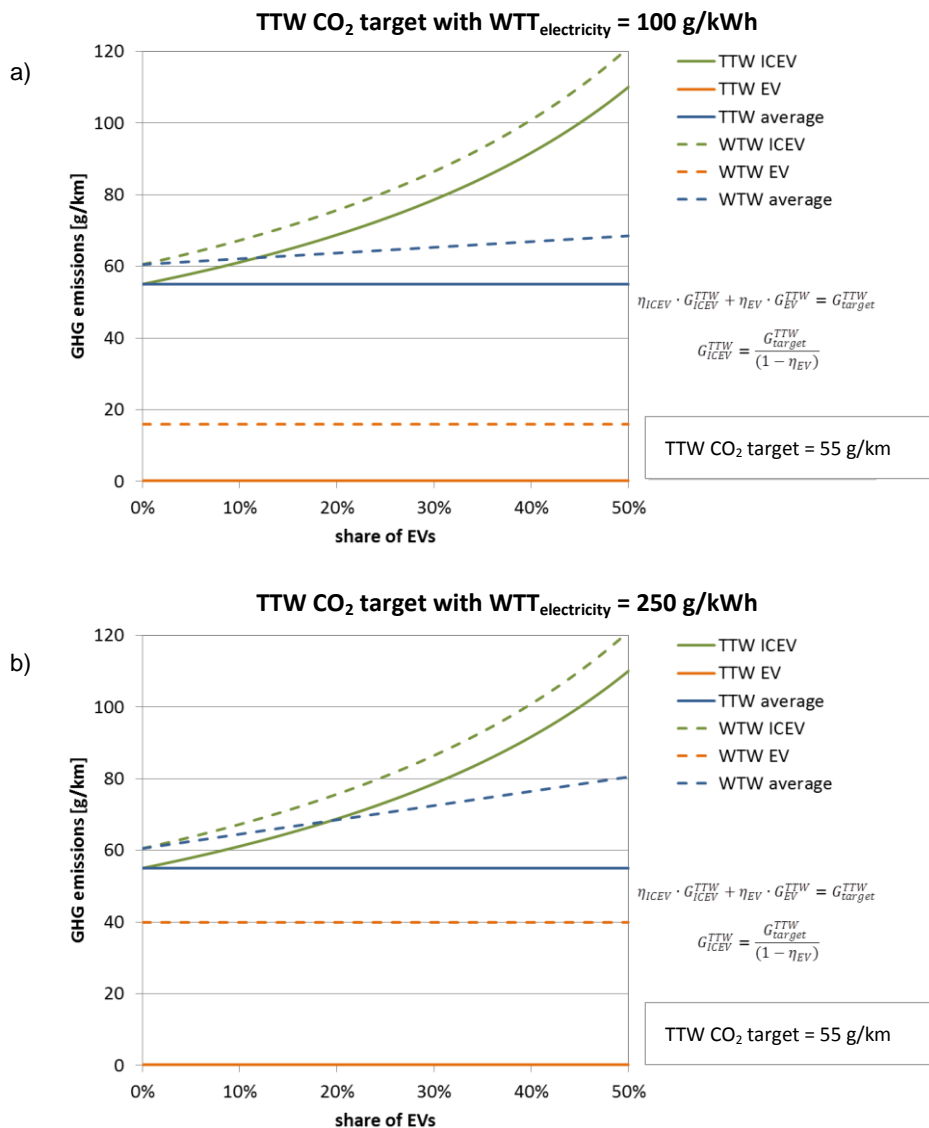
Figure 5   Dependence of the TTW and WTW emissions on the share of EVs under a TTW CO_2 based metric

How to read the graphs?

Definition of equivalent targets for a TTW and WTW CO$_2$ based target and illustration of the dependence of the TTW and WTW CO$_2$ emissions of ICEVs and the averages for new vehicles on the share and WTT emissions of EVs

Effect of WTT$_{electricity}$ assumption on setting an equivalent WTW CO$_2$ target

a)

Equivalent WTW CO$_2$ target @ EV share = 25% and WTT electricity = 250 g/kWh

$$\eta_{ICEV} \cdot G_{ICEV}^{TTW} + \eta_{EV} \cdot G_{EV}^{TTW} = G_{target}^{TTW}$$

$$G_{ICEV}^{TTW} = \frac{G_{target}^{TTW}}{(1 - \eta_{EV})}$$

TTW CO$_2$ target = 55 g/km

EV share = 25%

Effect of EV share on WTW and TTW requirements under a WTW CO$_2$ target

b)

Equivalent TTW CO$_2$ target @ EV share = 25% and WTT electricity = 250 g/kWh

$$\eta_{ICEV} \cdot G_{ICEV}^{WTW} + \eta_{EV} \cdot G_{EV}^{WTW} = G_{target}^{WTW}$$

$$G_{ICEV}^{WTW} = \frac{G_{target}^{WTW} - \eta_{EV} \cdot G_{EV}^{WTW}}{(1 - \eta_{EV})}$$

WTW CO$_2$ target = 70.4 g/km

WTT$_{electricity}$ = 250 g/kWh

Effect of WTT$_{electricity}$ on WTW and TTW requirements under a WTW CO$_2$ target

c)

Equivalent TTW CO$_2$ target @ EV share = 25% and WTT electricity = 250 g/kWh

$$\eta_{ICEV} \cdot G_{ICEV}^{WTW} + \eta_{EV} \cdot G_{EV}^{WTW} = G_{target}^{WTW}$$

$$G_{ICEV}^{WTW} = \frac{G_{target}^{WTW} - \eta_{EV} \cdot G_{EV}^{WTW}}{(1 - \eta_{EV})}$$

WTW CO$_2$ target = 70.4 g/km

EV share = 25%

Figure 6   Definition of equivalent targets for a TTW and WTW CO$_2$ based target

4.3 GHG emission based metrics

4.3.1 Tailpipe CO_2 emissions as in existing Regulation (option 1.a)

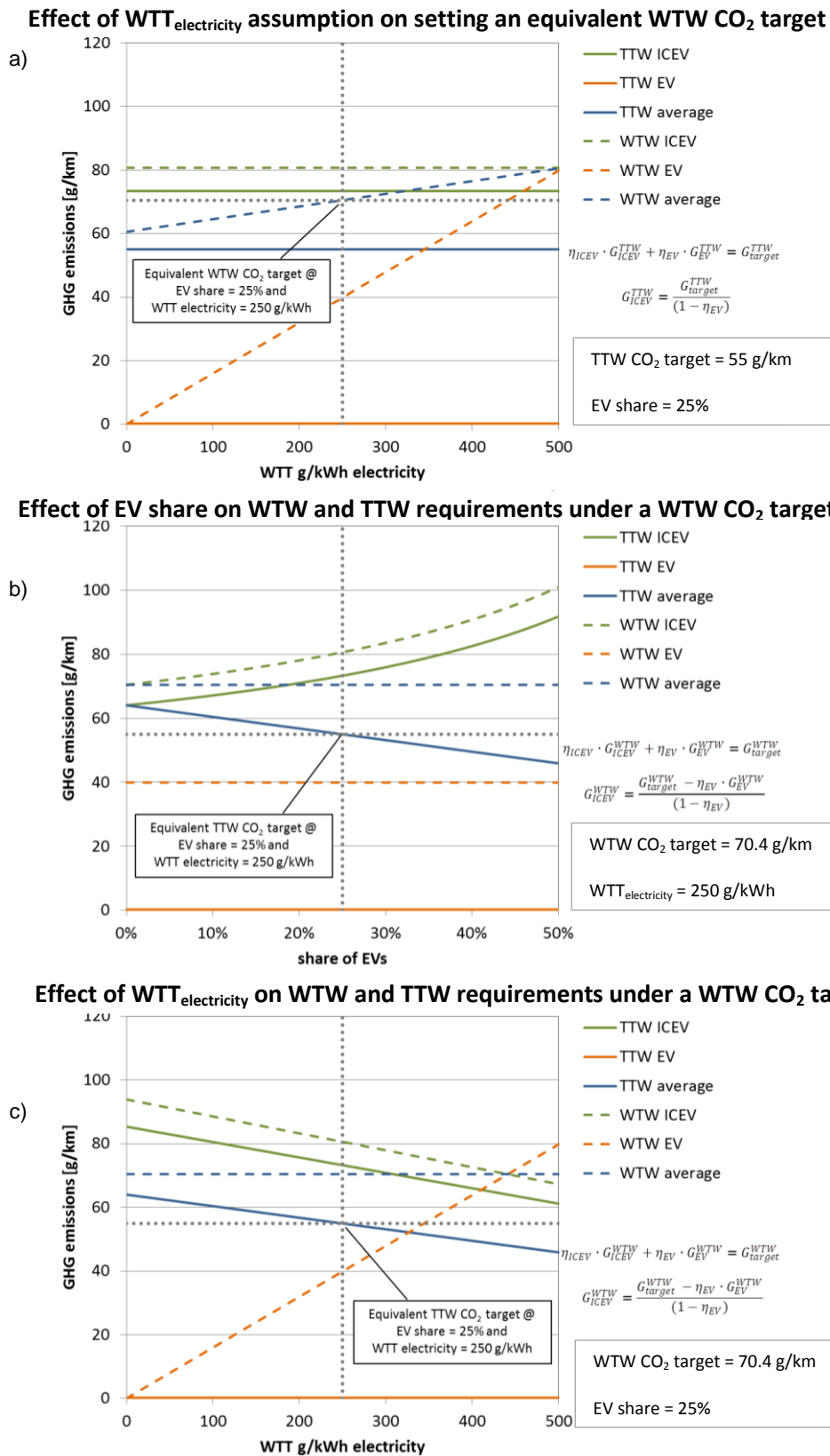| Results for TTW GHG based metric	
General comments	
EVs count as zero-emission under a TTW CO_2 based target. When EVs are introduced in the new vehicle sales the remaining ICEVs are allowed to emit more CO_2. As their WTW GHG emissions are not zero, an increasing EV share leads to increasing average WTW GHG emissions of new vehicles.	
Sensitivity of WTW emissions to WTT electricity GHG intensity (Figure 7)	
General	Obviously higher or lower WTT emissions from electricity generation would lead to a larger or smaller impact from the introduction of EVs on the average new vehicle WTW CO_2 emissions under a TTW CO_2 based target for the same EV share.
2020	**Weak** For the 95 g/km TTW target in 2020 WTW emissions are not very sensitive to variations in WTT emissions from electricity production. This is due to the low assumed share of EVs in 2020 (1%).
2030	**Strong** If the 2030 target is met by a large share of EVs or PHEVs, as is assumed in this example, the WTW emissions are found to vary strongly with the actual WTT emissions from electricity production. This is caused by the high share of EVs on the one hand and the significant WTT emissions from electricity production on the other hand.
2050	**Weak** Although the share of EVs further increases towards 2050, the sensitivity of WTW emissions to variations in WTT emissions from electricity production decreases, as a result of the fact that it is assumed these emissions are becoming very small.
Sensitivity of WTW emissions to EV share (Figure 8)	
General	
2020	**Strong** For the 95 g/km TTW target in 2020 WTW emissions are very sensitive to variations in the actual share of EVs. This is due to their high WTT emissions.
2030	**Strong** WTW emissions are found to vary strongly with the actual share of EVs. This is caused by the still significant WTT emissions from electricity production in 2030.
2050	**Weak** By 2050 the sensitivity of WTW emissions to variations in the share of EVs decreases, as a result of the fact that it is assumed their WTW emissions are becoming very small.
Sensitivity of ICE TTW emissions to EV share (Figure 8)	
General	As can be seen from Figure 7, the TTW emissions of ICEVs, required for meeting the TTW GHG based target, do not depend on the WTT emissions of electricity production. However, the TTW emissions of ICEVs do depend on the share of EVs in the new vehicle fleet.
2020	**Moderate** The change in TTW emissions of ICEVs for a given change in the share of EVs is similar to that in 2030, but given the low share absolute variations are expected to be smaller.
2030	**Moderate** In the medium to long term a lower than expected share of EVs in the new vehicle fleet may lead to TTW emission reduction requirements for ICEVs that may be difficult or impossible to meet.
2050	**Strong** Especially for very low TTW CO_2 targets, that will be necessary in the long term (2050), the TTW emissions of ICEVs become very sensitive to variations in the share of EVs.
Impact of over/under estimating EV share	
A larger than expected share of EVs allows for higher TTW emissions of ICEVs.	
Other remarks	
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TTW GHG based target

Impact of the WTT emissions of EVs on the average WTW GHG emissions of new vehicles, for an assumed share of EVs in 2020, 2030 and 2050

2020

TTW target = 95 g/km
1% EVs
WTT = 205 g/kWh for EVs (EU avg)

| = assumed WTT emissions of EVs in 2020

— WTW emissions with EVs
— WTW emissions without EVs
– – TTW emissions of ICEVs

2030

TTW target = 55 g/km
34% EVs
WTT = 101 g/kWh for EVs (EU avg)

| = assumed WTT emissions of EVs in 2030

— WTW emissions with EVs
— WTW emissions without EVs
– – TTW emissions of ICEVs

2050

TTW target = 21 g/km
69% EVs
WTT = 4 g/kWh for EVs (EU avg)

| = assumed WTT emissions of EVs in 2050

— WTW emissions with EVs
— WTW emissions without EVs
– – TTW emissions of ICEVs

Figure 7   Illustration of the impact of the GHG intensity of electricity generation on average WTW GHG emissions of new vehicles, for an assumed share of EVs. The upper, middle and lower graphs are examples case for 2020, 2030 resp. 2050.

TTW GHG based target
Impact of the share of EVs on the average WTW GHG emissions of new vehicles,
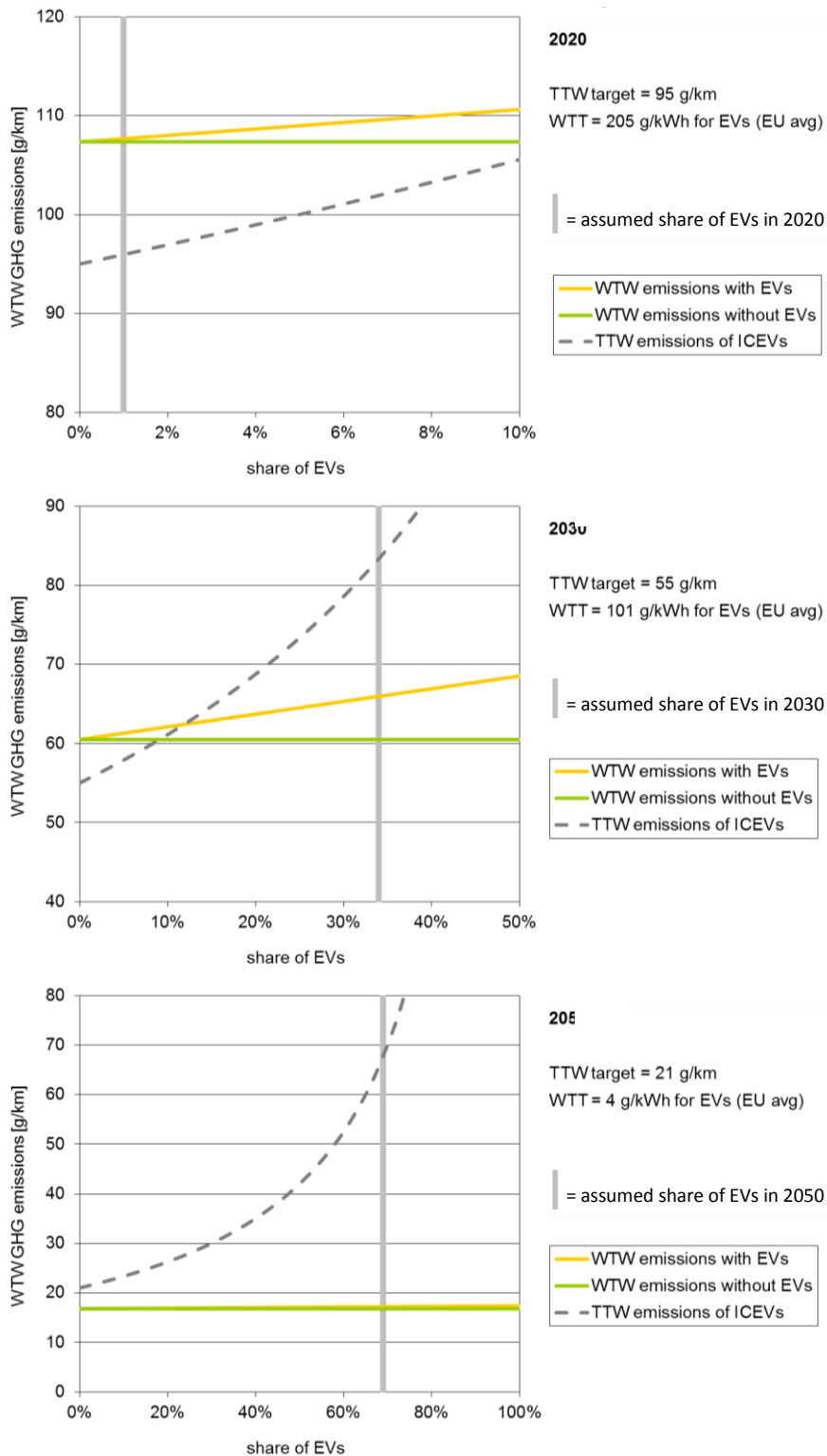for an assumed GHG intensity of electricity in 2020, 2030 and 2050

Figure 8   Illustration of the impact of the share of EVs on the average WTW GHG emissions in g/km for new vehicles. The upper, middle and lower graphs are examples case for 2020, 2030 resp. 2050.

4.3.2 Tailpipe CO$_2$ emissions for ICEVs with exclusion of Zero Emission Vehicles (option a.2)

Under this metric the energy efficiency and CO$_2$ emissions of ICEVs are not affected by the share of EVs nor by the assumed WTT GHG emissions of electricity production. The impact of an increasing share of EVs (or other alternative vehicles) on new vehicle average WTW emissions depends on the assumed targets for ICEVs, the efficiency of the alternative vehicles and the WTW GHG emissions of the various energy carriers. Table 3 shows WTW emissions of ICEVs and EVs for the assumptions used in this chapter (see Table 2). It shows that for this metric average WTW emissions will decrease with an increasing share of EVs in all target years. This would even be the case if the assumed WTT emissions from electricity production would be twice as large or if the assumed TTW targets for ICEVs in the target years would be significantly lower than those assumed in Table 3. A specific challenge with this metric would be to determine which vehicles would be excluded, in particular in relation to PHEVs.

Table 3   Comparison of average WTW emissions of ICEVs and EVs based on the assumptions as listed in Table 2

	2020	2030	2050	
TTW target for ICEVs	95.0	55.0	55.0	g/km
WTW emissions of ICEVs	107.4	60.5	44.0	g/km
WTW emissions of EVs	32.8	16.0	0.6	g/km

4.3.3 Tailpipe CO$_2$ emissions with notional GHG intensity for Zero Emission Vehicles (option a.3)

Below a number of example cases are discussed which are based on the general assumptions as listed in Table 2. The notional WTW GHG intensity factors for EVs as used in the examples are presented in Table 4. These factors are derived by the method indicated in section 2.2.3 on the basis of assumed WTT emission factors for electricity generation and the WTT/TTW emissions of conventional fuels.

Table 4   Notional WTW GHG intensity factors for EVs as used in the examples discussed below.

	2020	2030	2050	
notional WTT factor for ZEVs a1	24.6	12.6	0.0	g/MJ
- equivalent to WTT CO2 factor for electriciy generation	100.0	50.0	0.0	g/kWh
notional WTT factor for ZEVs a2	49.2	25.3	1.7	g/MJ
- equivalent to WTT CO2 factor for electriciy generation	200.0	100.0	5.0	g/kWh
notional WTT factor for ZEVs a3	73.7	50.5	6.9	g/MJ
- equivalent to WTT CO2 factor for electriciy generation	300.0	200.0	20.0	g/kWh

Using these notional factors the target is defined as:

$$G_{target}^{TTW} = \eta_{ICEV} \cdot G_{ICEV}^{TTW} + \eta_{EV} \cdot a \cdot E_{EV}^{TTW}$$

with E_{EV}^{TTW} the average TTW energy consumption of EVs.

Given a target G_{target}^{TTW} and an assumed value E_{EV}^{TTW} for the TTW energy consumption of EVs it is possible to calculate the average TTW CO$_2$ emission of ICEVs G_{ICEV}^{TTW}, that is required for meeting the target, as function of the share of EVs and their assumed nominal GHG intensity. This can be interpreted as an effective target for ICEVs under the overall target defined using the metric assessed here. In the following graphs these TTW CO$_2$ emission of ICEVs are depicted as dashed grey lines.

Results for TTW GHG based metric with notional GHG intensity for ZEVs Equivalent targets based on the assumption that the TTW CO_2 target can be met with 100% ICEVs	
General comments	
If the equivalent target for this metric is based on the assumption that the TTW CO_2 target is met by ICEVs only, the target for this alternative metric is equal to the original TTW CO_2 target and does not vary with the assumed notional WTT emission factor for ZEVs.	
Sensitivity of WTW emissions to WTT electricity GHG intensity (Figure 9)	
General	The leverage of ZEVs on WTW emissions is not fundamentally changed by using notional WTT factors but its pivot point is shifted.
2020	**Weak**
2030	**Strong** The impact depends on the share of EVs and their actual WTT emissions, and is in this example therefore the largest for the 2030 case.
2050	**Weak**
Sensitivity of WTW emissions to EV share (Figure 10)	
General	The use of notional WTT factors makes the average WTW emissions of new cars less sensitive to changes in the share of EVs. The impact of EVs on average WTW emissions is completely cancelled if the notional WTT factor equals the actual WTT factor of electricity generation divided by the WTW/WTT factor for conventional fuels.
2020	**Moderate – none (depending on value of notional GHG intensity)** Effect is smaller than for TTW GHG based metric. If the notional GHG intensity for EVs is higher than the actual WTT emissions, the average WTW emissions decrease with increasing EV share.
2030	**Moderate – none (depending on value of notional GHG intensity)** For notional GHG intensity for EVs smaller or larger than the actual WTT emissions of EVs.
2050	**Weak – none** Variations in the share of EVs are compensated by variations in the TTW emissions of ICEVs. For low shares of EVs these variations go beyond levels that can be reached by presently known technologies and existing vehicle configurations.
Sensitivity of ICE TTW emissions to EV share (Figure 10)	
General	For a given share of EVs the TTW emissions of ICEVs decrease with increasing notional WTT factor for EVs. The TTW emissions of ICEVs can still increase with an increasing share of ZEVs, but this increase is less for higher notional WTT emission factors. The TTW emissions of ICEVs is especially sensitive for EV shares that are higher than expected value.
2020	**Moderate (but less than TTW GHG based metric)** EVs shares for 2020 are expected to be low. A larger than expected share of EVs allows for higher TTW emissions of ICEVs (above 95 g/km).
2030	**Moderate (but less than TTW GHG based metric)** Sensitivity is reduced for higher values of the notional GHG intensity of ZEVs. A 10% higher share already brings the TTW emissions of ICEVs back to levels compatible with the 2020 target of 95 g/km.
2050	**Strong** If the actual share of EVs in 2050 is low, the TTW emissions of ICEVs need to be reduced to levels that cannot be reached by presently known technologies and existing vehicle configurations. A 10% higher share already brings the TTW emissions of ICEVs back to levels compatible with the 2020 target of 95 g/km.
Impact of over/under estimating EV share	
--	
Other remarks	
TTW emissions to be realised by ICEVs are independent of the actual WTT emissions of EVs.	

TTW GHG based target with notional GHG intensity for ZEVs
Impact of the WTT emissions of EVs on the average WTW GHG emissions of new vehicles, for an assumed share of EVs in 2020, 2030 and 2050

Equivalent targets based on ICEVs only

Figure 9   Illustration of the impact of actual WTT emissions of EVs on average WTW GHG emissions for new vehicles, for an assumed share of EVs. All graphs are for the case where the equivalent target is determined under the assumption that it can be met by ICEVs only.

TTW GHG based target with notional GHG intensity for ZEVs

Impact of the share of EVs on average WTW GHG emissions of new vehicles and TTW GHG emissions of ICEVs, for an assumed GHG intensity of electricity in 2020, 2030 and 2050

Equivalent targets based on ICEVs only
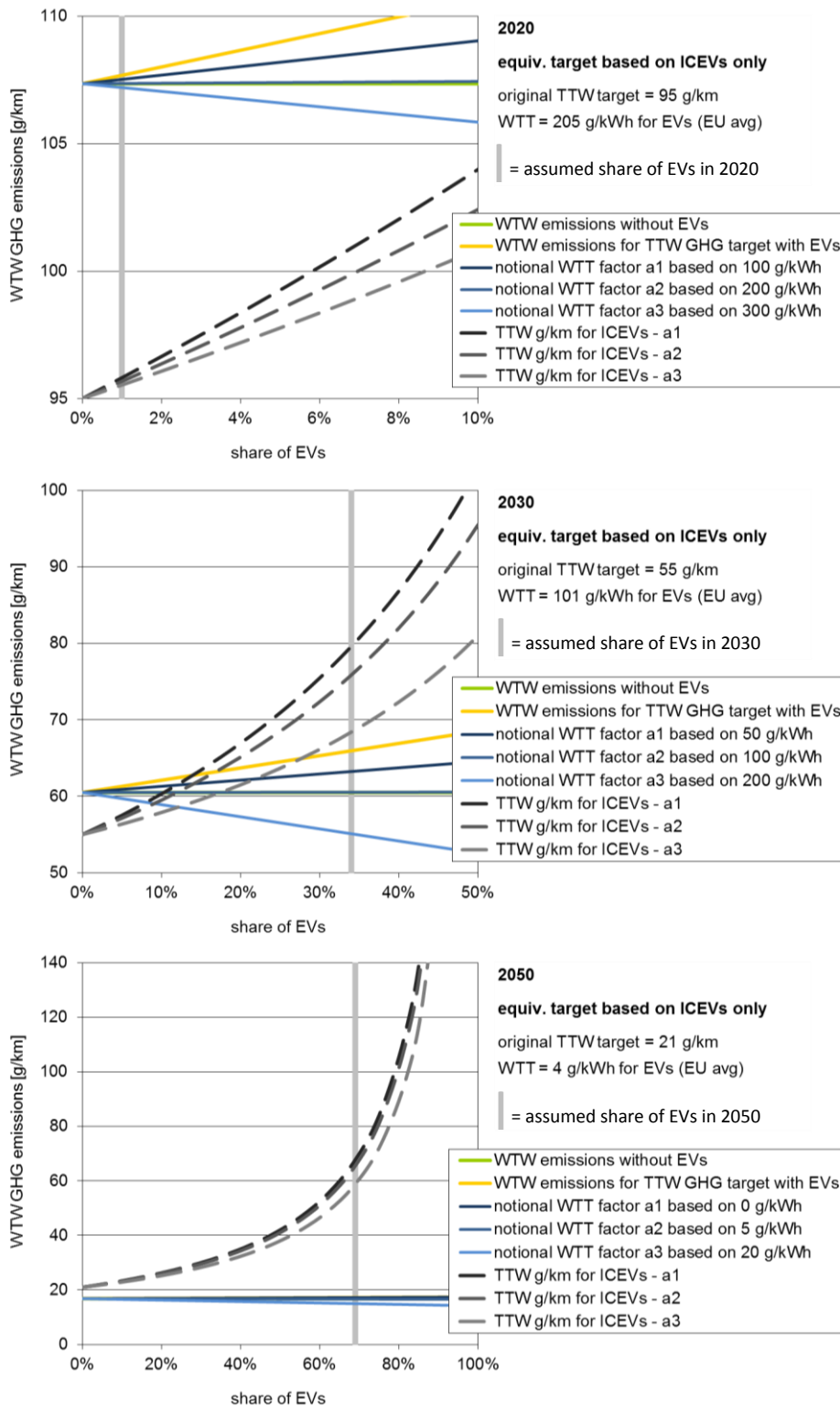
Figure 10   Illustration of the impact of the share EVs in the new vehicle sales on average WTW GHG emissions of new vehicles. All graphs are for the case where the equivalent target is determined under the assumption that it can be met by ICEVs only.

Results for TTW GHG based metric with notional GHG intensity for ZEVs Equivalent targets are based on the assumption that the TTW CO_2 target is met with a specified mix of ICEVs and EVs		

General comments

If the equivalent target for the option of using a notional WTT emission factor for ZEVs is based on the assumption that the TTW CO_2 target is met by a mix of ICEVs and ZEVs, the target for this alternative metric increases with an increasing notional WTT emission factor for ZEVs. As a result for a given EV share the TTW emissions of ICEVs are not affected by the assumed notional WTT factor for ZEVs. As a result the lines for the TTW emissions of ICEVs in Figure 11 overlap.

Sensitivity of WTW emissions to WTT electricity GHG intensity (Figure 11)

General	The assumed notional WTT factor for ZEVs does not affect the average WTW emissions of new cars. This means that this alternative metric does not reduce the adverse impact of ZEVs on the new vehicle average WTW emissions, if the equivalent target is based on the assumption that the TTW CO_2 target is met by a mix of ICEVs and ZEVs.
2020	**Weak** Same as for TTW GHG based metric.
2030	**Strong** Same as for TTW GHG based metric.
2050	**Weak** Same as for TTW GHG based metric.as for TTW GHG based metric.

Sensitivity of WTW emissions to EV share (Figure 12)

General	Changes in the actual share of ZEVs compared to what was assumed for setting the equivalent target still affect the new vehicle average WTW emissions. If the actual share of EVs is higher than the value assumed for setting the equivalent target, the use of notional WTT factors will lead to lower WTW emissions than in the case of the TTW CO_2 based target. However, if the actual ZEV share is lower than the assumed value, this alternative metric leads to higher WTW emissions. In principle this alternative metric, in combination with setting the equivalent target based on an assumed share of ZEVs, could therefore enhance the problem it is intended to solve. This danger is most prominent for the medium term.
2020	**Moderate – none (depending on value of notional GHG intensity)** Impact of EV share is smaller than for TTW GHG based metric.
2030	**Moderate – none (depending on value of notional GHG intensity)** Size and sign of the impact depend on deviation of actual EV share from the share assumed for setting the equivalent target.
2050	**Weak – none**

Sensitivity of ICE TTW emissions to EV share (Figure 12)

General	This sensitivity is the same as for the case when the equivalent target is based on 100% ICEVs (see Figure 10), but centres around the assumed EV share rather than around 0% EVs. Again the TTW emissions of ICEVs increase less with an increasing share of ZEVs for higher notional WTT emission factors.
2020	**Moderate (but less than TTW GHG based metric)** Same as for case with equivalent target based on 100% ICEVs.
2030	**Moderate (but less than TTW GHG based metric)** Same as for case with equivalent target based on 100% ICEVs.
2050	**Strong** Same as for case with equivalent target based on 100% ICEVs.

Impact of over/under estimating EV share

A larger than expected share of EVs allows for higher TTW emissions of ICEVs. In the medium and long term this could even allow ICEV emissions above the target levels for 2015 and 2020.
A lower than expected share of EVs requires lower TTW emissions of ICEVs. In 2030 and 2050 these could even be below what is currently considered technically feasible.

Other remarks

TTW emissions to be realised by ICEVs are independent of the actual WTT emissions of EVs.

TTW GHG based target with notional GHG intensity for ZEVs
Impact of the WTT emissions of EVs on the average WTW GHG emissions of new vehicles, for an assumed share of EVs in 2020, 2030 and 2050
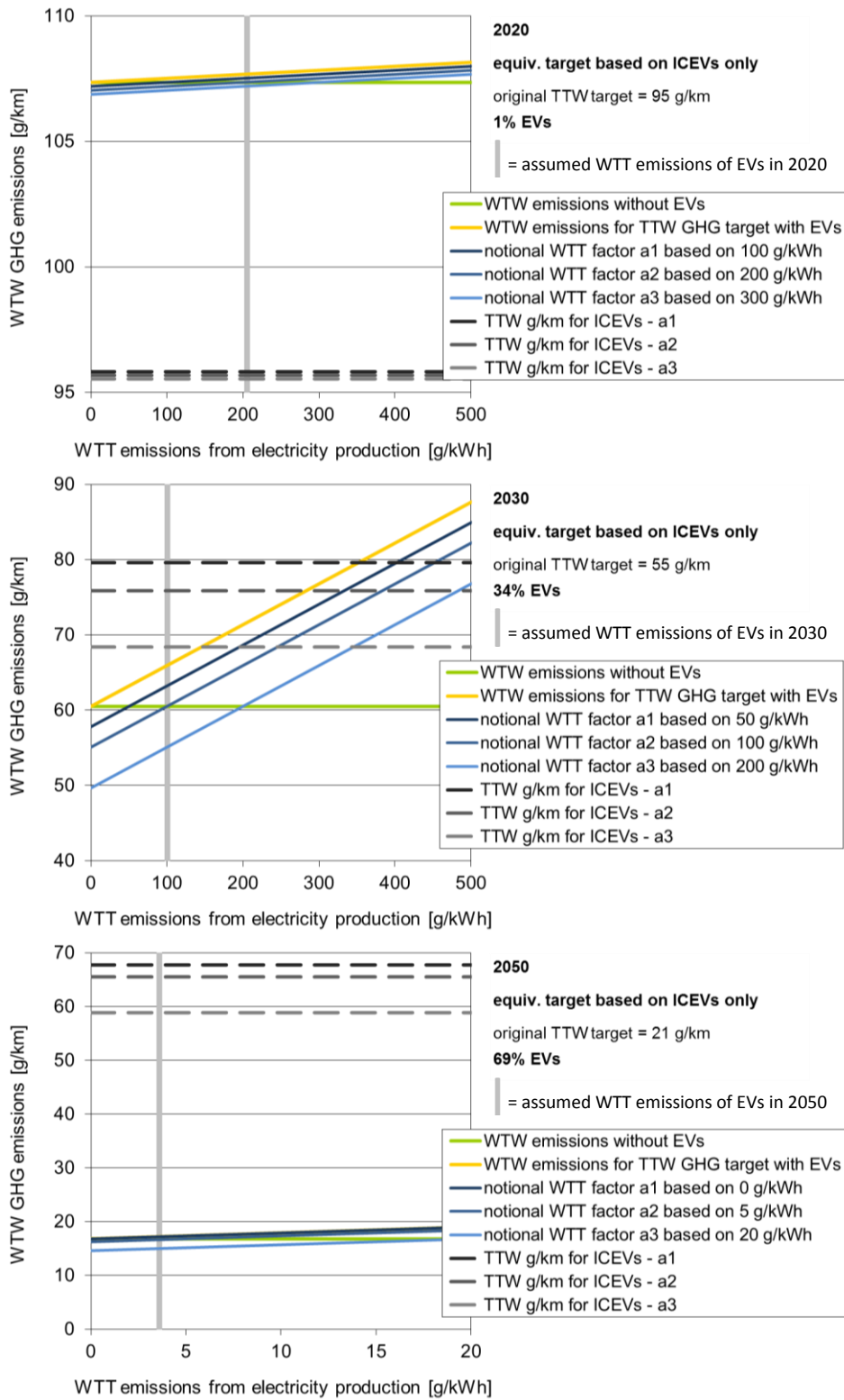
Equivalent targets based on ICEVs / EVs mix

Figure 11   Illustration of the impact of the GHG intensity of electricity generation on WTW GHG emissions of new vehicles, for an assumed share of EVs. All graphs are for the case where the equivalent target is determined under the assumption that it will be met by a specified mix of ICEVs and EVs.

TTW GHG based target with notional GHG intensity for ZEVs
Impact of the share of EVs on average WTW GHG emissions of new vehicles and TTW GHG emissions of ICEVs, for an assumed GHG intensity of electricity in 2020, 2030 and 2050

Equivalent targets based on ICEVs / EVs mix
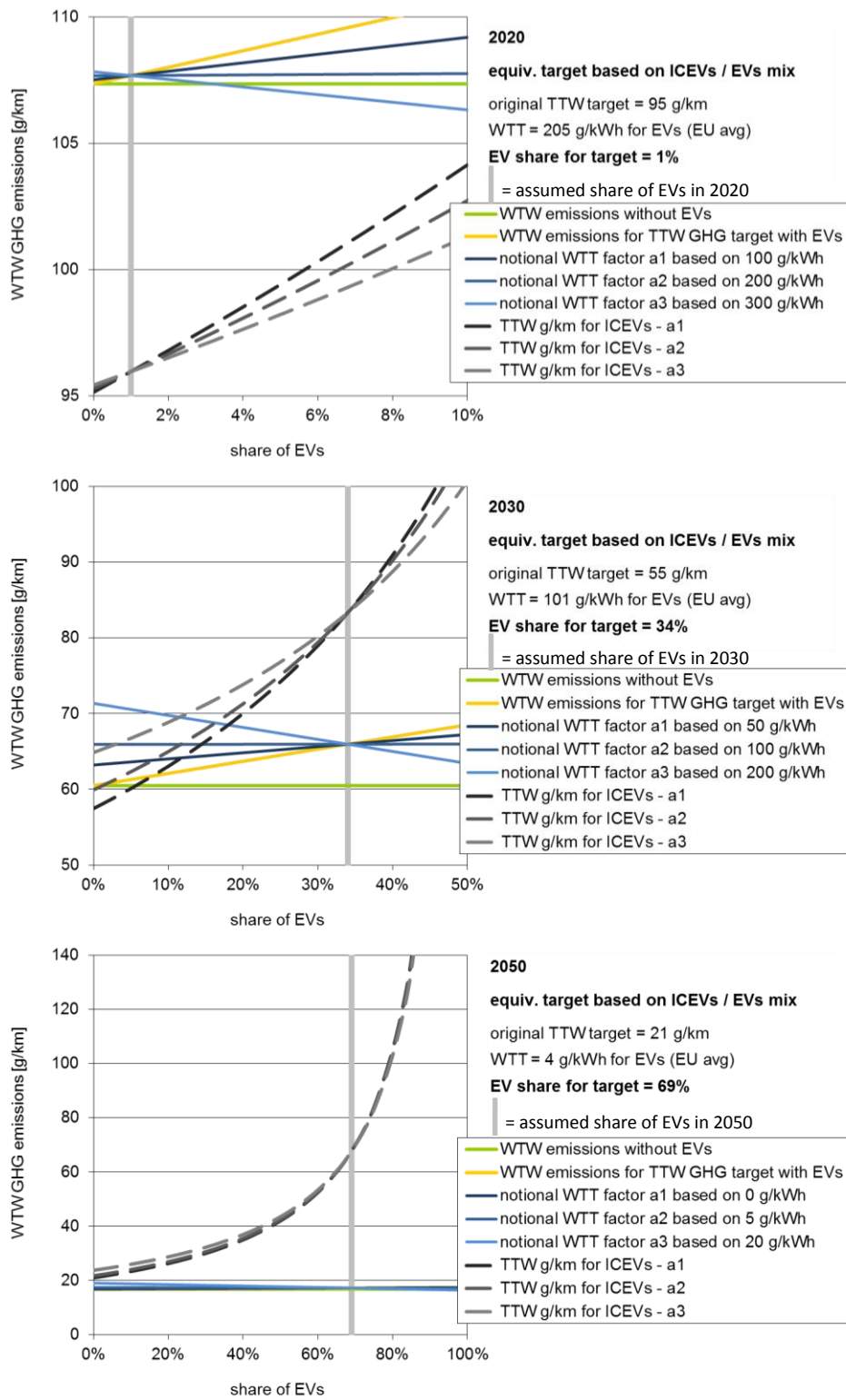
Figure 12   Illustration of the impact of the share of EVs in the new vehicle sales on WTW GHG emissions of new vehicles. All graphs are for the case where the equivalent target is determined under the assumption that it will be met by a specified mix of ICEVs and EVs.

Conclusions for a TTW CO$_2$ based metric with notional GHG intensity for Zero Emission Vehicles

- The use of a notional WTT factor for ZEVs reduces the WTW CO$_2$ leakage resulting from introducing ZEVs only when the equivalent target is based on the assumption that the TTW target without notional WTT emission factors for ZEVs can be met with ICEVs only. For equivalent targets based on an assumed ICEVs/ZEVs mix for meeting the TTW-based target the target with notional WTT emission factors for ZEVs shifts with applied notional WTT factors, so that the WTW CO$_2$ leakage is not affected.
- The required response in terms of adjusting the TTW emissions of ICEVs to variations in the ZEV share depends somewhat on the equivalent target setting (TTW target assumed to be met by ICEVs only or by a mix of ICEVS and ZEVs). In both cases, however, there is a strong sensitivity of required TTW emissions of ICEVs to variations in the actual share of ZEVs.
    o This sensitivity is of the same order (but less) as for a TTW GHG based target without notional GHG intensity for ZEVs.
    o Especially in the long term a smaller share of ZEVs than expected requires unrealistic improvements in efficiency of ICEVs.

4.3.4 Tailpipe CO$_2$ emissions adjusted to take account of WTW emissions (option a.4)

In this option the target is defined at the level of the average WTW GHG emissions of all new vehicles sold.

Results for WTW GHG based metric
Equivalent targets based on the assumption that the
TTW CO$_2$ target can be met ICEVs only

General comments

Due to the definition of the metric average WTW emissions are intrinsically insensitive to variations in share and WTT emissions of ZEVs, provided that the efficiency of ICEVs and ZEVs can be adjusted to meet the target.

Sensitivity of WTW emissions to WTT electricity GHG intensity

General	A WTW GHG based metric effectively makes the average WTW emissions of new vehicles insensitive to the WTT emissions of ZEVs.
2020	**None**
2030	**None** In the medium term higher than expected WTT emissions of ZEVs may lead to requirements on the WTW emissions of ICEVs that are below what is currently considered technically feasible.
2050	**None**

Sensitivity of WTW emissions to EV share (Figure 14)

General	A WTW GHG based metric effectively makes the average WTW emissions of new vehicles insensitive to the share of ZEVs that is used to achieve the target.
2020	**None**
2030	**None**
2050	**None**

Sensitivity of ICE TTW emissions to EV share (Figure 15)

General	The graphs contain two scenarios: one in which the efficiency of EVs is assumed constant and that of ICEVs is adjusted in response to the changing share of EVs, and one in which the efficiency of ICEVs is assumed constant and that of EVs is adjusted. Figure 14 shows that for the average WTW emissions it does not make a difference which approach is taken. But from Figure 15 it is clear that the TTW energy consumption of ICEVs and / or EVs (required for meeting the target) is very sensitive to variations in the share of EVs especially for the lower long term targets.
2020	**Weak**
2030	**Moderate (but less than TTW GHG based metric)**
2050	**Strong** The graph for 2050 is for an equivalent target that is based on the 21 g/km TTW target multiplied by the WTW/TTW factor for ICEVs (so assuming that this can be met by ICEVs only). For the case in which the efficiency of ICEVs is kept constant two different assumptions can be made. If the 21 g/km can be met by ICEVs the TTW energy consumption of EVs does not vary with a changing share of EVs as every EV added from 0% upwards simply needs to have the same WTW emissions as the ICEVs in the new vehicle sales. In the case depicted here, however, it is assumed that the lowest achievable TTW emission from ICEVs is 55 g/km rather than 21 g/km. In that case the TTW energy consumption of EVs is extremely sensitive to the share of EVs and is only within a realistic bandwidth for EV shares between 62.3% and 63%. For lower shares of EVs the target cannot be met, while higher EV shares would lead to WTW emissions below the target if the energy consumption of ICEVs is not adjusted upwards.

Impact of over/under estimating EV share

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Other remarks

The graphs in Figure 15 for 2020 and 2030 show that if the energy consumption of ICEVs is not adjusted upwards in response to an increasing share of EVs, the WTW GHG target would lead to EVs with energy consumption figures which are 3 to 4 times higher than the assumed baseline value of 0.57 MJ/km (or 160 Wh/km). This will not happen, but it does show that if WTT emission factors for electricity generation become as low as assumed in these graphs, the WTW target may not provide sufficient incentives to develop more energy efficient EVs. For higher WTT emission factors for electricity generation this risk will be smaller.

WTW GHG based target
Impact of the WTT emissions of EVs on the average WTW GHG emissions of new vehicles, for an assumed share of EVs in 2020, 2030 and 2050

Equivalent targets based on ICEVs only

Figure 13   Illustration of the impact of the WTT emissions of EVs on average WTW GHG emissions of new vehicles, for an assumed share of EVs. All graphs are for the case where the equivalent target is determined under the assumption that it can be met by ICEVs only.

WTW GHG based target

Impact of the share of EVs on the average WTW GHG emissions of new vehicles, for assumed WTT emissions of EVs in 2020, 2030 and 2050

Equivalent targets based on ICEVs only
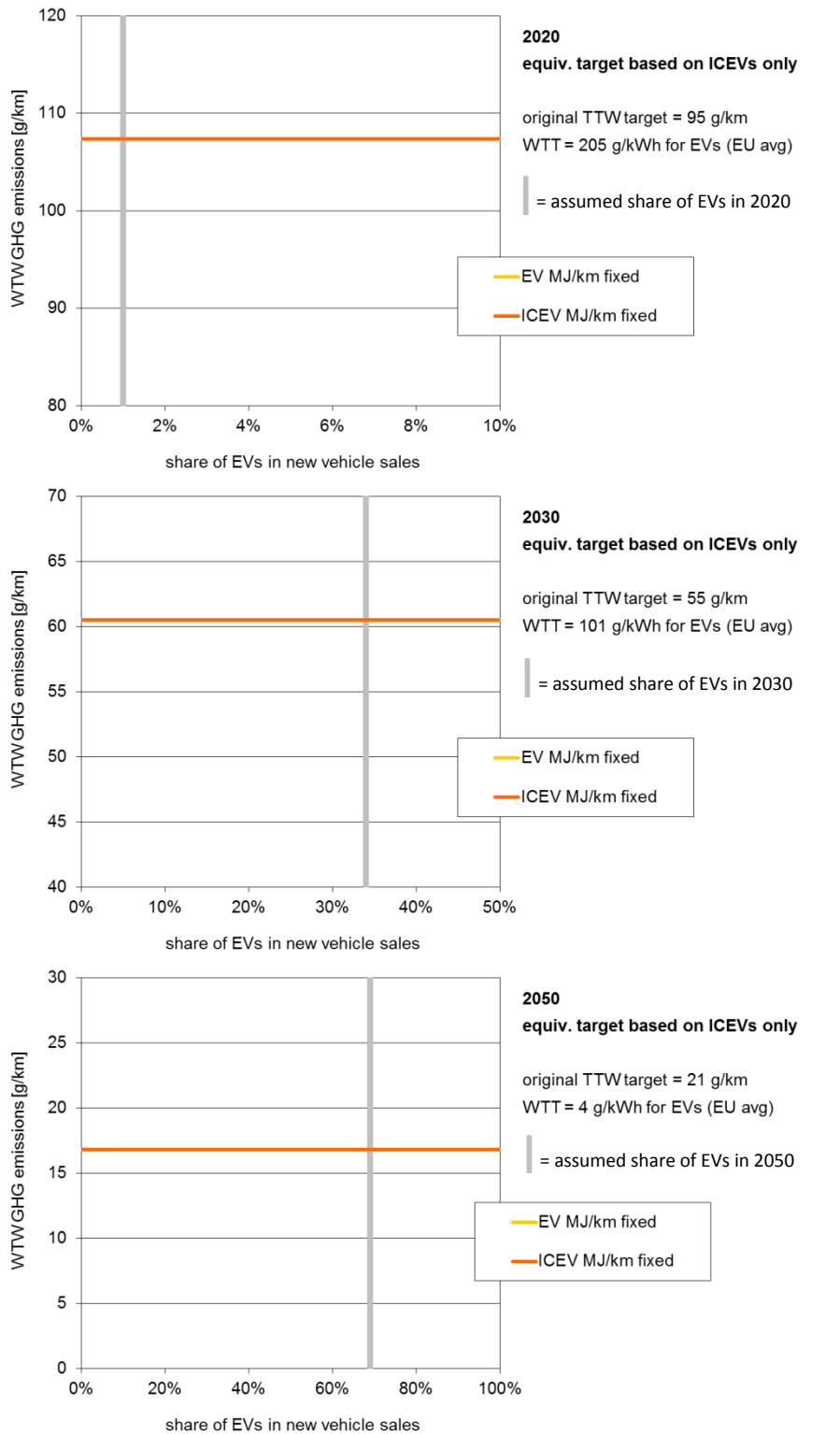
Figure 14   Illustration of the impact of the share of EVs in the new vehicle sales on average WTW GHG emissions of new vehicles sold. All graphs are for the case where the equivalent target is determined under the assumption that it can be met by ICEVs only.

WTW GHG based target

Impact of the share of EVs on the TTW energy consumption of ICEVs and EVs, required for meeting the target, for assumed WTT emissions of EVs in 2020, 2030 and 2050

Equivalent targets based on ICEVs only

2020
equiv. target based on ICEVs only

original TTW target = 95 g/km
WTT = 205 g/kWh for EVs (EU avg)

| = assumed share of EVs in 2020

- TTW MJ/km EVs (EV MJ/km fixed)
- TTW MJ/km ICEVs (EV MJ/km fixed)
- TTW MJ/km EVs (ICEV MJ/km fixed)
- TTW MJ/km ICEVs (ICEV MJ/km fixed)

2030
equiv. target based on ICEVs only

original TTW target = 55 g/km
WTT = 101 g/kWh for EVs (EU avg)

| = assumed share of EVs in 2030

- TTW MJ/km EVs (EV MJ/km fixed)
- TTW MJ/km ICEVs (EV MJ/km fixed)
- TTW MJ/km EVs (ICEV MJ/km fixed)
- TTW MJ/km ICEVs (ICEV MJ/km fixed)

2050
equiv. target based on ICEVs only

original TTW target = 21 g/km
WTT = 4 g/kWh for EVs (EU avg)

| = assumed share of EVs in 2050

- TTW MJ/km EVs (EV MJ/km fixed)
- TTW MJ/km ICEVs (EV MJ/km fixed)
- TTW MJ/km EVs (ICEV MJ/km fixed)
- TTW MJ/km ICEVs (ICEV MJ/km fixed)

Figure 15　Illustration of the impact of EVs in the new vehicle sales on average TTW energy consumption for new vehicles sold as function of the assumed share of ZEVs. All graphs are for the case where the equivalent target is determined under the assumption that it can be met by ICEVs only.

Results for WTW GHG based metric
Equivalent targets based on the assumption that the
TTW CO_2 target will be met with a specified mix of ICEVs and EVs

General comments
The conclusion that a WTW GHG based metric effectively makes the average WTW emissions of new vehicles insensitive to the WTT emissions of ZEVs and to the share of ZEVs is independent of whether the equivalent target is based on the assumption that it is met by ICEVs only or by a specified mix of ICEVs and ZEVs.

Sensitivity of WTW emissions to WTT electricity GHG intensity (Figure 16)	
General	A WTW GHG based metric effectively makes the average WTW emissions of new vehicles insensitive to the share of ZEVs that is used to achieve the target.
2020	**None**
2030	**None**
2050	**None**

Sensitivity of WTW emissions to EV share (Figure 17)	
General	A WTW GHG based metric effectively makes the average WTW emissions of new vehicles insensitive to the share of ZEVs that is used to achieve the target.
2020	**None**
2030	**None**
2050	**None**

Sensitivity of ICE TTW emissions to EV share (Figure 18)	
General	In this case the sensitivity of the energy consumption of ICEVs and ZEVs to variations in the ZEVs share is very different from the case of an equivalent target based on 100% ICEVs.
	The graphs contain two scenarios: one in which the efficiency of EVs is assumed constant and that of ICEVs is adjusted in response to the changing share of EVs, and one in which the efficiency of ICEVs is assumed constant and that of EVs is adjusted.
	The TTW energy consumption of ICEVs and / or EVs (required for meeting the target) is found to be very sensitive to variations in the share of EVs.
2020	**Weak**
	If the efficiency of ICEVs is assumed fixed, the energy consumption of EVs is extremely sensitive to deviations of the EV share from the value assumed for the equivalent target. However, for 2020 the assumption of fixed ICEV energy consumption is not so relevant, but for 2030 and beyond this is a more likely scenario.
2030	**Moderate (but somewhat less than TTW GHG based metric)**
	If the efficiency of EVs is assumed fixed, the energy consumption of ICEVs is sensitive to deviations of the EV share from the value assumed for the equivalent target only for 2030 and beyond.
	If the efficiency of ICEVs is assumed fixed, the energy consumption of EVs is extremely sensitive to deviations of the EV share from the value assumed for the equivalent target. In 2030 a marginally lower EV share already requires unrealistically low EV energy consumption values for the target to be met.
2050	**Strong**
	If the efficiency of EVs is assumed fixed, a 10% lower EV share in 2050 will require ICEV energy consumption values that are not feasible with currently known technologies and existing vehicle configurations.
	If the efficiency of ICEVs is assumed fixed, the energy consumption of EVs is extremely sensitive to deviations of the EV share from the value assumed for the equivalent target. In 2050 a marginally lower EV share already requires unrealistically low EV energy consumption values for the target to be met.

Impact of over/under estimating EV share
For 2030 and beyond the room to compensate (by means of adjusting the energy efficiency of ICEVs and ZEVs within feasible bandwidths) for deviations in the actual ZEV share from the share assumed for setting the target is extremely limited.

Other remarks
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WTW GHG based target

Impact of the WTT emissions of EVs on the average WTW GHG emissions of new vehicles, for an assumed share of EVs in 2020, 2030 and 2050
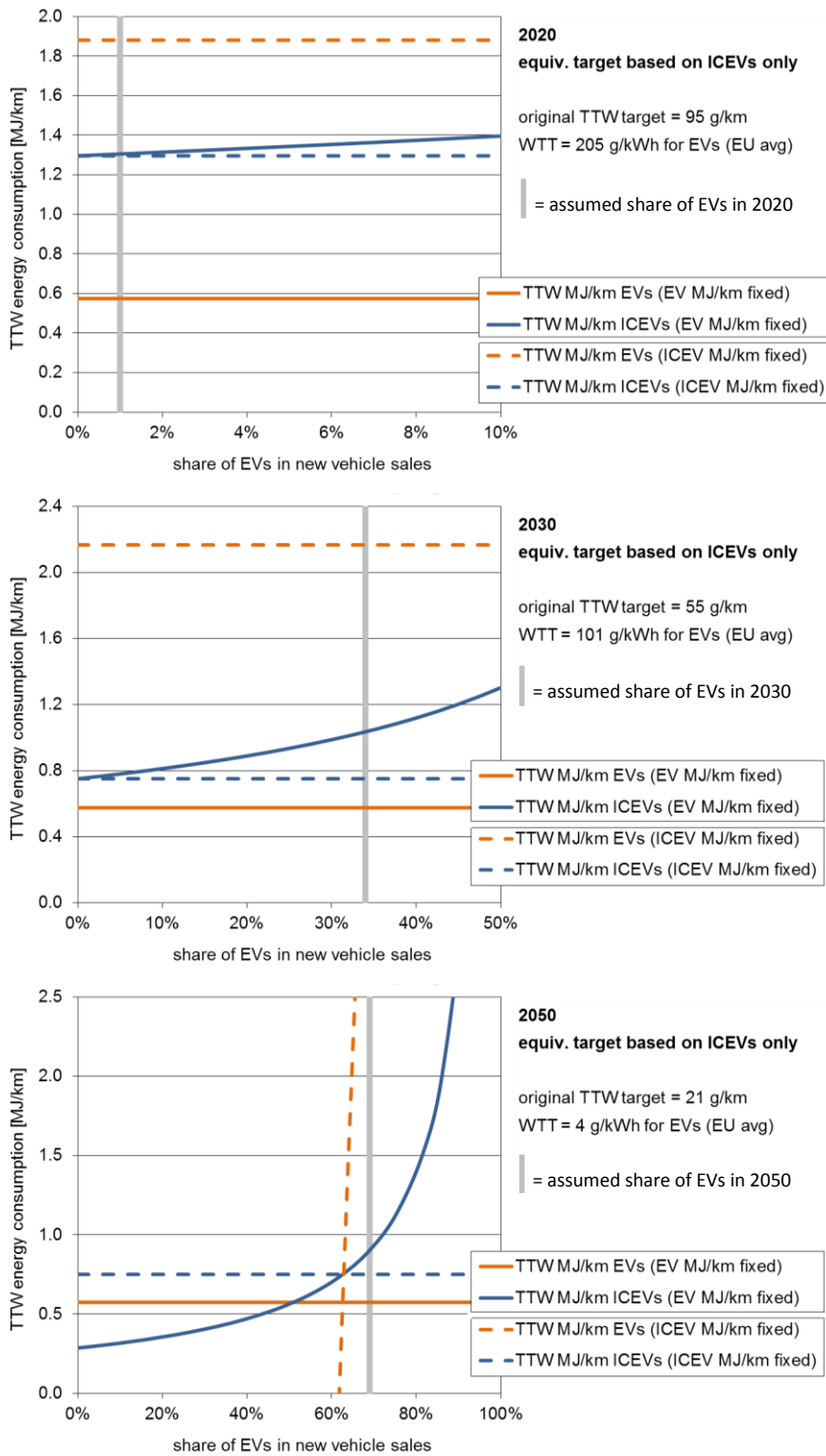
Equivalent targets based on ICEVs / EVs mix

2020
equiv. target based on ICEVs / EVs mix

original TTW target = 95 g/km
WTT = 205 g/kWh for EVs (EU avg)
EV share for target = 1%

| = assumed WTT emissions of EVs in 2020

2030
equiv. target based on ICEVs / EVs mix

original TTW target = 55 g/km
WTT = 101 g/kWh for EVs (EU avg)
EV share for target = 34%

| = assumed WTT emissions of EVs in 2030

2050
equiv. target based on ICEVs / EVs mix

original TTW target = 21 g/km
WTT = 4 g/kWh for EVs (EU avg)
EV share for target = 65%

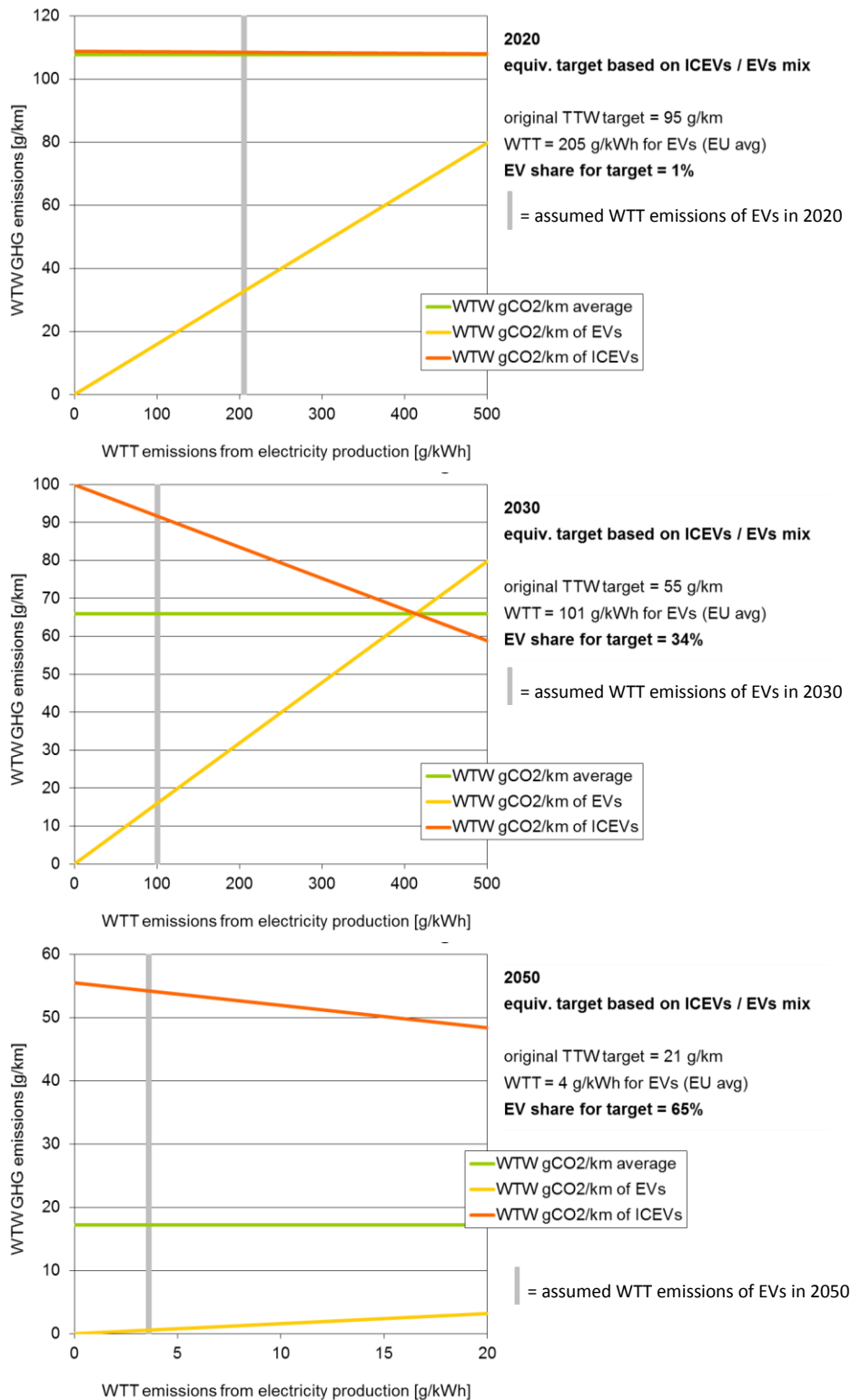| = assumed WTT emissions of EVs in 2050

Figure 16   Illustration of the impact of the WTT emission of EVs on average WTW GHG emissions for new vehicles, for an assumed share of EVs. All graphs are for the case where the equivalent target is determined under the assumption that it is met with a mix of ICEVs and ZEVs.

WTW GHG based target

Impact of the share of EVs on the average WTW GHG emissions of new vehicles, for assumed WTT emissions of EVs in 2020, 2030 and 2050

Equivalent targets based on ICEVs / EVs mix

2020
equiv. target based on ICEVs / EVs mix

original TTW target = 95 g/km
WTT = 205 g/kWh for EVs (EU avg)
EV share for target = 1%

| = assumed share of EVs in 2020

EV MJ/km fixed
ICEV MJ/km fixed

2030
equiv. target based on ICEVs / EVs mix

original TTW target = 55 g/km
WTT = 101 g/kWh for EVs (EU avg)
EV share for target = 34%

| = assumed share of EVs in 2030

EV MJ/km fixed
ICEV MJ/km fixed

2050
equiv. target based on ICEVs / EVs mix

original TTW target = 21 g/km
WTT = 4 g/kWh for EVs (EU avg)
EV share for target = 69%

| = assumed share of EVs in 2050
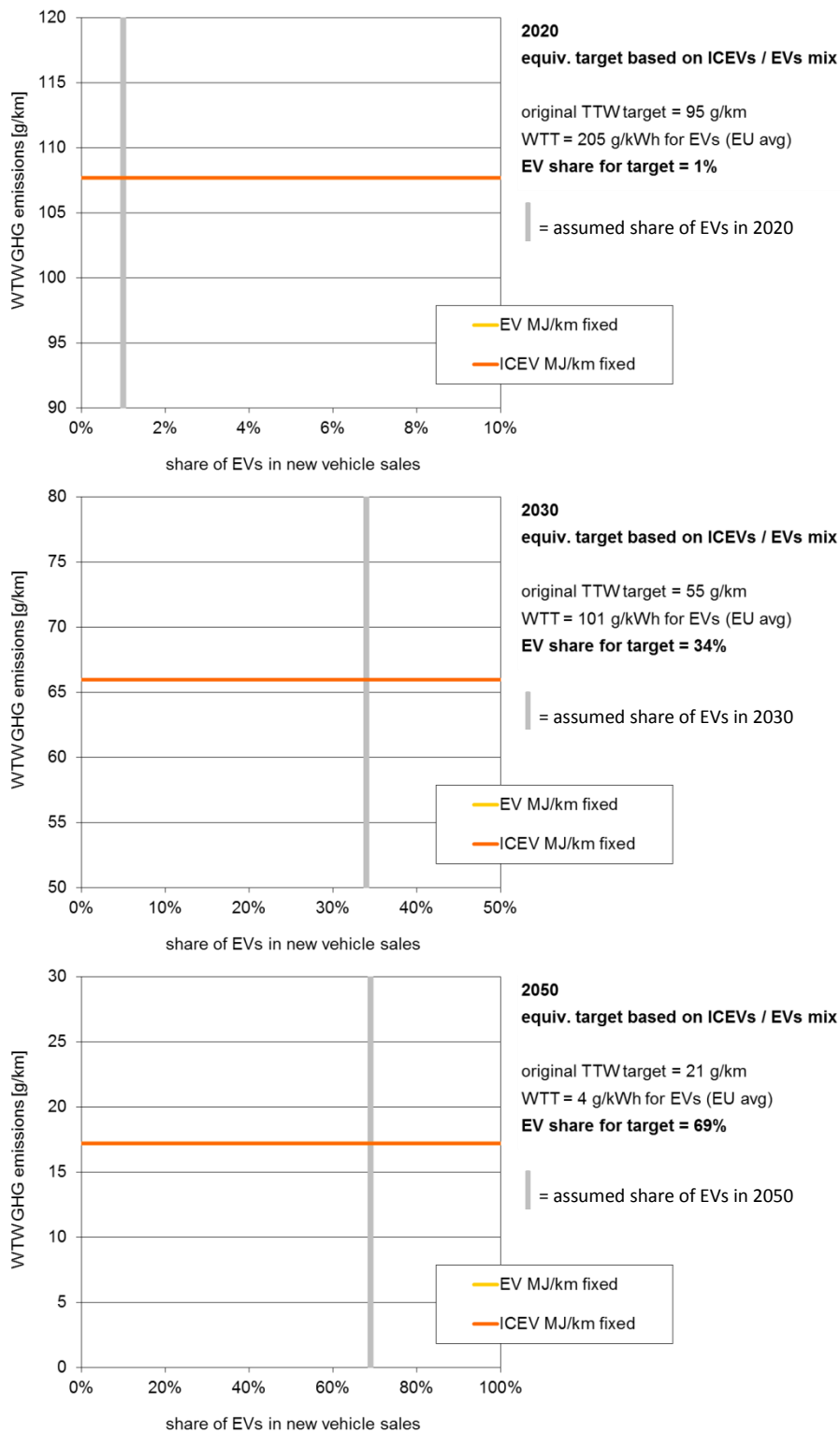
EV MJ/km fixed
ICEV MJ/km fixed

Figure 17   Illustration of the impact of the share of EVs in the new vehicle sales on average WTW GHG emissions of new vehicles sold. All graphs are for the case where the equivalent target is determined under the assumption that it is met with a mix of ICEVs and ZEVs.

WTW GHG based target
Impact of the share of EVs on the TTW energy consumption of ICEVs and EVs, required for meeting the target, for assumed WTT emissions of EVs in 2020, 2030 and 2050

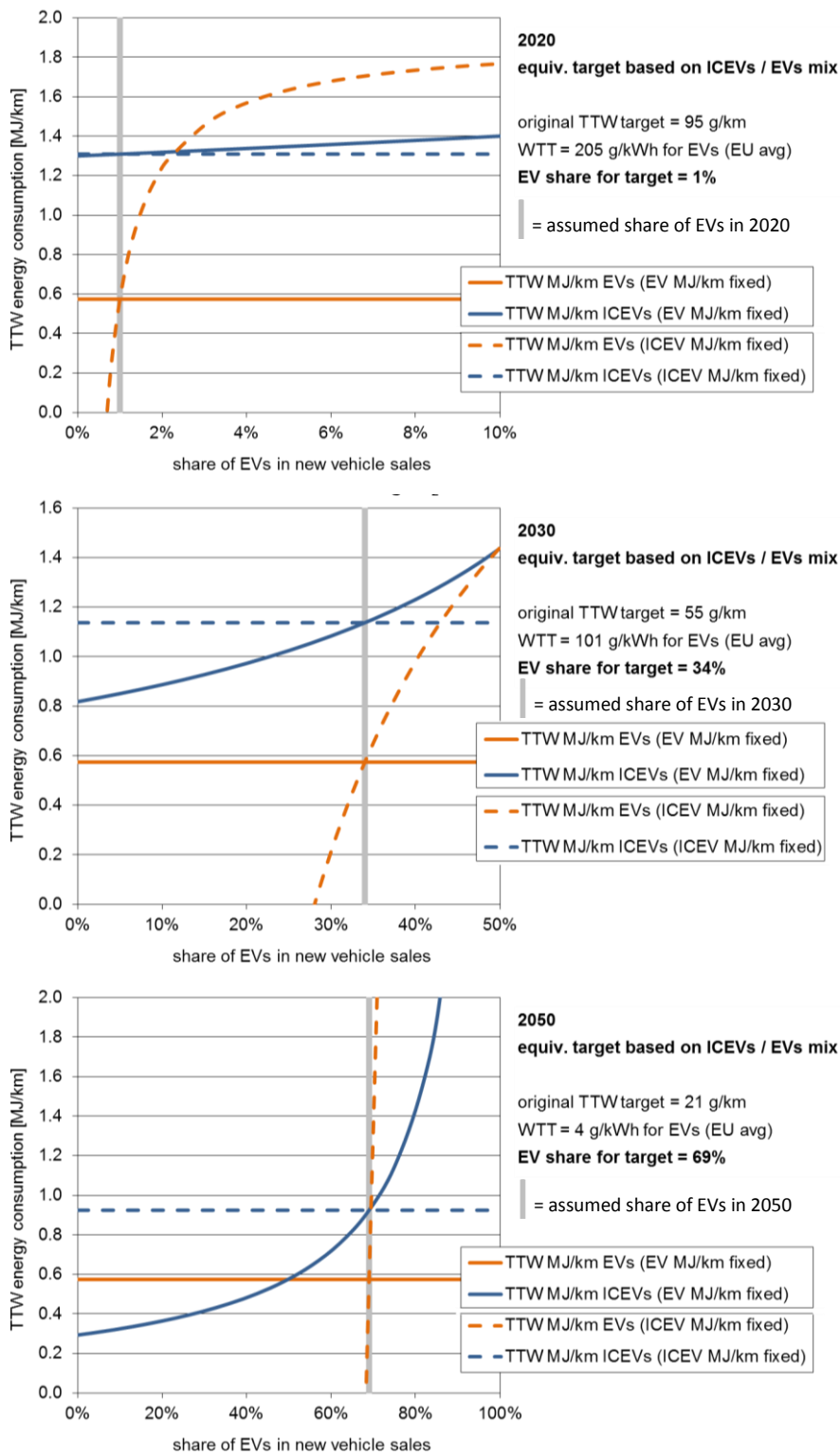**Equivalent targets based on ICEVs / EVs mix**

Figure 18   Illustration of the impact of share of EVs in the new vehicle sales on average TTW energy consumption for new vehicles. All graphs are for the case where the equivalent target is determined under the assumption that it is met with a mix of ICEVs and ZEVs.

Conclusions for a WTW CO$_2$ based metric

- Under a WTW GHG based target the WTW GHG emissions are obviously independent of the share of ZEVs and actual WTT factors for ICEVs and ZEVs.
- But the flexibility with respect to changes in the share of ZEVs (relative to the assumed share for determination of the equivalent WTW based target) appears rather limited and depends on the possibility for ICEVs to respond to a changing ZEV-share.
  - In case the equivalent WTW target is based on the assumption that the TTW target is met by a mix of ICEVs and ZEVs, the following can be concluded:
    - If the efficiency of ZEVs is assumed to be fixed, required changes in TTW MJ/km of ICEVs in response to a varying ZEV share appear feasible in the medium term. In the long term, however, the efficiency improvements of ICEVs, necessary to respond to a lower than expected share of ZEVs, become very large.
    - If the efficiency of ICEVs is assumed to be fixed, which is specifically likely in by 2030 and beyond when ICEV technologies may have reached their limits, the required energy efficiency of ZEVs is extremely sensitive to the ZEV share both in the medium and long term, and quickly moves beyond feasible values if realised ZEV shares are somewhat below the expected values.
  - In case the equivalent WTW target is based on the assumption that the TTW target can be met by ICEVs only, the efficiency of ZEVs does not need to be adjusted in response to a changing ZEV share, even when the efficiency of ICEVs is assumed constant. For longer term targets the assumption that the TTW target can be met with ICEVs only becomes very improbable. If we assume that under a long term WTW target the TTW emissions of ICEVs are fixed to a value that is higher than the equivalent TTW target, the efficiency of ZEVs becomes very sensitive to changes in the share of ZEVs.

4.4 Energy consumption based metrics

4.4.1 *Energy used in the vehicle per vehicle-km (option b.1)*

The following analysis applies to the metric that is based on WTT energy consumption.

Results for TTW energy based metric Equivalent targets based on the assumption that the TTW CO_2 target can be met with ICEVs only	
General comments	
This example shows that for a TTW energy consumption based target it is necessary to determine the equivalent target on the basis of the assumption that the target for TTW GHG emissions is met by a mix of ICEVs and ZEVs. This, however, can be considered a facet of the approach to carrying out the analysis. If a TTW energy target were being established it would be done in a way that was achievable.	
Sensitivity of WTW emissions to WTT electricity GHG intensity (Figure 19)	
General	The sensitivity is similar to that for the TTW GHG based metric, but the pivot point is shifted. For values of the WTT emissions of EVs below 300 g/kWh the WTW emissions are lower than for the case without EVs, while only for WTT emissions of EVs above 300 g/kWh they are higher. Under similar assumptions this metric thus leads to lower WTW emissions.
2020	**Weak** See under 2030
2030	**Strong** The TTW energy consumption for the ICEVs is a bit higher than it would have been without EVs, but the increase in WTW emissions that results from that is more than compensated by the lower WTW emissions of EVs, provided the WTT emissions from electricity production are below around 300 g/kWh.
2050	**Weak** For 2050 the WTW emissions for this case are negative, as are the TTW emissions of ICEVs required to meet the target. This obviously is not feasible and results from the fact that the equivalent target is lower than the assumed energy consumption of EVs. In order to meet the target therefore, ICEVs need to have negative energy consumption.
Sensitivity of WTW emissions to EV share (Figure 20)	
General	WTW emissions of new vehicles decrease with an increasing share of EVs in this example case. This is opposite to the case of the TTW GHG-based metric.
2020	**Strong (but opposite sign compared to TTW GHG based metric)** For 2020 and 2030 this is despite the fact that the WTW emissions of ICEVs increase with increasing share of EVs.
2030	**Strong (but opposite sign compared to TTW GHG based metric)** Idem
2050	**Strong (but opposite sign compared to TTW GHG based metric)** For 2050 the WTW emissions decrease with increasing EV share. As they are already lower than what is achievable with known technologies and existing vehicle specifications for 0% EVs, they will become unfeasibly low when the share of EVs is increased, reaching negative levels for EV shares over 50%.
Sensitivity of ICE TTW emissions to EV share (Figure 20)	
General	The sensitivity of the ICEV TTW emissions required for meeting the target as function to variations in the actual ZEV share is significantly weaker than for the TTW GHG-based target.
2020	**Moderate**
2030	**Moderate**
2050	**Strong (but opposite sign compared to TTW GHG based metric)** But case is not realistic for the assumptions made in this example
Impact of over/under estimating EV share	
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Other remarks	
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TTW energy based target

Impact of the WTT emissions of EVs on the average WTW GHG emissions of new vehicles, for an assumed share of EVs in 2020, 2030 and 2050

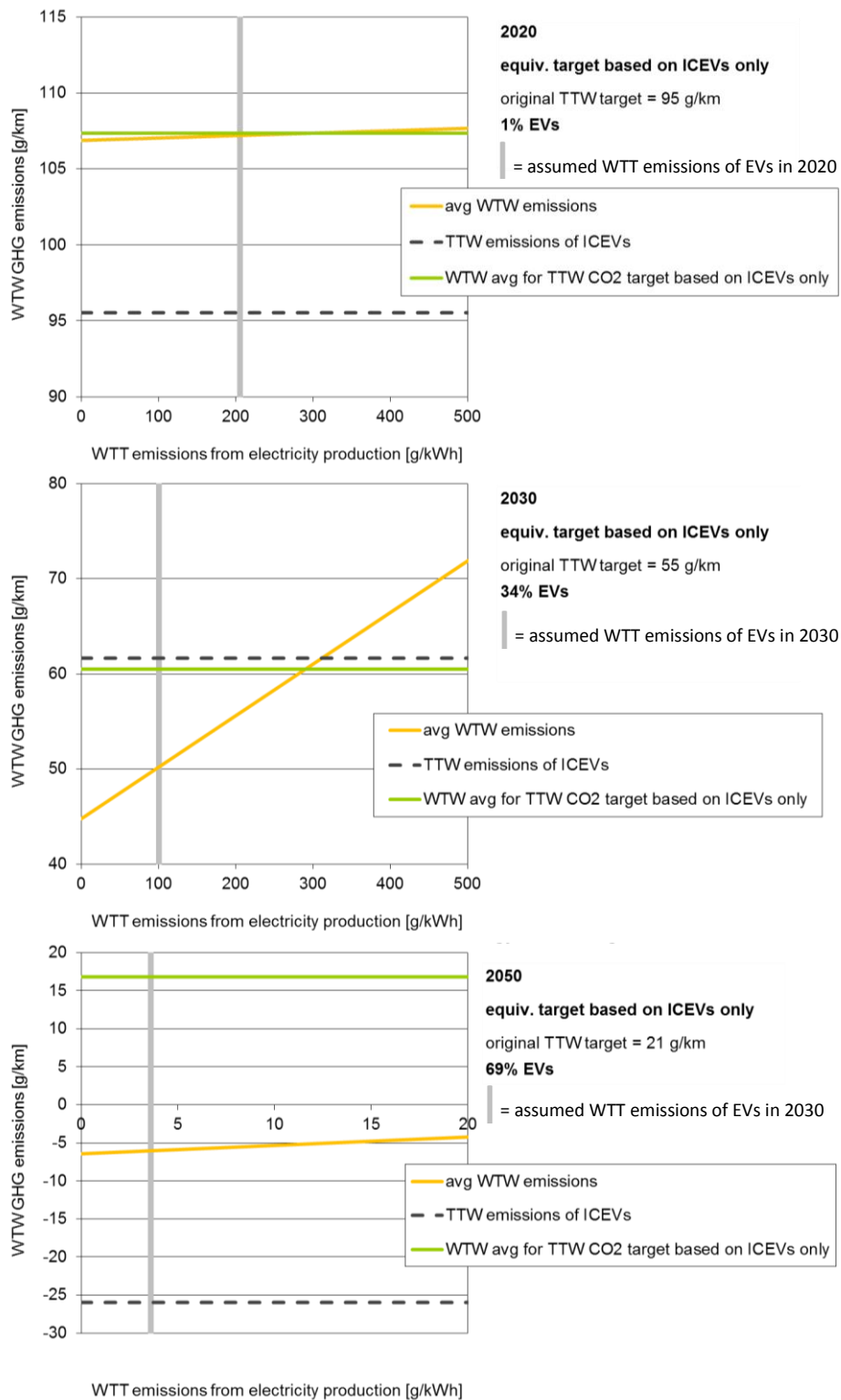## Equivalent targets based on ICEVs only

Figure 19 Illustration of the impact of the WTT emissions of EVs on average WTW GHG emissions in g/km for new vehicles, for an assumed share of EVs. All graphs are for the case where the equivalent target is determined under the assumption that it can be met by ICEVs only.

TTW energy based target

Impact of the share of EVs on average WTW GHG emissions of new vehicles and TTW GHG emissions of ICEVs, for an assumed GHG intensity of electricity in 2020, 2030 and 2050

Equivalent targets based on ICEVs only

2020

equiv. target based on ICEVs only

TTW target = 95 g/km

WTT = 205 g/kWh for EVs (EU avg)

| = assumed share of EVs in 2020

- avg WTW emissions
- TTW emissions of ICEVs
- WTW avg for TTW CO2 target based on ICEVs only

2030

equiv. target based on ICEVs only

TTW target = 55 g/km

WTT = 101 g/kWh for EVs (EU avg)

- avg WTW emissions
- TTW emissions of ICEVs
- WTW avg of TTW CO2 target based on ICEVs only

| = assumed share of EVs in 2030

2050

equiv. target based on ICEVs only

TTW target = 21 g/km

WTT = 4 g/kWh for EVs (EU avg)

| = assumed share of EVs in 2050

- avg WTW emissions
- TTW emissions of ICEVs
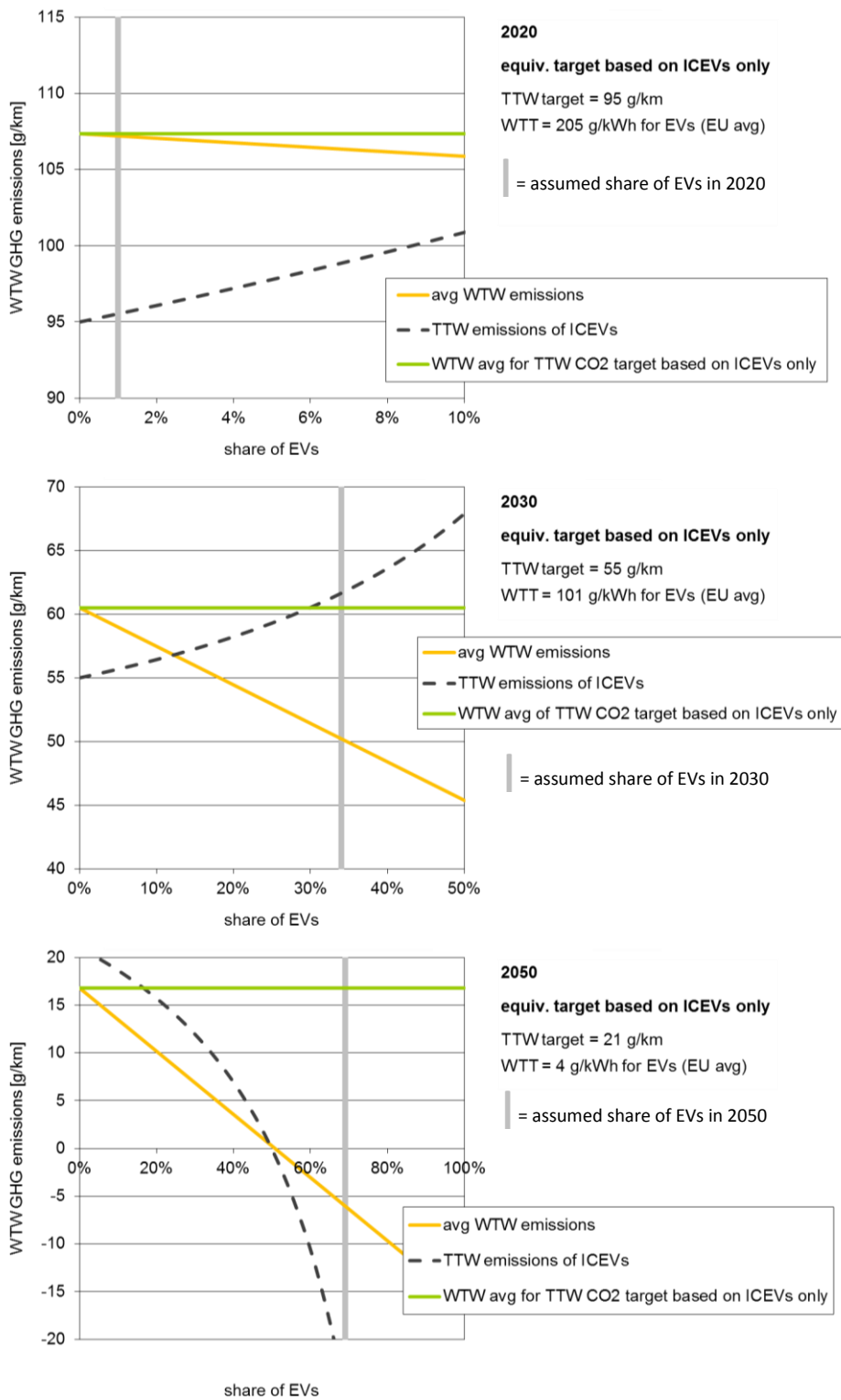- WTW avg for TTW CO2 target based on ICEVs only

Figure 20   Illustration of the impact of EVs in the new vehicle sales on average WTW GHG emissions in g/km for new vehicles sold as function of the assumed share of ZEVs. All graphs are for the case where the equivalent target is determined under the assumption that it can be met by ICEVs only.

Results for TTW energy based metric Equivalent targets based on the assumption that the TTW CO_2 target will be met with a specified mix of ICEVs and EVs	
General comments	
If the equivalent target is based on the assumption that the TTW GHG emission target is met by a mix of ICEVs and ZEVs, EVs still have a leverage on the emissions of ICEVs. The sensitivity is exactly the same as for the TTW GHG emission based target.	
Sensitivity of WTW emissions to WTT electricity GHG intensity (Figure 21**)**	
General	WTW emissions increase as a function of the WTT emissions from electricity generation for a given share of EVs. The sensitivity is exactly the same as for the TTW GHG emission based target.
2020	**Weak**
2030	**Strong**
2050	**Weak**
Sensitivity of WTW emissions to EV share (Figure 22)	
General	The sensitivity is reversed in sign but also somewhat weaker than for the TTW GHG-based metric. Average WTW emissions decrease with an increasing EV share. If the EV share equals the value on which the equivalent target is based the WTW emissions under the TTW energy based metric equal those under the TTW GHG emissions based target.
2020	**Strong (but opposite sign compared to TTW GHG based metric)**
2030	**Strong (but opposite sign compared to TTW GHG based metric)** For EV shares below what is assumed for determining the equivalent target the WTW emissions are higher than for the TTW GHG-based metric.
2050	**Strong (but opposite sign compared to TTW GHG based metric)** To meet the target in 2050 low levels of EVs still require very efficient ICEVs, to levels below what is currently foreseen as possible with existing vehicle configurations and specifications, but the required values stay positive.
Sensitivity of ICE TTW emissions to EV share (Figure 22)	
General	
2020	**Moderate** Similar to case for equivalent target based on assumption that target can be met with ICEVs only.
2030	**Moderate** Similar to case for equivalent target based on assumption that target can be met with ICEVs only.
2050	**Strong** For the 2050 situation the sign of the sensitivity is reversed compared to the case where the equivalent target is based on the assumption that the target can be met with ICEVs only. The sensitivity increases with increasing actual EV share.
Impact of over/under estimating EV share	
Compared to the previous example of the WTW GHG-based metric, the room to compensate (by means of adjusting the energy efficiency of ICEVs and ZEVs within feasible bandwidths) for deviations in the actual ZEV share from the share assumed for setting the target appears much larger for a TTW energy-based metric.	
Other remarks	
Going to a TTW energy-based metric could in the short term somewhat reduce the impact of ZEVs on the net WTW emissions achieved by the regulation, but certainly in the longer term cannot be considered a fundamental solution for the problem identified with the TTW CO_2 based metric.	

TTW energy based target

Impact of the WTT emissions of EVs on the average WTW GHG emissions of new vehicles, for an assumed share of EVs in 2020, 2030 and 2050
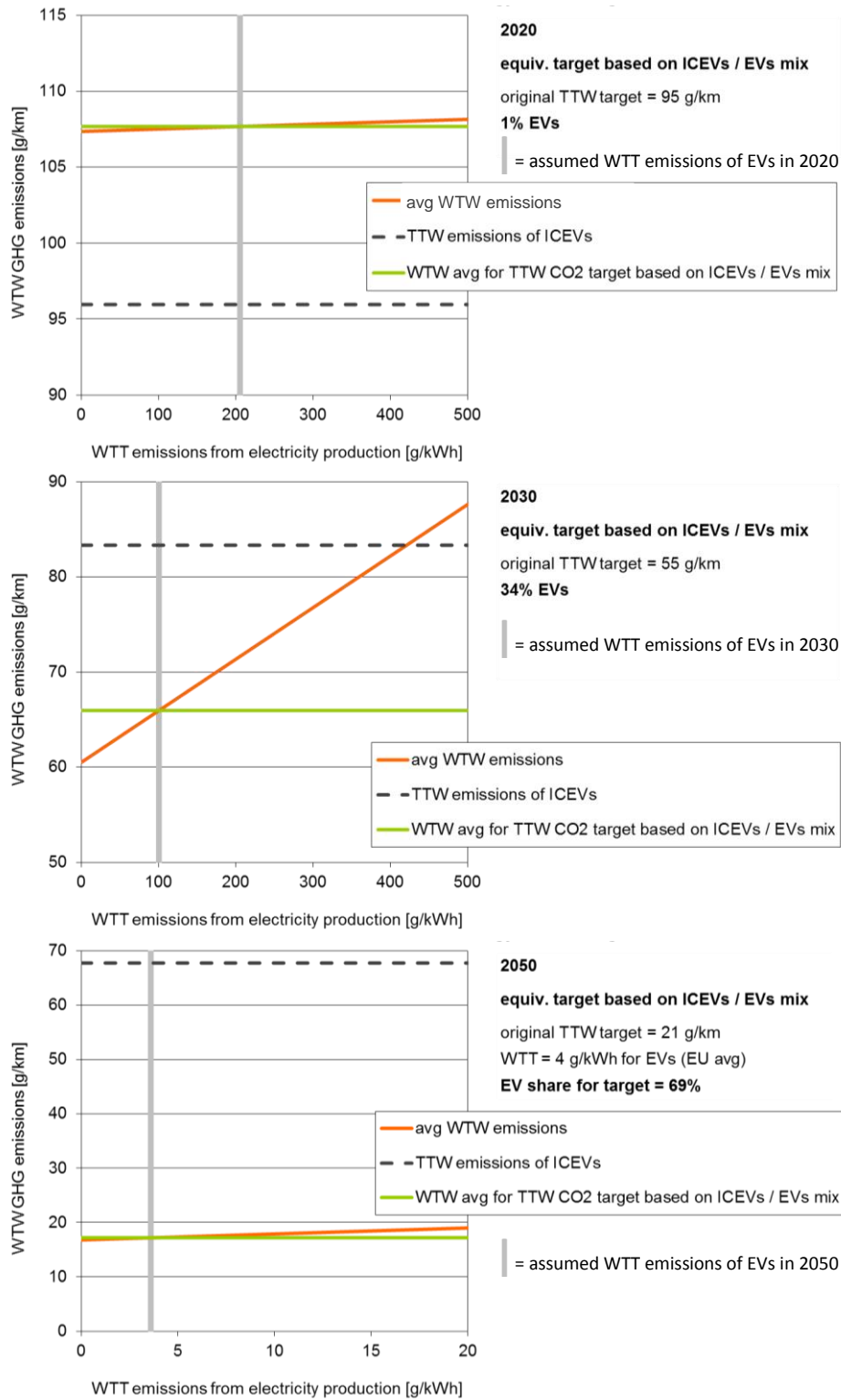
Equivalent targets based on ICEVs / EVs mix

Figure 21   Illustration of the impact of the WTT emissions of EVs on average WTW GHG emissions of new vehicles, for an assumed EV share. All graphs are for the case where the equivalent target is determined under the assumption that it is met with a mix of ICEVs and ZEVs.

TTW energy based target
Impact of the share of EVs on average WTW GHG emissions of new vehicles and TTW GHG emissions of ICEVs, for an assumed GHG intensity of electricity in 2020, 2030 and 2050

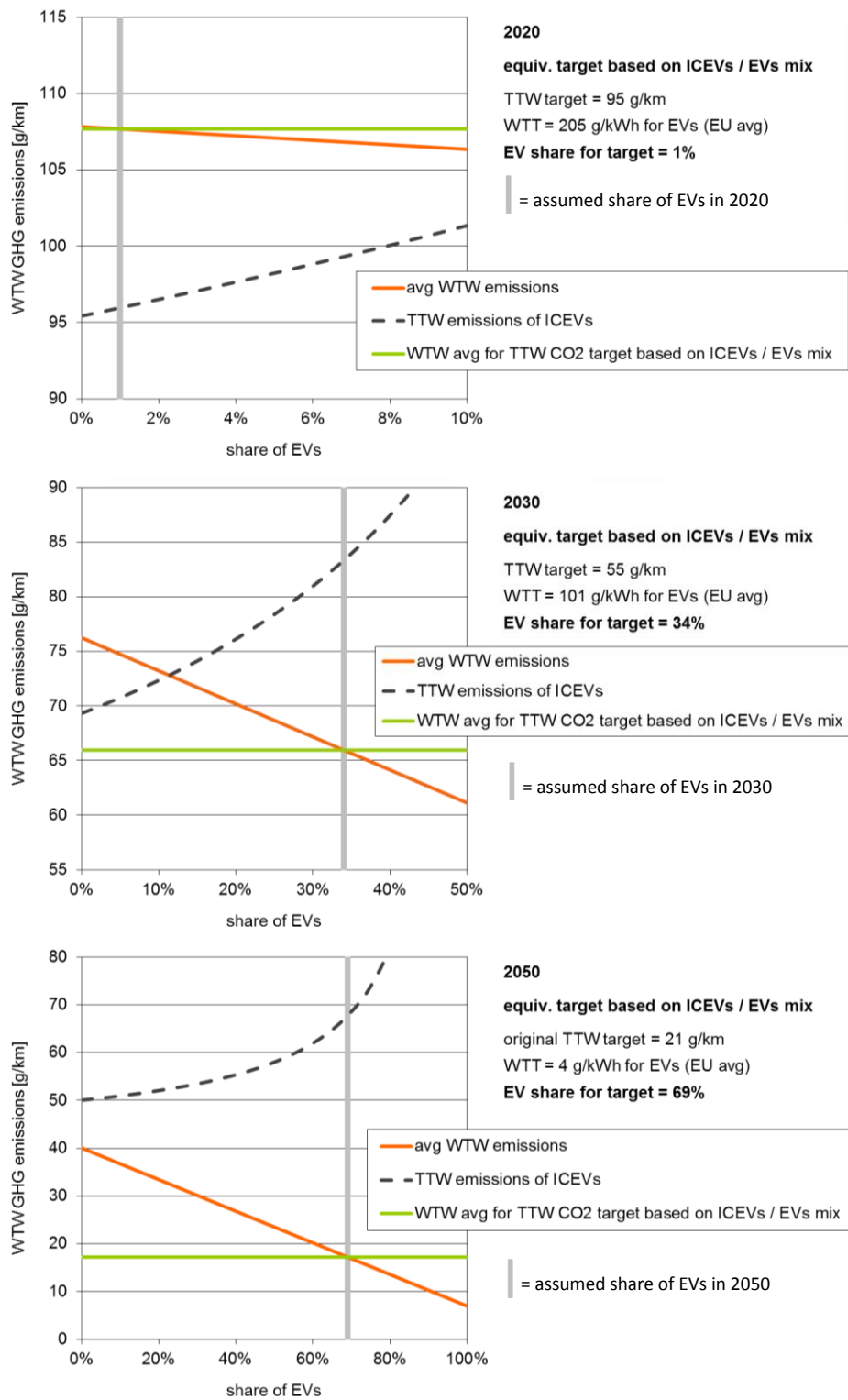## Equivalent targets based on ICEVs / EVs mix

Figure 22   Illustration of the impact the share of EVs on average WTW GHG emissions in g/km of new vehicles. All graphs are for the case where the equivalent target is determined under the assumption that it is met with a mix of ICEVs and ZEVs.

Conclusions for a TTW energy based metric

- Under a TTW MJ/km metric introduction of ZEVs in the new vehicle fleet has the following consequences:
    - o For a given share of ZEVs the WTW GHG emissions increase with increasing WTT emissions of ZEVs. The sensitivity of average WTW GHG emissions to variations in the WTT emissions of ZEVs is about the same as for a TTW CO_2 based metric;
    - o WTW GHG emissions decrease with an increasing share of ZEVs provided that WTT emission of these ZEVs are sufficiently low. This is opposite to what happens under a TTW CO_2 based metric. The sensitivity of average WTW GHG emissions to variations in the share of ZEVs is larger than in the case of a TTW CO_2 based metric. This most notable in the medium to long term.
- A TTW energy based target can be considered to solve the problem of "WTW CO_2 leakage" as observed in a TTW CO_2 based metric, as WTW emissions decrease rather than increase with an increasing share of ZEVs if WTT emissions of these ZEVs are sufficiently low.
    - o If WTT emissions of ZEVs are sufficiently low, the behaviour of average WTW emissions of new vehicles under a TTW energy based target can be considered more "logical" than under a TTW CO_2 target. However, desired WTW reductions are not achieved if the share of ZEVs is smaller than planned.
    - o "WTW CO_2 leakage" as observed in a TTW CO_2 based metric only occurs when WTT emissions of ZEVs are much higher than foreseen for the medium to long term. In that case WTW emissions may be higher that aimed for if the share of ZEVs is larger than planned.
- In the medium to long term equivalent targets for a TTW energy based target must be defined under the assumption that the original TTW CO_2 based target is met by a mix of ICEVs and ZEVs. If the target is translated under the assumption that the original TTW CO_2 based target is met by ICEVs only, the equivalent target ends up below the minimum feasible energy consumption of ICEVs and ZEVs.

4.4.2 Separate efficiency targets for different classes of propulsion systems (option b.2)

The effect of introducing ZEVs on the overall average WTW emissions depends on the TTW MJ/km targets set for the different technologies and the associated WTT emission factors for the different energy carriers.

4.4.3 Energy use per vehicle-km adjusted for WTW consumption (option b.3)

The analysis for this metric is complicated by the fact that if WTT emissions from electricity generation change also the WTT energy consumption is likely to change. However, there is no fixed relationship between the two. WTT emissions and WTT energy consumption are low in case electricity is predominantly produced from renewable sources such as solar and wind power. On the other hand low WTT emissions are accompanied by high WTT energy consumption if this decarbonisation is achieved by large-scale application of carbon capture and storage (CCS).

In the analysis below it is assumed that WTT emissions from electricity production can be varied independently from the WTT energy consumption.

Results for WTW energy based metric
Results for WTW energy based metric Equivalent targets based on the assumption that the TTW CO_2 target can be met with ICEVs only

General comments	
Note that in the analysis below it is assumed that WTT emissions from electricity production can be varied independently from the WTT energy consumption. This means that for a given share of EVs the WTW emissions of ICEVs are independent from the WTT emissions from electricity generation, if these changing WTT emissions do not affect the WTT energy consumption from electricity generation.	
Sensitivity of WTW emissions to WTT electricity GHG intensity (Figure 23)	
General	For a given share of EVs the average WTW emissions from new vehicles increase with increasing WTT emissions from electricity generation. For 2030 the effect is quite pronounced.
2020	**Very weak** For 2020 this effect is negligible due to the low share of EVs.
2030	**Strong** For 2030 the effect is quite pronounced due to the higher share of EVs.
2050	**Weak** The very low WTT emissions of EVs, assumed for 2050, make that relative variations around the assumed value have little impact. Also for this metric very low 2050 targets require the energy consumption of ICEVs to be negative, meaning that for this metric such long term equivalent targets cannot be set under the assumption that the original TTW GHG emission target can be met by ICEVs only.
Sensitivity of WTW emissions to EV share (Figure 24)	
General	The graphs contain two scenarios: one in which the efficiency of EVs is assumed constant and that of ICEVs is adjusted in response to the changing share of EVs, and one in which the efficiency of ICEVs is assumed constant and that of EVs is adjusted. For the latter case the sensitivity is smaller than for the first case. Compared to the TTW GHG-based metric the sensitivity is reversed in sign and stronger.
2020	**Strong (but opposite sign and stronger compared to TTW GHG based metric)**
2030	**Strong (but opposite sign and stronger compared to TTW GHG based metric)**
2050	**Strong (but opposite sign and stronger compared to TTW GHG based metric)** If the TTW energy consumption of EVs is kept constant WTW GHG emissions decrease to negative values with increasing EV share.
Sensitivity of ICE TTW emissions to EV share (Figure 25)	
General	The graphs contain two scenarios: one in which the efficiency of EVs is assumed constant and that of ICEVs is adjusted in response to the changing share of EVs, and one in which the efficiency of ICEVs is assumed constant and that of EVs is adjusted. However, as the equivalent target is set by assuming that it is met with ICEVs only, the WTW energy consumption of EVs does not change with increasing EV share when the efficiency of ICEVs is kept constant, as every EV added to the new vehicle fleet simply needs to have the same WTW energy consumption as the ICEVs.
2020	**Very weak**
2030	**Moderate (but opposite sign and less strong compared to TTW GHG based metric)**
2050	**Strong (but opposite sign compared to TTW GHG based metric)** If the equivalent target is based on 100% ICEVs the energy consumption of ICEVs at a 0% share of EVs is already unrealistically low. If the share of EVs increases and their energy consumption is kept constant, the energy consumption of the remaining ICEVs needs to go down even further to meet the target eventually reaching negative values. For the assumptions made in this example the case is therefore not realistic.
Impact of over/under estimating EV share	
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Other remarks	
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WTW energy based target

Impact of the WTT emissions of EVs on the average WTW GHG emissions of new vehicles, for an assumed share of EVs in 2020, 2030 and 2050

Equivalent targets based on ICEVs only

2020
equiv. target based on ICEVs only

original TTW target = 95 g/km
1% EVs

| = assumed WTT emissions of EVs in 2020

WTW CO2/km average
WTW gCO2/km of EVs
WTW gCO2/km of ICEVs

2030
equiv. target based on ICEVs only

original TTW target = 55 g/km
34% EVs

| = assumed WTT emissions of EVs in 2030

WTW CO2/km average
WTW gCO2/km of EVs
WTW gCO2/km of ICEVs

2050
equiv. target based on ICEVs only

original TTW target = 21 g/km
69% EVs

| = assumed WTT emissions of EVs in 2050

WTW CO2/km average
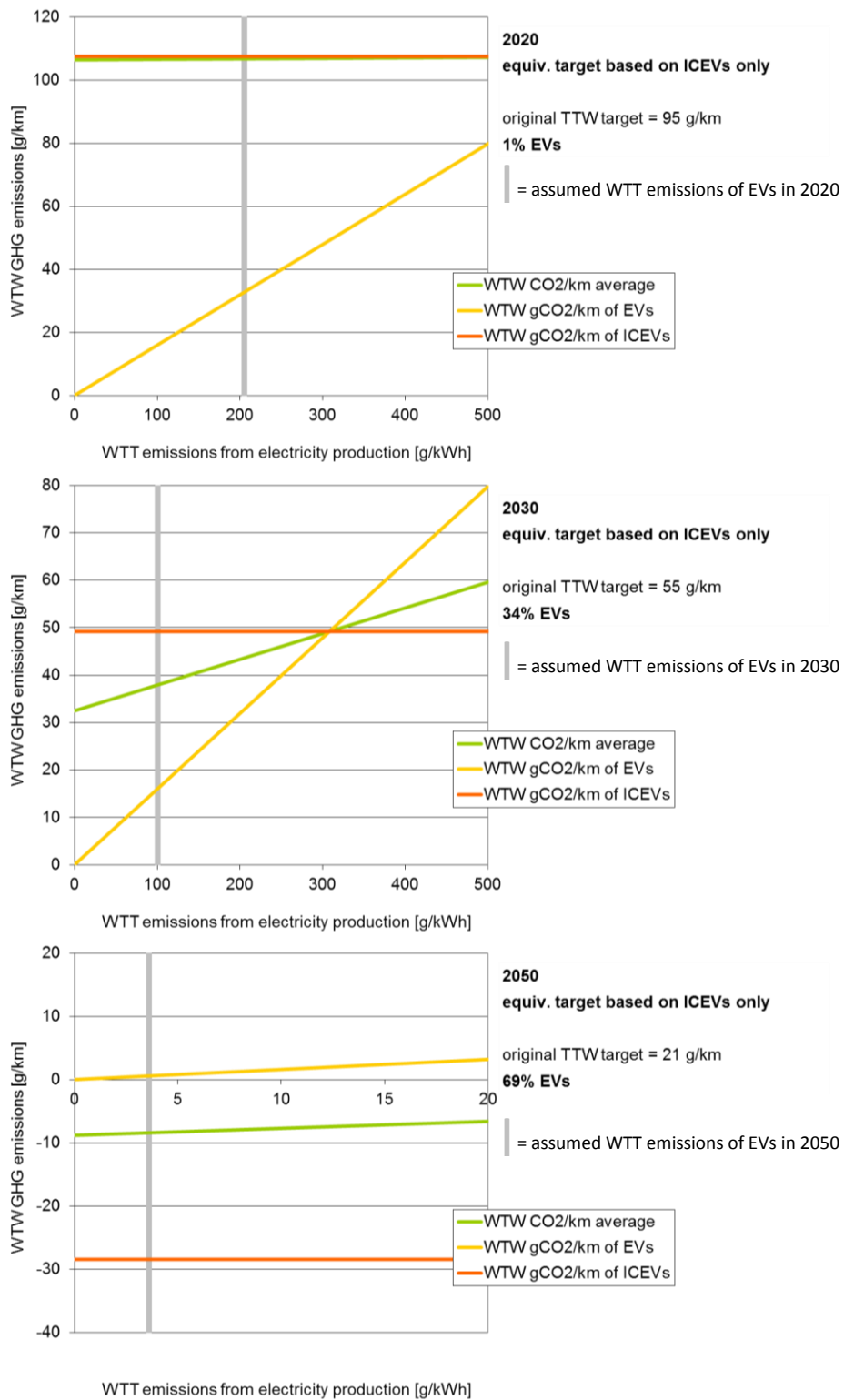WTW gCO2/km of EVs
WTW gCO2/km of ICEVs

Figure 23   Illustration of the impact of the WTT emissions of EVs on average WTW GHG emissions in g/km of new vehicles, for an assumed share of EVs. All graphs are for the case where the equivalent target is determined under the assumption that it can be met by ICEVs only.

WTW energy based target

Impact of the share of EVs on the average WTW GHG emissions of new vehicles, for assumed WTT emissions of EVs in 2020, 2030 and 2050
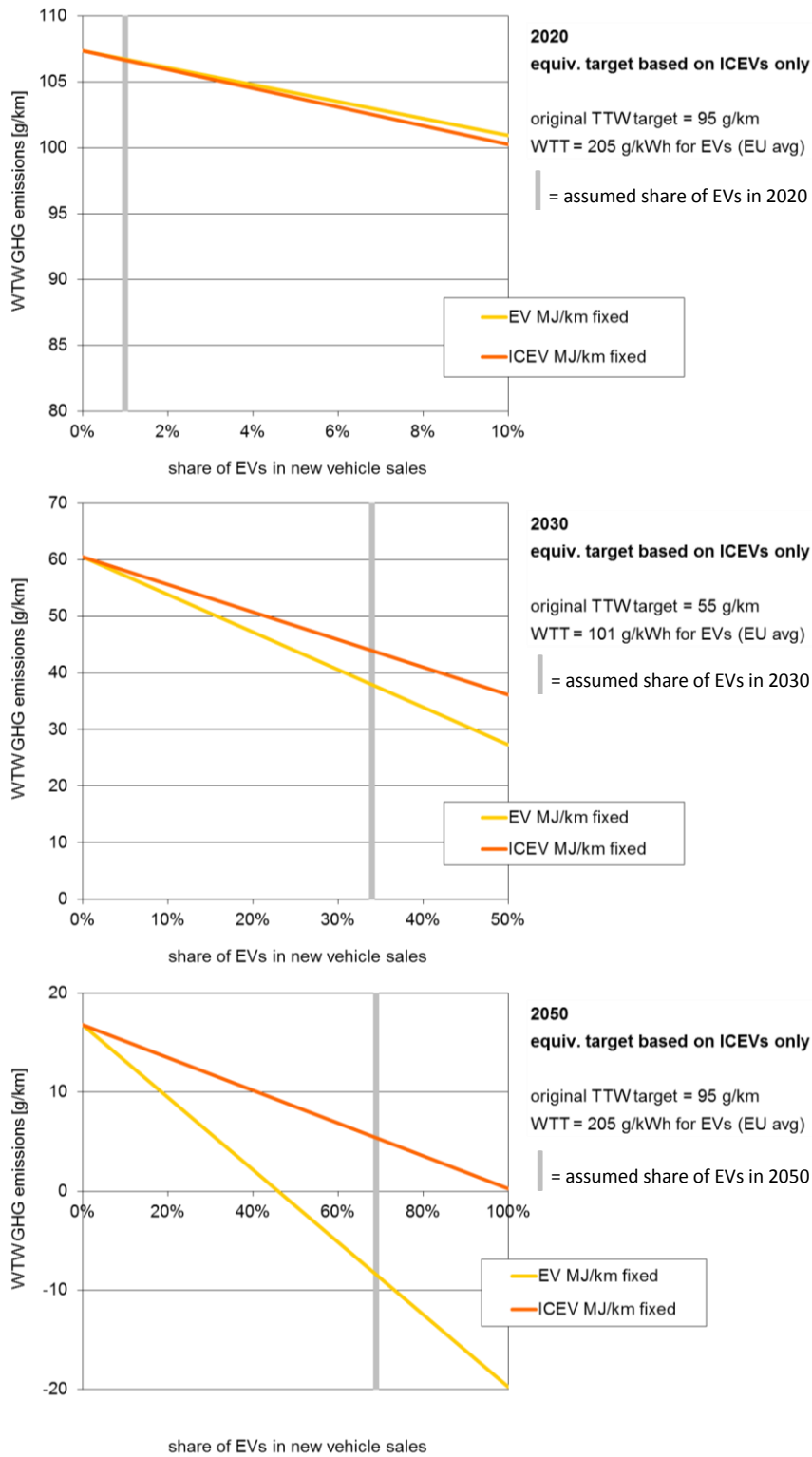
Equivalent targets based on ICEVs only

Figure 24   Illustration of the impact of the share of EVs in the new vehicle sales on average WTW GHG emissions of new vehicles. All graphs are for the case where the equivalent target is determined under the assumption that it can be met by ICEVs only.

WTW energy based target

Impact of the share of EVs on the TTW energy consumption of ICEVs and EVs, required for meeting the target, for assumed WTT emissions of EVs in 2020, 2030 and 2050
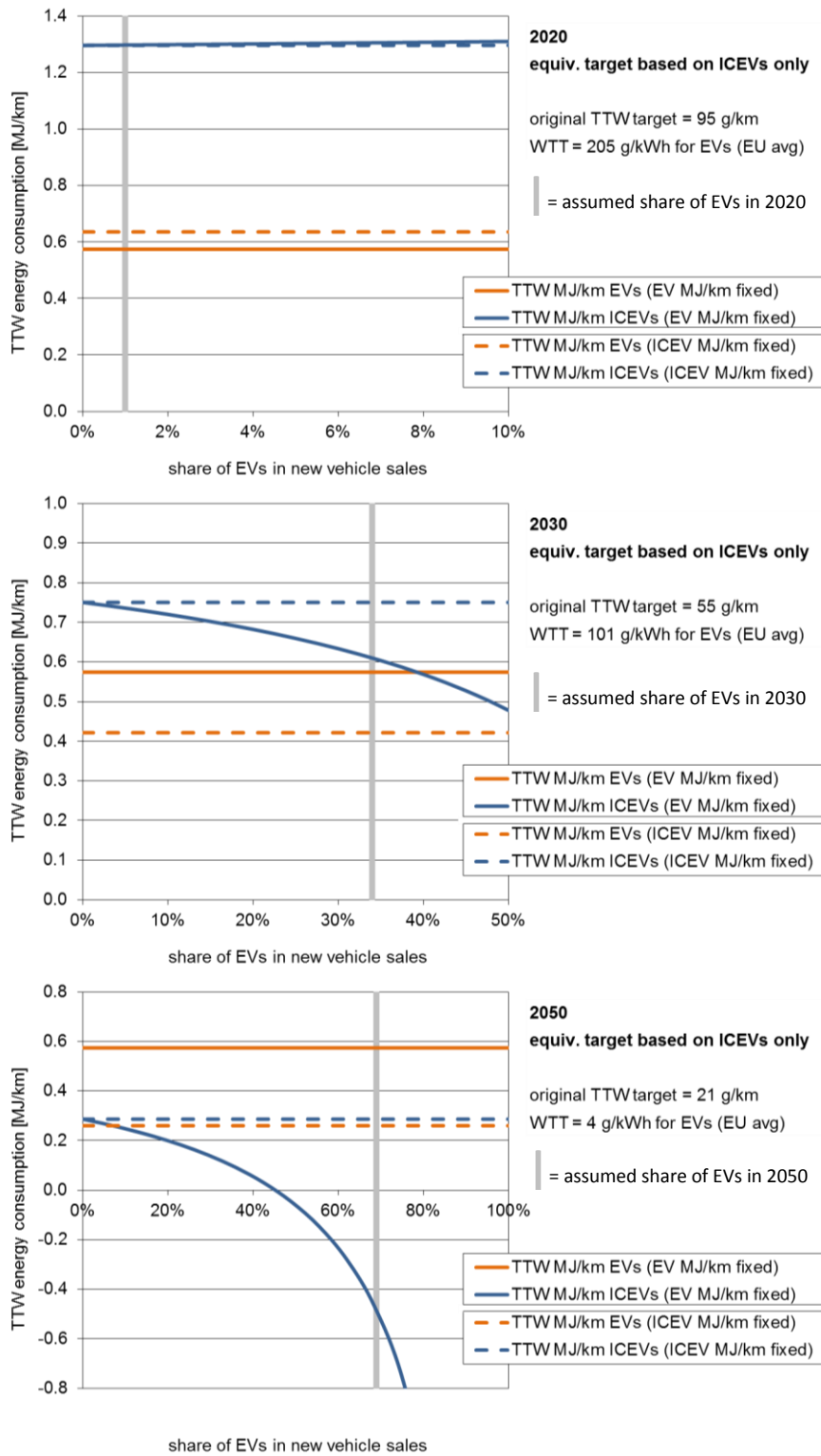
Equivalent targets based on ICEVs only

Figure 25   Illustration of the impact of the share of EVs in the new vehicle sales on average TTW energy consumption for new vehicles. All graphs are for the case where the equivalent target is determined under the assumption that it can be met by ICEVs only.

Results for WTW energy based metric Equivalent targets based on the assumption that the TTW CO_2 target will be met with a specified mix of ICEVs and ZEVs	
General comments	
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Sensitivity of WTW emissions to WTT electricity GHG intensity (Figure 26)	
General	In this case the sensitivity of WTW emissions to the WTT emissions of EVs is the same as for a target based on 100% ICEVs. The main difference is an off-set in the emissions of ICEVs. For 2020 the difference is negligible, but for 2030 and 2050 it is quite pronounced.
2020	**Very weak** For 2020 this effect is negligible due to the low share of EVs.
2030	**Strong** WTW emissions of ICEVs are > 40 g/km higher than for the target based on 100% EVs.
2050	**Weak** The very low WTT emissions of EVs, assumed for 2050, make that relative variations around the assumed value have little impact.
Sensitivity of WTW emissions to EV share (Figure 27)	
General	Also for this equivalent target definition the WTW emissions of new vehicles go down with increasing shares of EVs for a WTW energy consumption based metric. The graphs contain two scenarios: one in which the efficiency of EVs is assumed constant and that of ICEVs is adjusted in response to the changing share of EVs, and one in which the efficiency of ICEVs is assumed constant and that of EVs is adjusted. The sensitivity is overall equally strong as for the case when the equivalent target is based on the assumption that the TTW target can be met with ICEVs only. However, in this scenario the sensitivity is stronger for the case in which the efficiency of ICEVs is kept constant.
2020	**Strong (opposite sign and stronger compared to TTW GHG based metric)**
2030	**Strong (opposite sign and stronger compared to TTW GHG based metric)**
2050	**Strong (opposite sign and stronger compared to TTW GHG based metric)**
Sensitivity of ICE TTW emissions to EV share (Figure 28)	
General	If the efficiency of ICEVs is kept constant the required efficiency of EVs is very sensitive to changes in the EV share in all years. If the efficiency of EVs is assumed constant, the energy consumption of ICEVs only become sensitive to the share of EVs beyond 2030.
2020	**Very weak** For 2020 this combination of metric and equivalent target setting TTW energy consumption shows a high sensitivity for the efficiency of EVs, if the efficiency of ICEVs is assumed to be fixed. However, for 2020 the opposite situation is the case: the efficiency of EVs may be difficult to change, but there will still be sufficient potential to improve ICEVs.
2030	**Weak** For 2030 the end of the reduction potential for ICEVs may come into sight, making the scenario of fixed energy consumption of ICEVs much more realistic. In that case one sees that smaller shares of EVs than assumed for the equivalent target would require significant efficiency improvements in EVs for the target to be met.
2050	**Strong** In 2050 both scenarios are probable and both show strong sensitivity to varying EV shares. If the efficiency of EVs is assumed constant the energy consumption of ICEVs is particularly sensitive if the EV share is higher than assumed for the target and quickly rises to levels above those needed to meet the 95 g/km target in 2020. If on the other hand the efficiency of ICEVs is assumed constant, the energy consumption of EVs needs to reduce drastically if EV shares are below the level assumed for setting the equivalent target.
Impact of over/under estimating EV share	
For small variations around the level of EVs assumed for setting the target, the impact of a deviating actual EV share is smaller than for the WTW GHG based metric.	
Other remarks	
If the target is based on a mix of ICEVs and EVs, the required energy efficiency of ICEVs can be realistically achieved in 2050.	

WTW energy based target

Impact of the WTT emissions of EVs on the average WTW GHG emissions of new vehicles, for an assumed share of EVs in 2020, 2030 and 2050
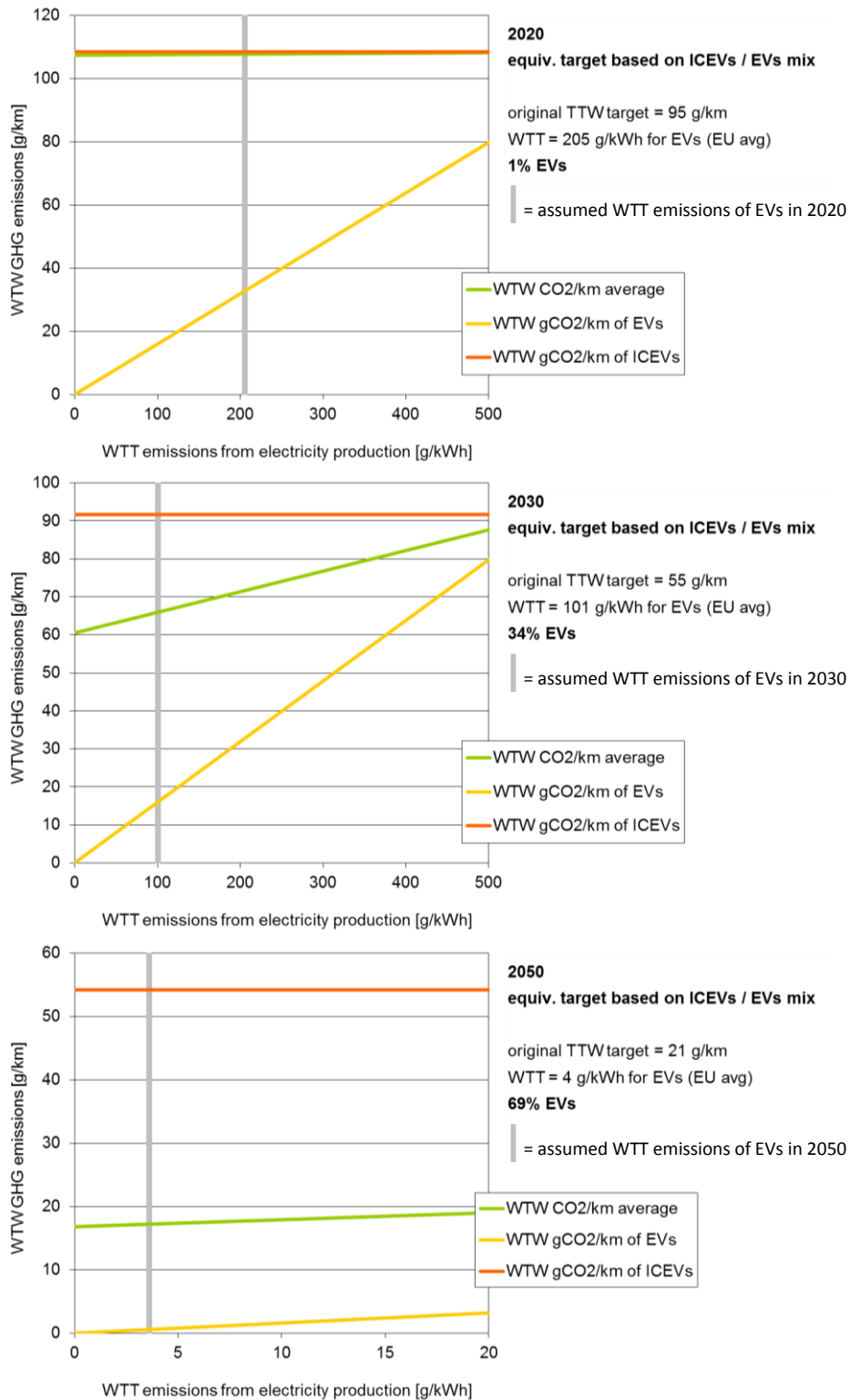
Equivalent targets based on ICEVs / EVs mix

2020
equiv. target based on ICEVs / EVs mix

original TTW target = 95 g/km
WTT = 205 g/kWh for EVs (EU avg)
1% EVs

| = assumed WTT emissions of EVs in 2020

— WTW CO2/km average
— WTW gCO2/km of EVs
— WTW gCO2/km of ICEVs

2030
equiv. target based on ICEVs / EVs mix

original TTW target = 55 g/km
WTT = 101 g/kWh for EVs (EU avg)
34% EVs

| = assumed WTT emissions of EVs in 2030

— WTW CO2/km average
— WTW gCO2/km of EVs
— WTW gCO2/km of ICEVs

2050
equiv. target based on ICEVs / EVs mix

original TTW target = 21 g/km
WTT = 4 g/kWh for EVs (EU avg)
69% EVs

| = assumed WTT emissions of EVs in 2050

— WTW CO2/km average
— WTW gCO2/km of EVs
— WTW gCO2/km of ICEVs

Figure 26   Illustration of the impact of the WTT emissions of EVs on average WTW GHG emissions of new vehicles, for an assumed share of EVs. All graphs are for the case where the equivalent target is determined under the assumption that it is met with a mix of ICEVs and ZEVs.

WTW energy based target

Impact of the share of EVs on the average WTW GHG emissions of new vehicles, for assumed WTT emissions of EVs in 2020, 2030 and 2050

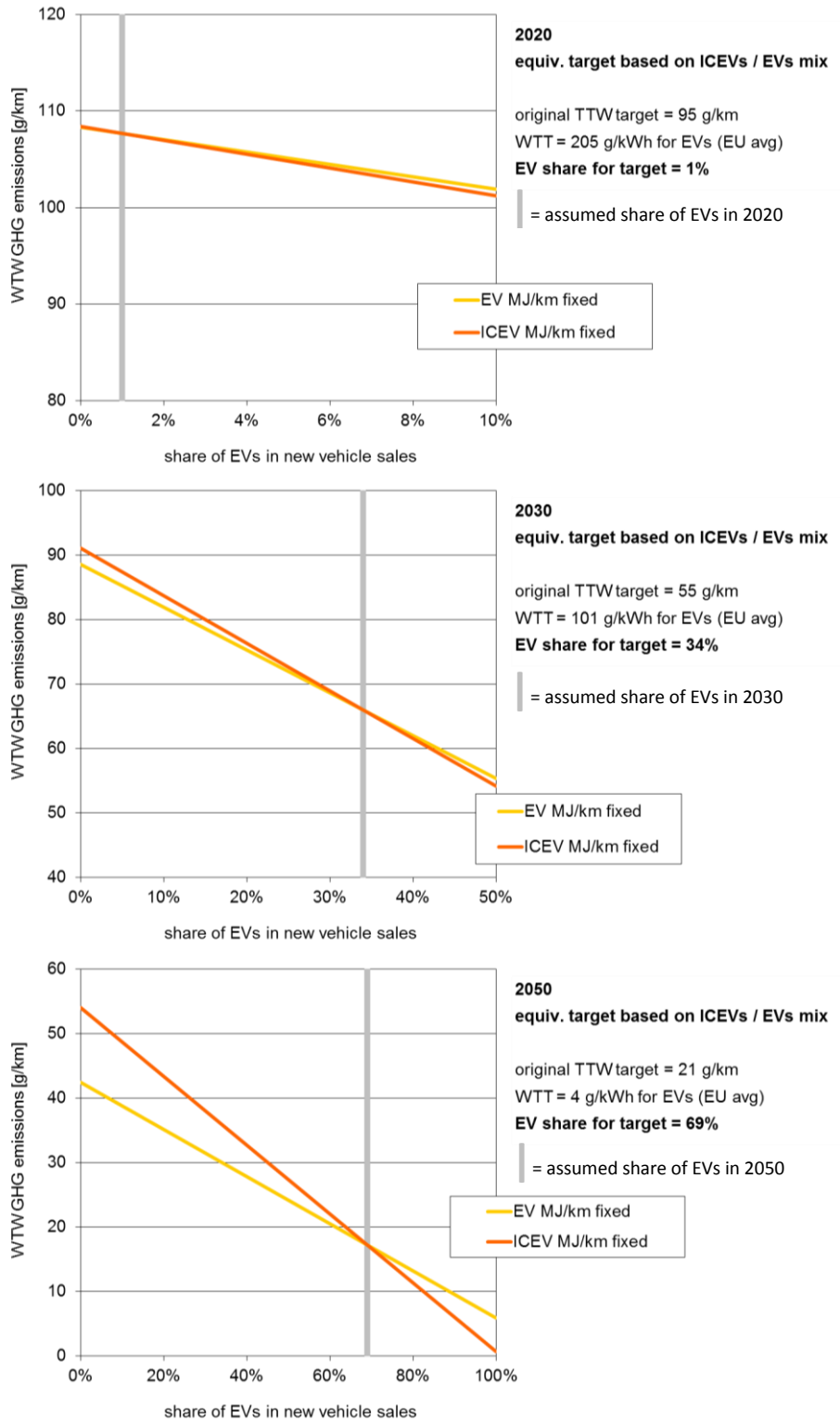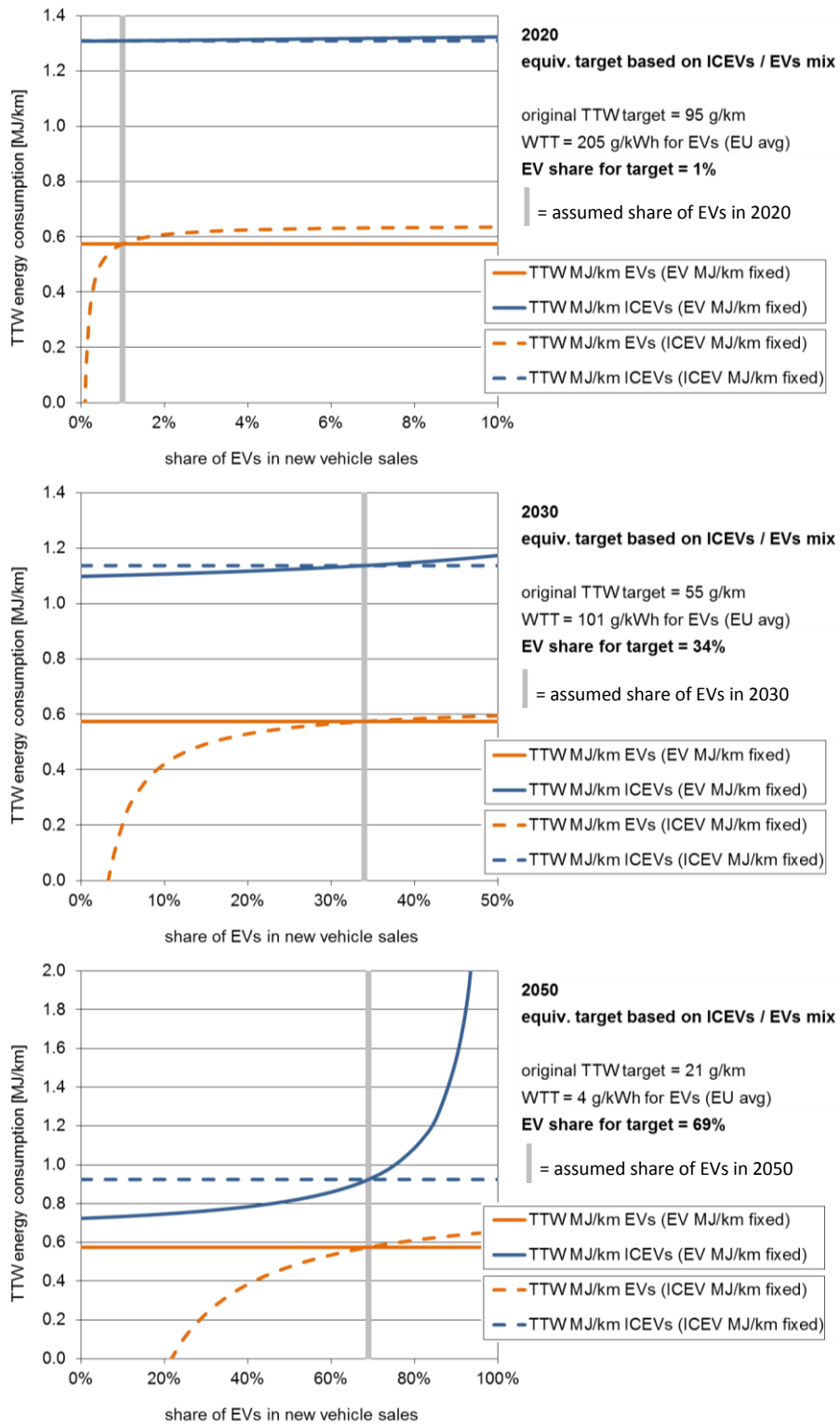### Equivalent targets based on ICEVs / EVs mix

Figure 27 Illustration of the impact of the share of EVs in the new vehicle sales on average WTW GHG emissions of new vehicles. All graphs are for the case where the equivalent target is determined under the assumption that it is met with a mix of ICEVs and ZEVs.

WTW energy based target

Impact of the share of EVs on the TTW energy consumption of ICEVs and EVs, required for meeting the target, for assumed WTT emissions of EVs in 2020, 2030 and 2050

Equivalent targets based on ICEVs / EVs mix

Figure 28　Illustration of the impact of the share of EVs in the new vehicle sales on average TTW energy consumption for new vehicles. All graphs are for the case where the equivalent target is determined under the assumption that it is met with a mix of ICEVs and ZEVs.

Conclusions for a WTW energy based metric

- WTW GHG emissions are moderately sensitive to variations in the actual WTT emission factor of ZEVs, but are quite sensitive to a varying ZEV share.
    - o With targets getting lower in the medium to long term, the sensitivity to the ZEV share increases while the sensitivity of the average WTW GHG emissions to the WTT emissions of ZEVs further decreases;
    - o In the short to medium term there is sufficient room for the TTW MJ/km of ICEVs to respond within a feasible bandwidth to variations in the share of ZEVs;
    - o In the long term the sensitivity in terms of the required change in MJ/km of ZEVs or ICEVs in response to a changing ZEV share is much weaker than for a WTW CO_2 based metric.
- Furthermore it can be stated that a WTW MJ/km metric:
    - o generally promotes overall resource efficiency,
    - o but compares "apples and pears", in the sense that megajoules of finite fossil energy and renewable energy are treated equally.

4.4.4   Conclusions with respect to various metrics for regulation

The analyses presented above for the different metrics specifically investigated two aspects:
- the impact of the share of ZEVs and the WTT emissions of energy carriers used by these ZEVs on the WTW GHG emission of the new vehicle fleet under different metrics;
- the flexibility under the various metrics for meeting a given target with different combinations of improved ICEVs, shares of ZEVs and efficiency levels of these ZEVs.

Results are summarized in Table 5.

WTW CO_2 leakage with increasing ZEV shares

With respect to the first aspect it can be concluded that the "WTW CO_2 leakage" as function of an increasing ZEV share under a TTW CO_2 based metric is most pronounced in the medium term, with the ZEV share becoming significant while WTT emissions of their energy carriers are still relatively high. A WTW CO_2 based metric obviously safeguards against "WTW CO_2 leakage" as function of an increasing ZEV share.

A TTW energy based target can be considered to solve the problem of "WTW CO_2 leakage" as observed in a TTW CO_2 based metric, as WTW emissions decrease rather than increase with an increasing share of ZEVs if WTT emissions of these ZEVs are sufficiently low. A WTW MJ/km based metric shows similar behaviour. Whether WTW CO_2 emissions under this metric are more sensitive to variations in the share of ZEVs and their WTT emissions than under a TTW MJ/km based metric depends on the relation between WTT GHG emissions and WTT energy consumption. This relation is not straightforward. An increased share of renewables leads to lower WTT emissions and energy consumption, but the application of CCS on fossil fuelled power plants lowers WTT emissions while increasing WTT energy consumption. For a WTW M/km based metric in the medium to long term the sensitivity to variations in the actual share of ZEVs do appear less pronounced than for a WTW CO_2 based metric.

Using a TTW CO_2 based metric with notional WTT factors for ZEVs reduces the "WTW CO_2 leakage", but introduces similar sensitivities with respect to the technology mix (see next paragraphs) as a WTW CO_2 metric.

Flexibility with respect to the technology mix for meeting a target

The analyses also clearly show that there is hidden complexity attached to all metrics when applied to a single target for the average performance of the entire new vehicle sales. This complexity becomes apparent especially in the longer term.

A single target offers inherent flexibility and room for internal averaging by manufacturers with respect to distribution of reduction efforts over models and segments and the choice of advanced conventional or alternative technologies for meeting the target. In the short term a lot of combinations of improved ICEVs and ZEV-shares can lead to the same average performance on a given metric. In the medium

to long term, however, targets need to be set so low that they can no longer be met by improvements in conventional technologies alone. The contribution of alternative technologies, specifically of zero tailpipe emission technologies (ZEVs), to meeting a target is determined by their share in the new vehicle fleet and their performance under a given metric.

Setting targets that are beyond what is technically feasible with conventional cars requires assumptions about feasible market shares of new ZEV technologies. Under a given TTW CO_2 based target, variations in the share of ZEVs can only be compensated by adjustments of the efficiency of the remaining share of conventional vehicles. If in the longer term the remaining share of ICEVs becomes very small, and ICEVs are already at or near the end of their improvement potential, the room to compensate for ZEVs not meeting their expected market share becomes extremely limited. Under TTW or WTW energy based targets and under a WTW CO_2 based target variations in the share of ZEVs can also be compensated by adjustment of the energy efficiency of these ZEVs. The room for that, however, is expected to be much more limited than the current improvement potential for ICEVs, as e.g. electric powertrains already have a high energy efficiency.

Table 5   Summary of results of the evaluation of sensitivities of different metrics

Metric	TTW GHG	TTW GHG with notional GHG intensity		WTW GHG		TTW energy		WTW energy	
		ICEVs only	ICEVs + ZEVs	ICEVs only	ICEVs + ZEVs	ICEVs only	ICEVs + ZEVs	ICEVs only	ICEVs + ZEVs
Sensitivity of WTW emissions to WTT electricity GHG intensity									
2020	+	+	+	o	o	+	+	+/o	+/o
2030	+++++	+++++	+++++	o	o	+++++	+++++	+++++	+++++
2050	+	+	+	o	o	+	+	+	+
Sensitivity of WTW emissions to ZEV share									
2020	+++++	+++/o	+++/o	o	o	+++++ (-)	+++++ (-)	++++++ (-)	+++++ (-)
2030	+++++	+++/o	+++/o	o	o	+++++ (-)	+++++ (-)	+++++ (-)	+++++ (-)
2050	+	+/o	+/o	o	o	+++++ (-)	+++++ (-)	+++++ (-)	+++++ (-)
Sensitivity of ICE TTW emissions to ZEV share									
2020	+++	++	++	+	+	+++	+++	+/o	+/o
2030	+++	++	++	++	++	+++	+++	++ (-)	+
2050	+++++	+++++	+++++	+++++	+++++	+++++ (-)	+++++	+++++ (-)	+++++

o   =   not sensitive
+   =   weak sensitivity
+++   =   moderate sensitivity
+++++ =   strong sensitivity
(-)   =   sign of sensitivity reversed compared to TTW GHG based metric
score in red means that case is not realistic

4.5 Alternative options

4.5.1 Inclusion of road fuel use in EU ETS (option c)

For this option there is no straightforward way to estimate the impact of introducing ZEVs in the new vehicle fleet on average WTW GHG emission of new vehicles. Whether the CO_2 price under ETS stimulates the uptake of ZEVs depends on the CO_2 price itself as well as on the difference in vehicle costs and energy costs of these ZEVs compared to ICEVs, which in turn depend on the extent to which the CO_2 price stimulates further efficiency improvement in ICEVs. It is therefore essential to evaluate how much reduction in the road transport sector would be stimulated at different levels of the CO_2 price. The price differential between different technologies will furthermore depend on whether the existing taxes on various energy carriers remain unchanged or not. The effectiveness of a cap & trade system may further be affected by the way in which emission credits are distributed.

The main disadvantage of including road transport in the existing ETS, is that the current CO_2 price is very low and that this will not be significantly affected by the addition of the transport sector. A CO_2 price of 15 €/tonne translates into a fuel price increase of 0.04 €/litre. This will not have a significant impact on driving and purchasing behaviour. A CO_2 price of at least 100 €/tonne (or 0.25 €/litre) would be needed before significant impacts on energy efficiency and choice of energy carriers in the transport sector can be expected.

Recent evidence from the Commission's Impact Assessment shows that achieving the 2020 LDV targets has a negative cost for consumers and society and that further reductions beyond those targets are also possible at negative cost. This illustrates the existence of some market barriers to achieving economically optimal levels of GHG reduction and fuel efficiency for LDVs which would also be applicable to a system relying purely on a market mechanism based approach. Nevertheless a CO_2 price can be considered to further increase the attractiveness or cost-effectiveness of alternative propulsion systems and energy carriers, which might help OEMs to overcome uncertainties.

4.5.2 A manufacturer-based trading system based on lifetime GHG emissions (option d)

If a manufacturer-based trading scheme were used in addition to a manufacturer-based target with one of the above metrics, regardless of whether it is based on g/km GHG emissions or lifetime GHG emissions, it is not expected to directly affect the net impact on average WTW GHG emissions. The fleet average target set in the applied metric will be reached with or without trading, but in case of trading the costs for meeting the target may be smaller. Indirect impacts on the WTW GHG emissions only occur if the metric is not WTW GHG emissions and in that case depend on the choice of technologies for meeting the target.

In the medium term, when large-scale application of ZEVs is not necessary for meeting the target, the option of trading may in fact slow down their introduction as it allows some manufacturers to avoid application of ZEVs for meeting the target and instead to buy credits from other manufacturers that have less difficulty in meeting their target by further improvements in ICEVs.

If the metric is TTW CO_2 based, trading does not solve the leverage between the share of ZEVs and the emissions of ICEVs. Manufacturers selling ZEVs can still increase the TTW emissions of the remaining ICEVs they sell. Using lifetime GHG emissions rather than g/km emission may somewhat alleviate the leverage if the lifetime mileage of ZEVs is smaller than that of ICEVs, but is this only to be expected for EVs. In any case it will be difficult to predict lifetime mileage for technologies that are not yet applied in the market at large scale and in a mature way.

4.5.3 A cap & trade system for vehicle manufacturers based on CO_2 emissions (option e.1)

An overall cap on total vehicle CO_2 emissions introduces a joint responsibility of OEMs and shared interest in reducing CO_2 emissions. This could encourage more collaboration, but beyond pre-competitive research such collaboration may be difficult to arrange between competitors.

Capping total emissions not only targets vehicle efficiency and CO_2 emissions but also total sales, and thus avoids market growth leading to increased emissions.

Similar to option d, allowing trading under a given target reduces incentives for investing early in more expensive technologies that are needed for the longer term.

This option makes the engineering target for vehicle efficiency very dependent on economic or market fluctuations. Especially in the longer term there will be limited room to compensate growth in sales volumes by reduction of the average CO_2 emissions per vehicle kilometre. In the medium term fluctuations in sales volume might be compensated by changing the share of ZEVs in the new vehicle fleet. The room to manoeuvre depends on whether the cap is based on TTW or WTW CO2 emissions.

If the metric is TTW CO_2 based, trading does not solve the leverage between the share of ZEVs and the emissions of ICEVs. Manufacturers selling ZEVs can still increase the TTW emissions of the remaining ICEVs they sell.

4.5.4 A cap & trade system for vehicle manufacturers based on total energy consumption of vehicles sold (option e.2)

Similar considerations apply here as for option e.1.

The impact of using a MJ/km based metric rather than a g/km CO_2 based metric on average WTW emissions of new vehicles is not expected to depend on the application of a cap & trade system.

4.5.5 Inclusion of embedded emissions in WTW approaches (option f)

Including embedded emissions in the metric only affects the impact of ZEVs on the average WTW GHG emissions of new vehicles if embedded emissions of ZEVs differ significantly from those of ICEVs. There is evidence for EVs and PHEVs that this is the case. As such the purpose of this metric is to avoid possible undesired rebound effects on global GHG emissions through increased embedded emissions resulting from the increased uptake of ZEVs that may be promoted by vehicle regulation.

This option promotes OEMs to take responsibility for environmental impacts occurring in the production of materials, components and vehicles as well as in the decommissioning phase. Such chain management is becoming more and more common as a way for companies to control their ecological footprint and other direct and indirect societal impacts.

4.5.6 Combining different options with e.g. size-dependent mileage weighting (option g)

The current vehicle emissions regulation only looks at CO_2 emissions per kilometre, as measured on the type approval test. A number of options are explored in this report to also include life cycle or upstream emissions of the energy carriers used to drive the vehicles. However, a different issue not yet discussed is whether it would be useful to take into account that some vehicles typically drive less kilometres than others – per year but also during their whole lifetime.

This can be illustrated with the following example. A car manufacturer sells a sports car with relatively high CO_2 emissions as measured during type approval, say about 240 gCO_2/km. This car is typically used occasionally, with an annual mileage of about 10,000 km, but it is well cared for and reaches 180.000 km over its lifetime Another car manufacturer sells a mid-size diesel family car with emissions of 115 gCO_2/km. This car is used for commuting, family trips and holidays, and drives about 25,000 km annually, and 300,000 over its lifetime. As a third example, a small petrol car with emissions of 100 gCO_2/km could be used as a shopping car mainly, driving e.g. about 8,000 km per year and 100,000 over its lifetime. Assuming that the real life emissions equal the type approval emissions in this example, the annual and total lifetime CO_2 emissions of these three cars can now be calculated. Results are shown in Table 6.

If we take the small car as the base case, we see that the sports car has a total life time emissions which is 4.3 times as high as that of the small car, whereas the emission factor used for the vehicle regulation is only 2.4 times as high. The family car only has 15% higher emission factor in the type approval, but overall emissions are 3.5 times as high due to its much higher overall mileage.

Table 6   Illustration of the impact of vehicle mileage on the annual and lifetime CO_2 emissions

	CO_2 emissions (g/km)	Average annual mileage over lifetime (km)	lifetime mileage (km)	CO_2 emissions per year (kg CO_2)	CO_2 emissions lifetime (ton CO_2)
Sports car	240	10,000	180,000	2,400	43
Family car	115	25,000	300,000	2,875	35
Small car	100	8,000	100,000	800	10

By introducing a mileage weighted vehicle CO_2 standard, manufacturers are stimulated to allocate their reduction efforts to a larger extent to the vehicle models and/or segments with relatively high average lifetime mileages. The actual impact of this shift is that the reduction efforts depends on the actual design of the mileage weighting. In case the mileage weighted target is set in such a way that the total lifetime emissions of new vehicle sales is equal for a mileage weighted scheme as for a non-mileage weighted scheme, the target could be reached in a more cost-effective way. This is due to the fact that vehicles with higher emissions generally cover longer distances, and exactly the CO_2 emissions of these vehicles are reduced by a mileage weighted target. [TNO 2009] shows that a cost reduction of at least 2% could be realised when mileage is taken on board as one of the weighting parameters (in addition to sales). However, in case the basic vehicle target (in g/km) for mileage weighted schemes is chosen to be the same as for non-weighted schemes, the overall effectiveness of the scheme will increase. Since manufacturers will allocate more of their reduction efforts to vehicle models/segments with relatively high average lifetime mileages, the overall CO_2 reduction realised by the weighted target will be higher than by the non-weighted target[14].

Combining the various possible metrics with mileage weighting may result in the above mentioned improvements of the effectiveness and/or efficiency of the schemes. However, there are two issues that should be mentioned here:

- Since the future usage pattern of electric/hydrogen passenger cars is uncertain, it is not possible to assess the impact of mileage weighting on the share of these non-fossil fuelled cars in the future vehicle fleets. However, it may be clear that the impact of mileage weighting on the environmental effectiveness of the vehicle regulation is larger in case a TTW target (as in the current Regulation) is applied instead of a WTW target. In case of a TTW target, the CO_2 emissions of electric and hydrogen cars are counted as zero and increasing/decreasing (depending on whether the average annual mileages of these cars will be higher/lower than for conventional cars) their contribution in the achievement of the target, may significantly affect the environmental effectiveness of the regulation. However, in case a WTW target is applied, the distortive effect of the zero emissions allocated to electric/hydrogen cars is (partly) removed and hence increasing/decreasing their contribution in the achievement of the target doesn't significantly affect the environmental effectiveness of the regulation.
- Combining the mileage weighted targets with the possibilities for manufacturers to trade in excess emissions may improve the efficiency of the vehicle regulation. In this case the reduction efforts are allocated to those vehicle models/segments in which lifetime CO_2 emission reductions could be realised against the lowest costs.

Given the positive impact mileage weighting could have to the effectiveness and/or efficiency of vehicle CO_2 regulation for passenger cars, the following questions are interesting to consider: would it be practically feasible to implement mileage weighting into this regulation and thus improve its effectiveness/efficiency, and would it be justified to hold car manufacturers accountable for the use of their cars?

To start with the last question, car manufactures cannot be held responsible for what car buyers do with these cars. They only have direct control over the emission factors of their vehicles. However, the mileage weighting would not have to be directly related to actual kilometres driven in these specific cars. Instead, average, empirically established values for specific vehicle types (car segments) could be used. This would represent a methodological change to the regulation that would not result in

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[14] Notice that the increase in effectiveness is the result of the fact that reduction efforts are applied to vehicles with relatively high annual mileages. The fact that efforts are also allocated to vehicles with relatively high average lifetimes doesn't affect the effectiveness of the vehicle regulation; vehicles with shorter lifetimes are replaced more often.

making car manufacturers responsible for what car users do, but would stimulate them to take the differentiated usage of cars into account in dividing reduction efforts over different car models, in order to improve the overall effectiveness of the regulation.

Whether or not this type of mileage weighting would be practically feasible mainly depends on whether it is possible to determine the average mileage over the lifetime of specific vehicle types, and to agree on these values being applied to all manufacturers. This is a prerequisite to include this parameter into the regulation, as incorrect data or lack of differentiation between vehicle types would reduce the efficiency of the measure. There are two main practical questions related to the feasibility of defining and applying average mileages for resp. to different vehicle types:

- The first question concerns the availability of sufficiently reliable data at the EU-27 level;
- The second question is whether it is possible to define vehicle segments that can a) be linked to objectively identifiable attributes of the vehicle, and b) show sufficiently homogeneous driving behaviour to justify different mileages for different segments.

The annual mileage typically ranges between 10,000-25,000 km for passenger cars, and reduces over the lifetime of the vehicle [Bodek 2008]. Diesel cars typically have higher annual mileage than passenger cars, mainly due to the fuel and vehicle taxation in the various EU countries [Bodek 2008][JRC, 2008]. Additionally, average annual mileage of cars may change over time, e.g. as result of other policies (e.g. road charging). At the moment there are no statistical data available on the EU-average lifetime mileage of the various vehicle segments. Data are available for a (limited) number of EU Member States, for specific years, and EU-wide estimates are available from models such as COPERT and PRIMES-TREMOVE, but this type of statistics is not generally gathered (see, for example, [LAT 2008], for a discussion on how vehicle annual and lifetime mileage can be estimated). However, as is mentioned by [TNO 2009], collecting reliable data on lifetime mileages seems feasible. A first option would be to set up an EU-wide survey, collecting data from sufficiently large samples of vehicles in different Member States. This may provide a sufficient basis for generating overall fleet average mileage data. Another option to collect more detailed data is to collect data from vehicle inspections; all cars (should) have to pass a vehicle inspection on a regular basis, at which time mileage statistics can be recorded. In addition to this information also data on the average total lifetime of vehicles is needed to estimate the lifetime mileages. According to [TNO 2009] this information could be gathered at the vehicle inspections too. The complexity of setting up a system to collect these kinds of information is expected to be limited. Finally, data should be gathered on trends in annual mileages to be able to take changes in lifetime mileages over time into account by updating the mileage statistics.

If mileage weighting is to be used in legislation, one needs to be able to attribute a lifetime mileage value to each newly sold car based on an easily verifiable characteristic of that car. This cannot be engine size, as engine sizes are expected to decrease due to downsizing without affecting vehicles' usage patterns. Also for hybrid and electric vehicles engine size is not a practical parameter. The most elegant categorisation of mileages would be to base them on the same utility parameter that is used to define the target per vehicle. This implies that yearly and lifetime mileages would need to be recorded together with the technical information which is feasible to be used as utility parameter, e.g. mass and footprint.

Summarising, including mileage weighting in the CO_2 regulation has the potential to increase the effectiveness and/or efficiency of the regulation as manufacturers would be stimulated to account of lifetime mileage in the distribution of reduction efforts over different vehicle models / segments. As different vehicle segments have different average annual mileages and different average lifetimes, these two parameters differ significantly. However, this measure requires reliable data on average life time mileage of different car segments, which are currently not available on EU-scale.

Using lifetime GHG emissions rather than g/km emissions may somewhat alleviate the leverage if the lifetime mileage of ZEVs is smaller than that of ICEVs, but this is only to be expected for EVs. In any case it will be difficult to predict lifetime mileage for technologies that are not yet applied in the market at large scale and in a mature way.

5 Assessment of impacts of different metrics on emissions and energy consumption at the fleet level

5.1 Introduction

Besides impacts on average WTW emissions of the new vehicle fleet, also impacts of different metrics on the total WTW GHG emissions of the passenger car fleet are relevant. A fleet model has been constructed to assess the sensitivity of certain metrics (indicated by differences in the WTW CO_2 emissions) to changes in the fleet composition in terms of shares of different drivetrain technologies and fuel types and the WTT GHG emissions of various energy carriers.

This chapter first describes the modelling approach, the different fleet composition scenarios used for the assessment, and the assumptions used for the WTT factors of the energy carriers in the model. After explaining how equivalent targets are defined for the different metrics, modelling results are presented and conclusions are drawn on the basis these assessment results.

Using the model 5 different metrics are compared:

M1   TTW gCO$_2$/km
M2   TTW MJ/km
M3   WTW gCO$_2$/km
M4   TTW CO_2 based metric with alternative accounting for EVs[15]
M5   WTW MJ/km

Background information on WTT energy use and GHG emissions van be found in Annex A, while a more detailed description of the assessment model can be found in Annex B.

5.2 The modelling approach

A simplified fleet model has been developed, that allows assessment of the impact of different technology uptake scenarios and different metrics for CO_2 regulation on total and average TTW and WTW GHG emissions of new car sales as well as the total European passenger car fleet.

A cohort model is used to describe the EU 27 passenger car fleet composition for all years between 2020 and 2050 (intervals of 5 years) in terms of:

- number of vehicles of 3 size classes and a range of different powertrain technologies per age category
- annual mileages of vehicles of 3 size classes and a range of different powertrain technologies per age category

Powertrain technologies include conventional ICEVs on petrol and diesel, plug-in hybrids (PHEVs) on petrol and diesel, battery-electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs).

TTW energy consumption and WTT energy consumption and GHG emissions of the different alternative powertrains and associated energy carriers are assumed fixed. The assumed values for the TTW energy consumption are listed in section B.3 of Annex B. WTT factors are described in section 5.4 and in Annex A.

Given a combination of metric and target level and the assumed new vehicle fleet composition in a target year, the TTW energy consumption of new vehicles of the various ICEV categories is adjusted to make sure that the target is met. Reduction efforts are distributed over petrol and diesel vehicles of the 3 size classes on the basis of cost-optimal divisions identified with the cost assessment model used in Service Request 1 [TNO 2011].

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[15] referred to as "tailpipe CO_2 emissions with notional GHG intensity for Zero Emission Vehicles" in previous chapters

Performing this calculation for different target years then defines the composition and performance of the total vehicle fleet in the different years. Based on the performance of vehicles from different age categories in a given year, and taking account of a factor for translating type approval energy consumption and emissions to real-world figures, the WTW GHG emissions of the total passenger car fleet in that year can then be assessed.

Running the model for the different metrics, and for different scenarios with respect to fleet composition scenarios and WTT factors, allows assessment of the sensitivity the fleet-wide WTW GHG emissions to variations in fleet composition and WTT factors and comparison of the different metrics on this aspect.

A more detailed description of the assessment model can be found in Annex B.

5.3   Fleet composition scenarios

The sensitivity of certain regulatory metrics with respect to the impacts of variations in fleet composition and WTT emissions on fleet-wide WTW GHG emissions is assessed using four different fleet composition scenarios. It should be noted that these scenarios are assumption-based, rather than arising as a result of the influence of the alternative metrics on manufacturer choices. The latter are explored in more detail in Service Request 8.

Scenario 1
The first fleet composition scenario (Scenario 1) is a reconstruction of the fleet development assumed for the main scenario underlying the 2011 White Paper [EC 2011]. As can be seen in Figure 29, PHEVs and BEV are assumed to be the dominant drivetrains in this scenario beyond 2030.

Scenario 2
In Scenario 2, a self-constructed scenario depicted in Figure 30, it is assumed that FCEVs will be the preferred drivetrain over BEVs. This is modelled by replacing all kilometres travelled by BEVs by kilometres travelled by FCEVs. Since it is assumed that FCEVs will have slightly higher annual mileages than BEVs, the share of FCEVs in Scenario 2 is smaller than the share of BEVs in Scenario 1.

Scenario 3
Scenario 3 is a variant of Scenario 1 in which the share of BEVs increases even more towards 2050 (see Figure 31). As the total demand of vehicle kilometres is preserved, the increased number of BEVs compared to Scenario 1, means a decrease of new sales for other drive trains. Up to 2035, this goes at the cost of all drivetrain types. However, beyond 2035 this goes fully at the expense of new registrations for PHEVs as these become the only significant shares of other drivetrains than BEVs.

Scenario 4
In scenario 4, the shares of the drivetrain types in new registrations are equal to those in Scenario 3. However, the shares of biofuels are decreased compared to Scenario 3. Since this is not represented in these figures, Figure 31 and Figure 32 are similar.
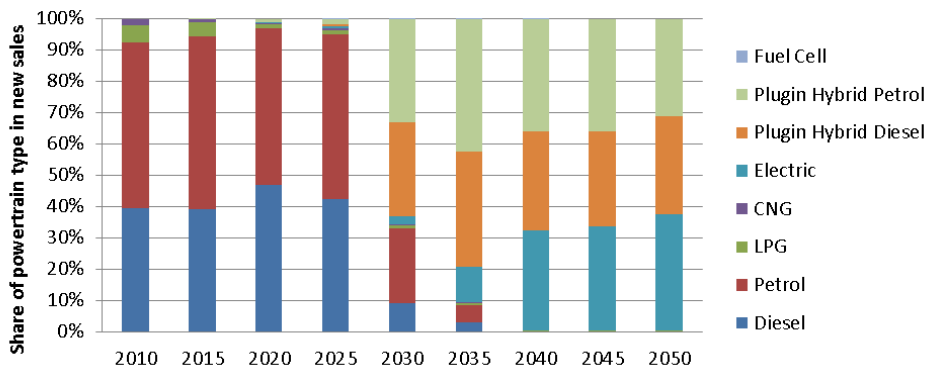

Figure 29   The development of powertrain type shares in the new sales between 2010 and 2050 (Scenario 1)
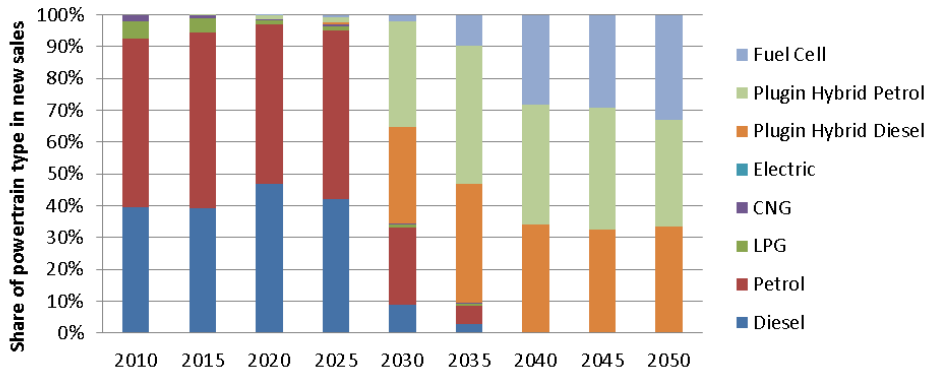
Figure 30   The development of powertrain type shares in the new sales between 2010 and 2050 (Scenario 2)
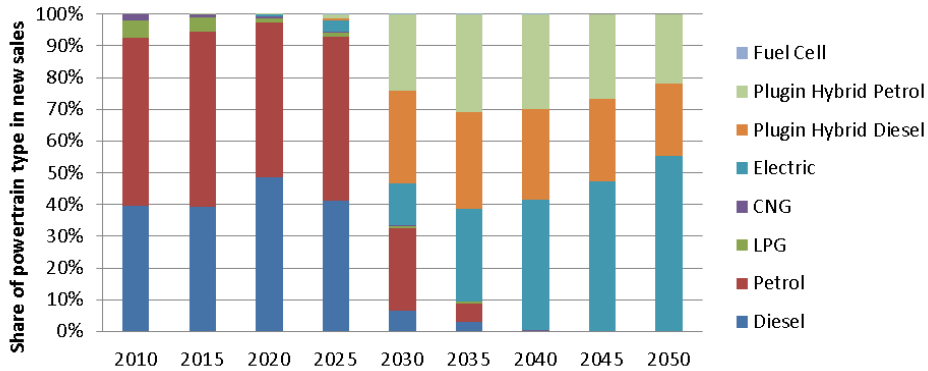

Figure 31   The development of powertrain type shares in the new sales between 2010 and 2050 (Scenario 3)
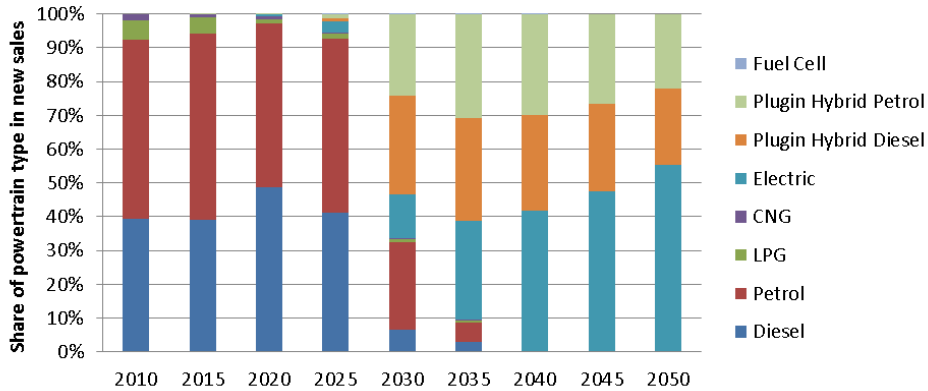

Figure 32   The development of powertrain type shares in the new sales between 2010 and 2050 (Scenario 4)

5.4   Energy carrier WTT emission scenarios

The main purpose for comparing alternatives to the tank-to-wheel (TTW) CO_2-based metric of the current CO_2 regulation for passenger cars and vans is to assure that future regulation of GHG emissions of the European vehicle fleet achieves the desired impacts in an efficient and cost-effective manner. Various alternative approaches are under consideration and some require the development of ways in which the well-to-tank (WTT) or upstream GHG emission impacts of various vehicle technologies and energy carriers can be factored into the regulation.

This section briefly explores methodological issues and derives WTT emission factors for use in the assessments presented in section 5.6 using a fleet model. A more detailed discussion of WTT factors can be found in Annex A.

5.4.1   Assumptions made for defining WTT emission factors

There are quite a number of choices to be made when defining a methodology to determine the upstream GHG emission intensity of the various energy carriers. Some of these will apply to all energy types, others are mostly relevant for some of them.

Standard life cycle analysis methodology should be used as a starting point, where all emissions along the life cycle of the fuel or energy carrier are considered, using a number of well-defined methodological assumptions. This approach is also taken in the Renewable Energy Directive and the Fuel Quality Directive, where upstream GHG emission factors are provided for all of these fuels and other energy carriers[16].

The main methodological choices to be made are the following:

- The fuel and energy categories that are differentiated;
- The methodology used for allocation of by-products and blends;
- How to account for indirect emissions, mainly due to indirect land use change (ILUC)?
- GHG intensity for average or marginal fuel production and energy generation? In the case of marginal, short or long term marginal emissions could be distinguished;
- One average factor for the EU, or differentiation between Member States?
- In case of electricity: whether to use consumption or generation data, and how to treat co-generation of heat?
- Emission factors of which year?
- Scope of emissions.

The assumptions made for the assessment presented in this chapter are described in more detail in Annex A.

5.4.2   Generation of indicative upstream emission factors for different scenarios (2020-2050)

In this section, upstream emission factors are generated for use in the fleet assessment model (described in Annex B). Values are developed for WTT figures from a global perspective as well as figures according to IPCC accounting rules for the EU. The expected development over time of these upstream emission factors will be described for the 2020-2050 timeframe, the scope of this study.

Assumptions need to be made regarding the most likely future developments of upstream emissions of all types of energy carriers. Modelling such a development is relevant for:

- conventional fuels: WTT emissions could increase as a result of using oil from increasingly less conventional sources, however, CO_2 mitigation options exist also in that part of the fuel chain.
- electricity and hydrogen: average and marginal WTT emissions are likely to go down as a result of declining caps under the EU-ETS and increased uptake of renewable electricity production;
- biofuels: WTT emissions may reduce if more stringent GHG emission criteria are implemented in the future (incl. inclusion of ILUC effects).

The question how the Fuel Quality Directive, Renewable Energy Directive and the ETS will develop after 2020 is relevant here, as these may affect the emission factors of the various fuels. Assumptions will also be needed about how WTT emissions will change over time. These should be compatible with the EU 2050 Roadmap as far as possible.

GHG intensity of conventional fuels

As mentioned above, WTT emissions of petrol and diesel are likely to increase as a result of using oil from increasingly less conventional sources, which require more energy than conventional oil production and thus have higher emissions – depending on the energy used. On the other hand, however, it can also be expected that more CO_2 mitigation options will be implemented in the future, due to the FQD (currently only relevant for the period until 2020, but perhaps further tightened

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[16] Note that the methodology and default values for fossil fuels, electricity and hydrogen are not yet decided on. However, the Commission has issued a draft proposal for the FQD that includes these in October 2011.

afterwards) and perhaps other (incl. global) climate policies. Venting and flaring can be reduced, energy efficiency could be improved, low-carbon energy sources could be deployed, etc.

The actual development of emissions thus depend strongly on the future policies in place: the FQD after 2020, policies in the oil producing countries and global climate policies.

Regarding natural gas, the same argumentation applies, although in this case, the main reason for a potential future increase of emissions would be an increase of the share of NG imports and transport distances (both via pipelines and with LNG tankers).

We thus propose to assess two different scenarios, one which assumes effective CO_2 reduction policies in the fossil fuel chains, and one which assumes that a future shift to high-carbon fossil fuels will gradually increase emissions:

- Scenario 1: Starting with current WTT emission factors, a 0.5% reduction per year is assumed[17].
- Scenario 2: Starting with current WTT emission factors, a 0.5% increase per year is assumed.

The baseline emission factor is based on the results in Annex II of [JEC 2011], for 2020.

Table 7   Potential scenarios for fossil fuel WTT GHG intensities (gCO_2/MJ)

	Scenario 1				Scenario 2			
	Petrol	Diesel	Natural gas	LPG	Petrol	Diesel	Natural gas	LPG
2020	14.2	15.9	8.7	8	14.2	15.9	8.7	8
2030	13.5	15.1	8.3	7.6	14.9	16.7	9.1	8.4
2040	12.8	14.4	7.9	7.2	15.7	17.6	9.6	8.8
2050	12.2	13.7	7.5	6.9	16.5	18.5	10.1	9.3

GHG intensity of biofuels

Biofuels need to achieve a minimum GHG emission reduction, compared to fossil fuels, to be able to count towards the RED and FQD target. The calculation methodology does not yet, however, include emissions due to indirect land use change (ILUC), and thus overestimates GHG emission savings very significantly for quite a large share of the current biofuels (especially for biodiesel, see [IFPRI 2011]). Efforts are on-going to include ILUC impacts, but it remains questionable whether the system can be made watertight for all biofuels, i.e. whether the GHG emission factor that is reported is indeed a realistic value[18]. We therefore propose to assess two different variants:

- Scenario 1: assumes that biofuels meet the minimum GHG reduction targets set by the EU policies, also in real life[19]. It is assumed that the minimum GHG reduction level follows the RED minimum levels until 2020, and then lowers to 70% from 2020 onwards and to 80% from 2030 onwards.
- Scenario 2: assumes that ILUC emissions cannot be effectively included in the policies (although some form of ILUC policy is implemented) or that they are included but the minimum levels are kept at higher levels than in scenario 1. The result is that GHG emission factors are effectively equal to fossil fuels in 2010, achieve an average reduction of 20% in 2020, and 40% from 2030 onwards, and 60% from 2040 onwards .

To convert these GHG reduction levels to GHG emission factors, the 2010 fossil fuel emission factors are used as a reference, as provided in the recent draft FQD proposal: 87.5 gCO_2/MJ for petrol, and 89.1 g CO_2/MJ for diesel.

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[17] For comparison: the current FQD requires a 6% emission reduction between 2010 and 2020, which amounts to -0,62% reduction per year. Assuming that part of this target will be met by shifts to alternative, low carbon fuels such as CNG and electricity, and assuming that this rate of emission reduction will continue after 2020, an annual reduction of 0.5% would seem a reasonable estimate.
[18] For example, the current ILUC debate focusses on biofuels from food crops. However, ILUC and other indirect effects also occur for biofuels from waste and residues, as many waste and residue streams are already in use in other sectors, or could be used in more efficient applications.
[19] The current minimum level is 35% (although installations from before 2008 do not have to comply until 1.5.2013), but this increases to 50% from 2017 onwards. Biofuel production plants that start production after 1.1.2017 must achieve a minimum of 60%.

Table 8   Potential scenarios for biofuels WTT GHG intensities (gCO_2/MJ)

Year	Scenario 1		Scenario 2	
	Biofuels for petrol vehicles	Biofuels for diesel vehicles	Biofuels for petrol vehicles	Biofuels for diesel vehicles
2010	70	71.3	87.5	89.1
2020	26.3	26.7	70	71.3
2030	17.5	17.8	52.5	53.5
2040	17.5	17.8	35	35.6
2050	17.5	17.8	35	35.6

Looking at current biofuels, there is a difference in average GHG intensity of ethanol and biodiesel, especially when ILUC effects are included (ethanol typically has lower GHG intensity than biodiesels from vegetable oils). It is not clear, however, how this will develop in the future. In these scenarios, we have therefore taken equal values for biofuels, irrespective if they replace petrol or diesel.

GHG intensity of electricity
To calculate the well-to-wheel GHG emissions of electric vehicles, the GHG emission per unit of electricity used is an important parameter. As discussed in the previous section, quite a number of choices will have to be made before the value of this parameter can be given (see annex A).

As we look at the timeframe until 2050 in this study, emission factors can best be based on the EU scenarios developed for the EU Roadmap 2050 [EC 2011]. As depicted in the roadmap, power generation in the EU will be almost completely decarbonized by 2050. Note that the PRIMES carbon intensity numbers are for 'Electricity *and Steam* production'.

The PRIMES emission data are in line with Eurostat statistics for 2009 (most recent data), and thus seem to use the same definitions. A different set of values seems to be used in the FQD draft proposal (of October 2011), however. This gives substantial higher GHG intensities than the PRIMES-TREMOVE scenarios.

In this study, we use the PRIMES-TREMOVE v.1 results of different scenarios to assess the sensitivity of the different options to variations in GHG intensity of electricity:

- Scenario 1: Decarbonisation scenario as used for the Roadmap 2050 (PRIMES-TREMOVE v.1, Decarbonisation scenario)
- Scenario 2. Reference scenario developed for the Roadmap 2050 (PRIMES-TREMOVE v.1, Reference scenario)

Table 9   Carbon intensities for electricity generation in the EU27.

Year	Scenario 1: Carbon intensity (ton CO_2/MWh)[20] Decarbonisation scenario	Scenario 2: Carbon intensity (ton CO_2/MWh) Reference scenario
1990	0.4624	0.4624
2000	0.3729	0.3729
2010	0.3113	0.3130
2020	0.2053	0.2256
2030	0.1005	0.1756
2040	0.0314	0.0992
2050	0.0036	0.0734

Source: DG CLIMA, Background data to [EC 2011]

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[20]   1 ton CO2/MWh = 0,278 kg CO2/MJ (MJ electricity or MJe, not primary energy)

GHG intensity of hydrogen

In the current situation, most of the world's hydrogen is produced from reforming of natural gas (about 90%). Most of this hydrogen is used in refineries [ECN 2011]. A large range of potential production routes exist, however, such as coal gasification, biomass processing (e.g. gasification of wood waste) and hydrogen production from electrolysis (i.e. from electricity).

Hydrogen production via electricity was found to result in a large range of GHG intensities, strongly dependent on the energy source for electricity generation. If fossil fuels are used to produce the electricity, GHG emissions are typically relatively high (up to 400-500 g/MJ in case of coal electricity, about half of this if natural gas is used). Using renewable energy sources such as wind will result in a much more attractive GHG intensity, around 10-30 g/MJ.

Comparing these results and general trends with future decarbonisation requirements, only a limited number of these hydrogen routes could be attractive energy routes for future transport:

- hydrogen production through gasification of wood waste and residues
- hydrogen produced from electricity from renewable energy sources
- hydrogen from gasification of fossil fuels with CCS (where natural gas would cause less GHG emissions that coal)

Assuming that the GHG intensity of transport fuels will be gradually reduced over time, for example because of further tightening of the FQD GHG emission reduction target, lower WTW GHG emissions will become increasingly financially attractive. It then seems reasonable to assume that during the coming decades, hydrogen production for transport fuels will gradually shift from the current natural gas reforming practice to either production from renewable energy sources (biomass, wind, solar), or that fossil fuels remain the main energy source but CCS is applied.

Based on these trends, two scenarios were developed for the GHG intensity of hydrogen use in transport: a decarbonisation scenario that is in line with that of electricity generation (see the previous paragraph), and a less optimistic scenario that is in line with the reference roadmap scenario for electricity generation. In both cases, emissions of hydrogen are assumed to be higher than that of electricity, because of the (additional) energy needed for H_2 production. This energy use is quite high: Appendix 2 of [JRC 2011] estimates that if in 2020 hydrogen is produced from the average EU electricity mix, almost twice as much energy is used to produce 1 MJ of hydrogen, compared to the energy needed to produce 1 MJ of electricity. However, as the decarbonisation of electricity progresses over time, the impact of this additional electricity use on CO_2 emissions reduced.

In view of the uncertain future developments described above, the uncertainty of these figures is relatively large, especially in the period between 2020 and 2040. During that time frame, natural gas reforming is likely to remain an economically attractive route, and decarbonisation of the hydrogen production pathways will depend on (yet uncertain) EU policies and/or own initiatives of the industry.

Table 10   Carbon intensities for hydrogen use in transport in the EU27, in g CO_2eq/MJ.

Year	Scenario 1: Carbon intensity (g CO_2eq/MJ) Decarbonisation scenario	Scenario 2: Carbon intensity (g CO_2eq/MJ) Reference scenario
2010	111	111
2020	89	100
2030	36	60
2040	13	35
2050	2	24

5.4.3   WTT energy use

Some of the regulatory options to be investigated in this study are based on well-to-wheel energy use, as an alternative to well-to-wheel CO_2 emissions. To this end, well-to-tank energy use factors need to be developed for the various fuels and energy carriers, similar to what was done for CO_2 in the previous paragraph.

In the current situation, WTT energy use is typically relatively low for fossil fuels and electricity, but it can be quite high in case of biofuels and hydrogen.

Conventional fuels

The WTW energy use of conventional diesel and petrol can be expected to reduce less fast than the GHG intensity, and is even likely to increase in the longer term. This increase depends quite strongly on the future shares of unconventional oil – the higher their shares in the EU fuels, the higher the WTW energy intensity of conventional fuels. Furthermore, some of the GHG mitigation options that are likely to be implemented will also increase energy use.

When looking at natural gas (CNG), energy use is also likely to increase in the future, mainly because average transport distances will increase as EU production declines. LPG is typically produced from condensates from remote gas production. Energy use is not likely to change much in that chain.

Results are given in the table below. Key assumptions are:

- petrol and diesel energy WTT intensity increases by 10% every 10 years;
- natural gas shifts from the current EU-mix towards increasing imports over long-distances (via pipeline or LNG tankers);
- LPG WTT energy use remains constant over time.

Table 11   WTT energy intensity of conventional fuels, in $MJ_{expended}/MJ_{final}$

Year	Petrol	Diesel	Natural gas	LPG
2020	0.17	0.20	0.12	0.12
2030	0.19	0.22	0.16	0.12
2040	0.21	0.24	0.19	0.12
2050	0.23	0.27	0.23	0.12

Biofuels

A number of developments can be identified that may impact the WTW energy use of biofuels in the coming decades: the feedstock used for biofuel production may change, new production technologies may come on the market and replace the current ones, and GHG mitigation measures will be implemented in response to sustainability criteria and climate policies.

One development that is to be expected in response to a future tightening of GHG emission targets and ILUC implementation is an increased use of feedstocks with low GHG impact such as waste and residues or commodities that are cultivated with relatively limited land and fertiliser use. Especially the latter are likely to also require less energy to produce than current biofuels from agricultural commodities. However. as shown in [JEC 2011], biofuels from waste, residues and wood typically require more energy than biofuels from commodities, as the waste streams need energy-intensive pre-processing. Other key GHG mitigation options that can be expected to be applied are an increasing use of renewable energy in the biomass-to-biofuel chain and use of CCS. Renewable energy is not likely to significantly impact on energy use. CCS will, however, increase overall WTT energy use. This effect may be relatively limited in case of ethanol, where the CO_2 is produced in pure form and there is no need for (potentially energy intensive) separation technologies.

Table 12   WTT energy intensity of biofuels, in $MJ_{expended}/MJ_{final}$

Year	Bio-petrol	Bio-diesel
2010	1.5	1.1
2020	1.5	1.1
2030	1.5	1.1
2040	1.5	1.1
2050	1.5	1.1

When comparing this potential future shift in biomass-to-biofuel routes with the WTT energy use factors in [JEC 2011], it can be concluded that the energy intensity will remain quite constant over the

coming decades. It may increase or decrease to some extent, mainly depending on the mix of feedstocks used and by product utilisation. In view of the uncertainties, it was decided to assume that these values will remain constant at the levels shown in Table 12.

Electricity
The WTT energy use of electricity production is relatively high in the current situation. The energy efficiency of coal or gas power plants is somewhat better than that average, while nuclear energy scores less than average. The WTT energy intensity of electricity production from woody biomass is comparable to that of coal powered plants if the biomass is co-combusted with coal, but increases if a gasification route is used. WTT energy input for wind and solar power is limited to losses in the grid, and almost negligible.

Therefore, if the electricity sector is decarbonized by shifting towards a mix of renewable energy sources, WTT energy intensity of electricity will reduce significantly in the future. However, if decarbonisation is for a large part achieved through CCS, where coal and gas remain the main energy source, this reduction will be much less, and even (partly) counterbalanced by the energy demand of the CCS.

In the EC Energy Roadmap 2050 a number of different decarbonisation scenarios are provided for the electricity sector, with very different mixes of energy sources, and different contributions of CCS. Upstream energy intensities were not specifically calculated, but in view of the above different mixes are likely to result in different WTT energy intensities. However, a number of consistencies were found throughout the decarbonisation scenarios. For example, power generation in 2050 was found to be based on renewables for around 60%-65% in all scenarios, except for the high renewable energy (RES) case, in which this share is much higher. Wind alone accounts for about one third of power generation in most decarbonisation scenarios. In the high RES case, the wind share reaches even close to 50% in 2050.

Looking at the energy mixes in the various scenarios, the following 'best guess' mix for 2050 has been derived: about 35% wind power and 30% of other renewables (mainly hydro, solar and biomass), 20% fossil power (for a large part with CCS) and 15% nuclear. The resulting estimates for WTT energy intensity of electricity are shown in Table 13[21].

Table 13   WTT energy intensity of electricity production, in $MJ_{expended}/MJ_{final}$

Year	WTT energy intensity of electricity production
2010	1.87
2020	1.61
2030	1.35
2040	1.09
2050	0.83

Hydrogen
As explained in Annex A.2.4, hydrogen can be produced from a whole range of energy carriers. In line with the approach taken above for electricity, it is assumed here that the hydrogen production will decarbonize in the future. The main options to achieve this are hydrogen production through gasification of wood waste and residues, from electricity from renewable energy sources and from gasification of fossil fuels with CCS.

We thus assume that in 2010 hydrogen production is 100% based on natural gas reforming, while in 2050 each of the three low-carbon routes contribute one third to the hydrogen production. The WTT energy intensity of hydrogen is then expected to increase, as shown in Table 14. The energy intensity was assumed to increased linearly between 2010 and 2050. Comparing these factors with that of electricity in the previous paragraph, it can be seen that hydrogen has a better energy efficiency in the short term, but this will change over time as less energy efficient routes are assumed to be used for hydrogen production in order to reduce GHG emissions. The energy intensity will only reduce over

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[21] For simplicity, a linear reduction of energy intensity is assumed between the current situation and 2050.

time if renewable electricity is used as a main energy source for hydrogen. Nevertheless, even in that case energy losses will be inevitable as the electricity will have to be converted to hydrogen: [JEC 2011] estimates energy intensity of wind-to-hydrogen to be about 0.8 MJ/MJ_{final}.

Table 14   WTT energy intensity of hydrogen, in $MJ_{expended}/MJ_{final}$

Year	WTT energy intensity of hydrogen
2010	0.84
2020	0.88
2030	0.92
2040	0.95
2050	0.99

5.5   Definition of equivalent targets

In order to compare alternative metrics, based on different variables with the current legislative metrics (TTW CO_2 emissions), trends have to be defined for the alternative metrics that are equivalent to the assumed TTW CO_2 reduction trend between 2020 and 2050 that is required to approximate a CO_2 reduction similar to that of the 2011 White Paper.

The approximation of the White Paper TTW CO_2 reduction trend (based on the IPCC accounting methodology), can also be expressed in an average TTW CO_2 emissions trend per vehicle kilometre. The current legislative metric, however, is based on type approval CO_2 emissions in which biofuels are not accounted for. Therefore the equivalent trends for alternative metrics must be derived from the TTW CO_2 emission trend in which the biofuels do not count as zero emissions. This is represented in Figure 33 as the dark blue line (M1 – TTW CO_2/km).
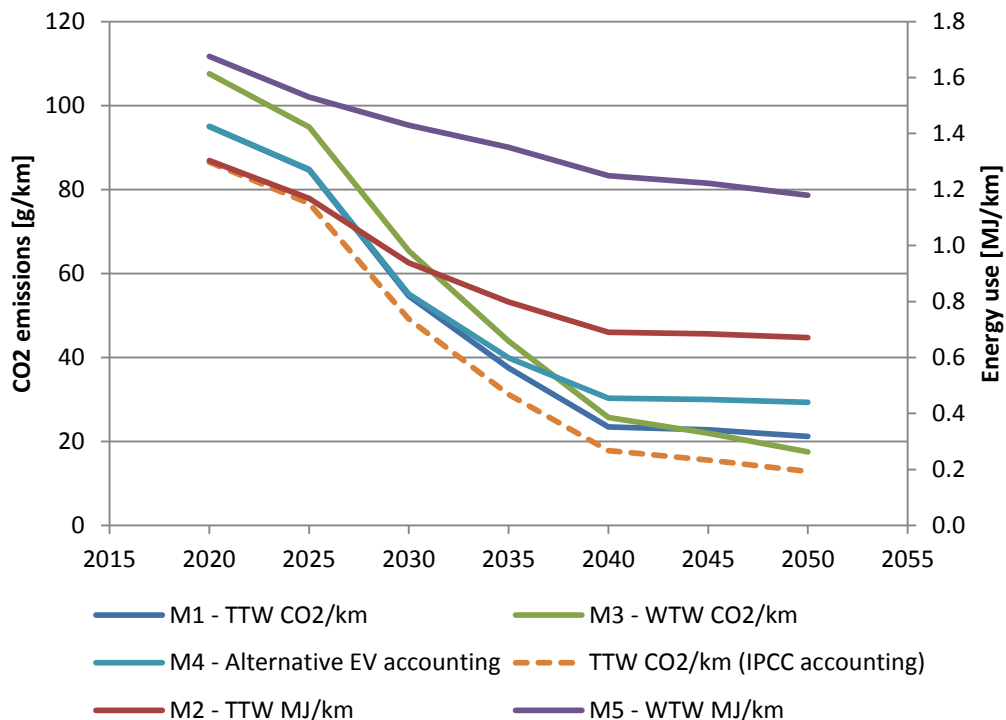

Figure 33   Trends for targets based on alternative regulatory metrics which are equivalent to the trend for the target based on the current regulatory metric (TTW CO_2 emissions) as given by Scenario 1.

As described in detail in section 4.2.2, the equivalents of this trend depend on the fleet composition. Since it is assumed that the CO_2 emission trend of Scenario 1 complies with the European Commission's ambitions, the equivalent trends are based on this Scenario 1 fleet composition. For

metric "M4 – Alternative EV accounting" imaginary TTW CO_2 emissions are attributed to BEVs and FCEVs. These CO_2 emissions are half that of CO_2 content per MJ of petrol.

5.6 Assessment of impacts of scenarios on GHG emissions for different regulatory options

As explained above, two scenarios have been derived for each of the fuels/energy carriers to capture the uncertainties of future developments. Especially the sensitivity of the CO_2 emissions to the electricity and hydrogen WTT emission factors is worth analysing, since:

- a significant share of new registrations beyond 2025 are expected to be (partly) powered by electricity;
- the future WTT emissions of these two energy carriers are currently rather uncertain.

Therefore the results of the model are presented in this study for both WTT scenarios for electricity and hydrogen. Firstly, the model outcomes are based on the decarbonisation scenario (low carbon intensity) as used for the Roadmap 2050 (PRIMES-TREMOVE v.1, Decarbonisation scenario). Hereafter, higher carbon intensities are applied based on a reference scenario developed for the Roadmap 2050 (PRIMES-TREMOVE v.1, Reference scenario).

5.6.1 Results for the case of electricity and hydrogen production with low carbon intensity

Overall WTW CO_2 emissions per metric

Results for the impact of different fleet composition scenarios on fleet-wide WTW CO_2 emissions in the case of low WTT emissions for alternative energy carriers are depicted in Figure 34 to Figure 38.
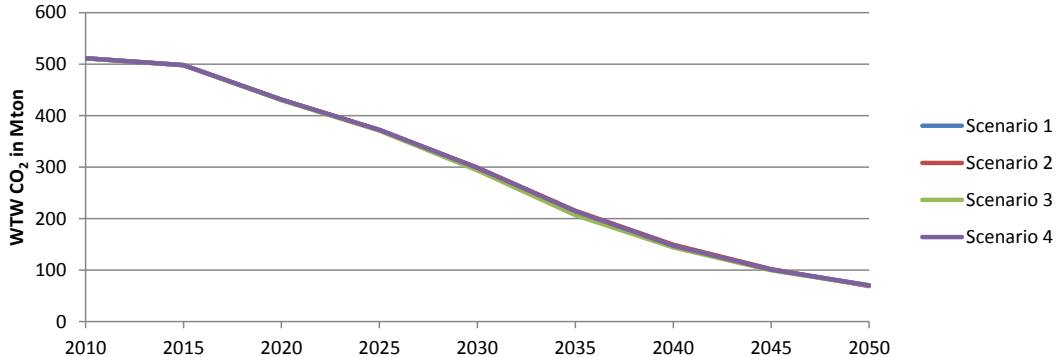

Figure 34   Overall WTW CO_2 emissions for a TTW CO_2 based metric for the four assessed scenarios
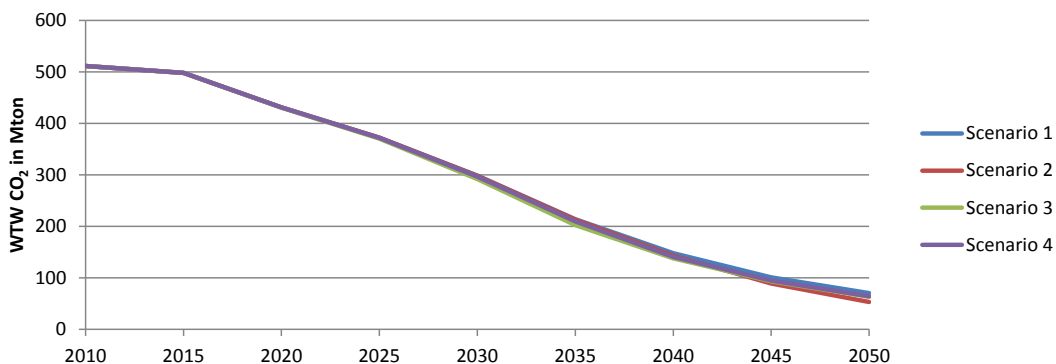

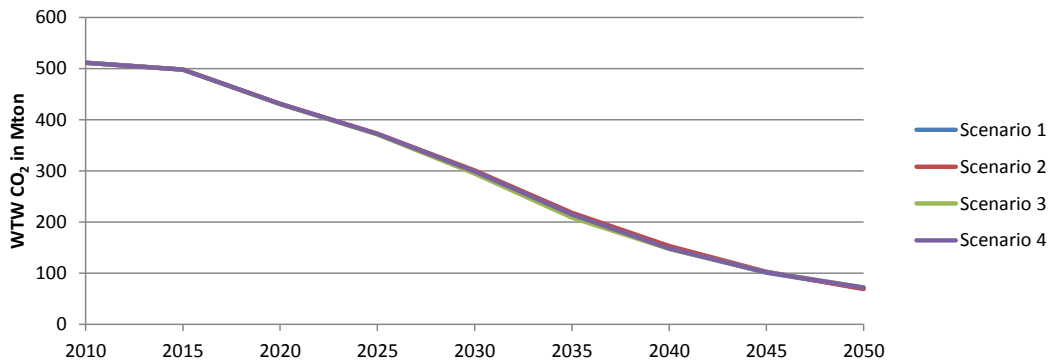Figure 35   Overall WTW CO_2 emissions for a TTW MJ based metric for the four assessed scenarios

Figure 36   Overall WTW CO_2 emissions for a WTW CO_2 based metric for the four assessed scenarios
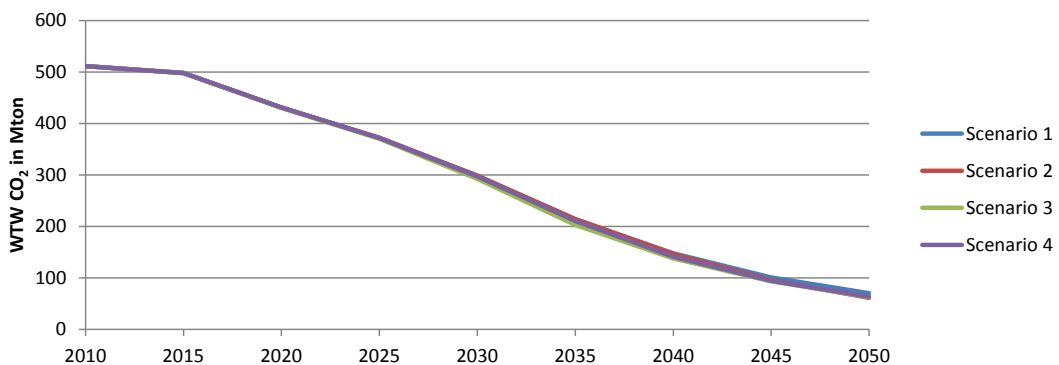

Figure 37   Overall WTW CO_2 emissions for a TTW CO_2 based metric with alternative accounting for emissions from electric vehicles
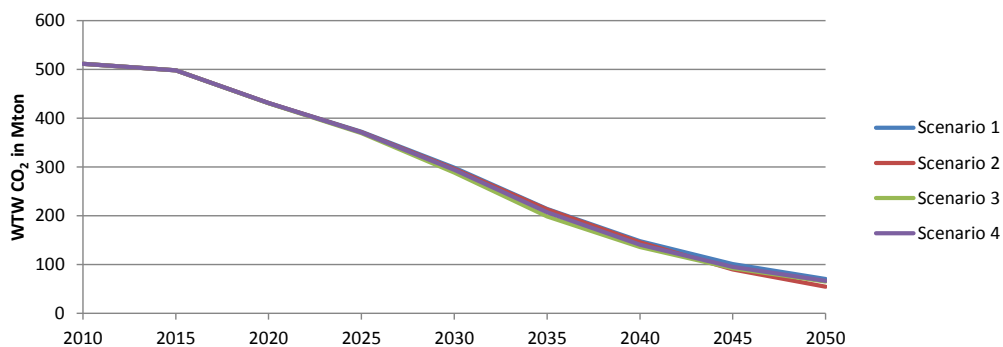

Figure 38   Overall WTW CO_2 emissions for a WTW MJ based metric for the four assessed scenarios

From Figure 34 to Figure 38 it can be concluded that all metrics are only limitedly sensitive to changes in the fleet composition, i.e. for all metrics the WTW CO_2 scenarios are similar for the various fleet compositions used in this assessment. Also this sensitivity is not significantly affected by the assumed scenarios for the WTT emission factors for alternative energy carriers. In Table 15 (equal to Table 17) can be seen that in 2050 the energy based metrics are most sensitive to the fleet composition.

This limited sensitivity is partly due to the large reductions that have to be realised between 2020 and 2050 to comply with the emission reduction as presented in the 2011 White Paper. As a result the options for assessing various fleet compositions are limited since the share of low CO_2 emission vehicles has to increase rather severely beyond 2020. It must also be borne in mind that this assessment assumes that the types of vehicles that manufacturers will market is not influenced by the choice of metric. This may not be correct and is explored further in Service Request 8.

Table 15   Overall WTW CO_2 emissions for the whole vehicle fleet in 2050

2050 overall WTW fleet emissions [Mton]	Scenario 1	Scenario 2	Scenario 3	Scenario 4
M1 - TTW gCO_2/km	70	69	70	71
M2 - TTW MJ/km	70	53	63	64
M3 - WTW gCO_2/km	70	69	72	72
M4 – Alternative accounting for EVs	70	61	63	64
M5 - WTW MJ/km	70	55	65	67

Cumulative WTW CO_2 emissions

For the four metrics the impact of the four different scenarios on cumulative emissions (total emissions over the 2010 – 2050 period) are depicted in Figure 39 to Figure 42. The small differences in the annual emissions, as visible from Figure 34 to Figure 38, result in even smaller relative differences in cumulative emissions. From this perspective no significant difference can be observed between the various metrics.
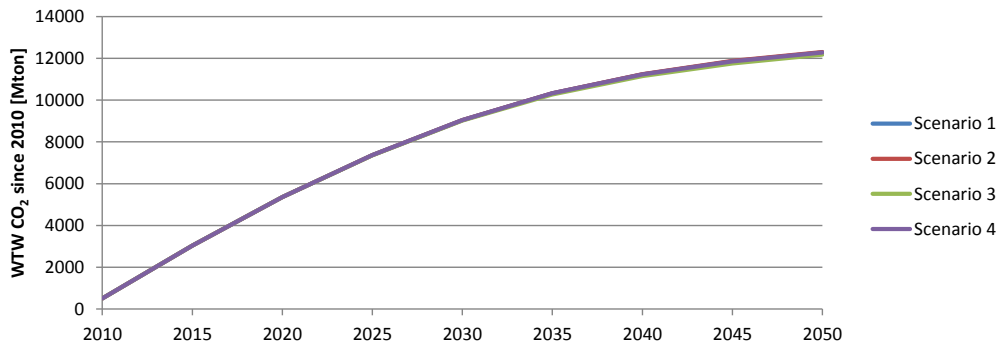

Figure 39   Cumulative WTW CO_2 emissions for a TTW CO_2 based metric for the four assessed scenarios
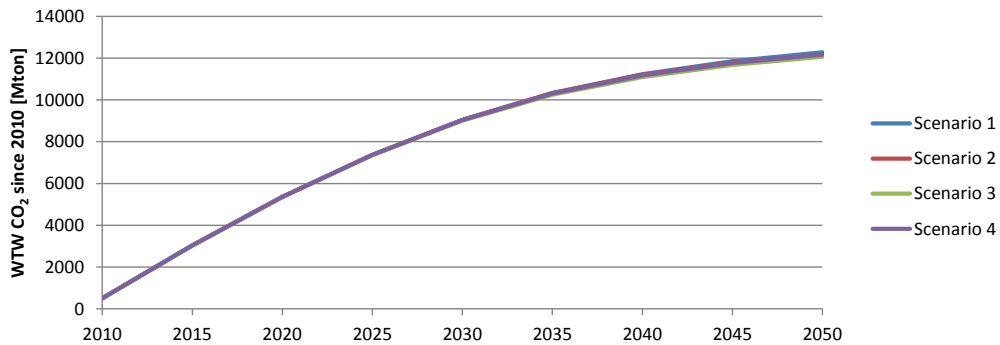

Figure 40   Cumulative WTW CO_2 emissions for a WTW CO_2 based metric for the four assessed scenarios
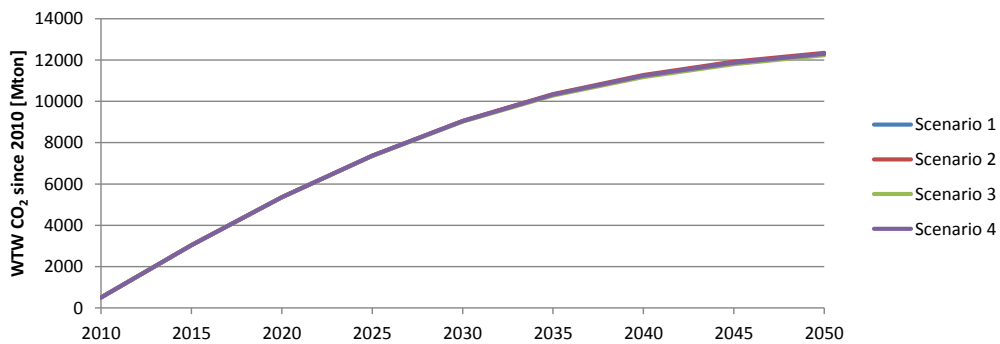

Figure 41   Cumulative WTW CO_2 emissions for a TTW energy based metric for the four assessed scenarios
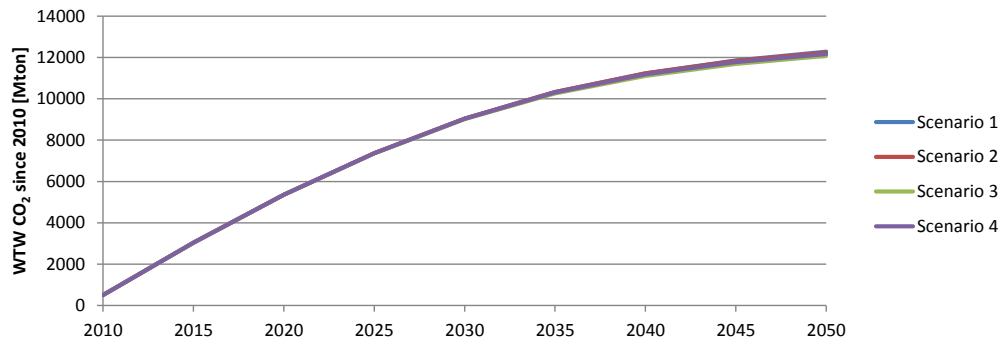
Figure 42   Cumulative WTW CO_2 emissions for a WTW energy based metric for the four assessed scenarios

Weighted average WTW CO_2 emissions per vehicle kilometre for the new vehicle fleet

Results for the impact of different fleet composition scenarios on average WTW CO_2 emissions per vehicle kilometre for the new vehicle fleet in the various years are depicted in Figure 43 to Figure 46 for the case of low WTT emissions for alternative energy carriers.
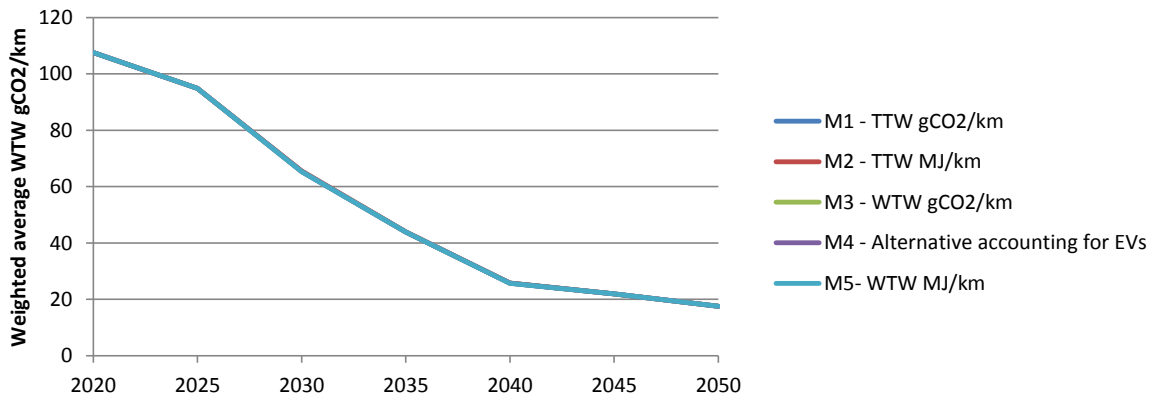

Figure 43   Weighted average WTW CO_2 emissions per kilometre for new vehicles for all metrics assessed (Scenario 1)
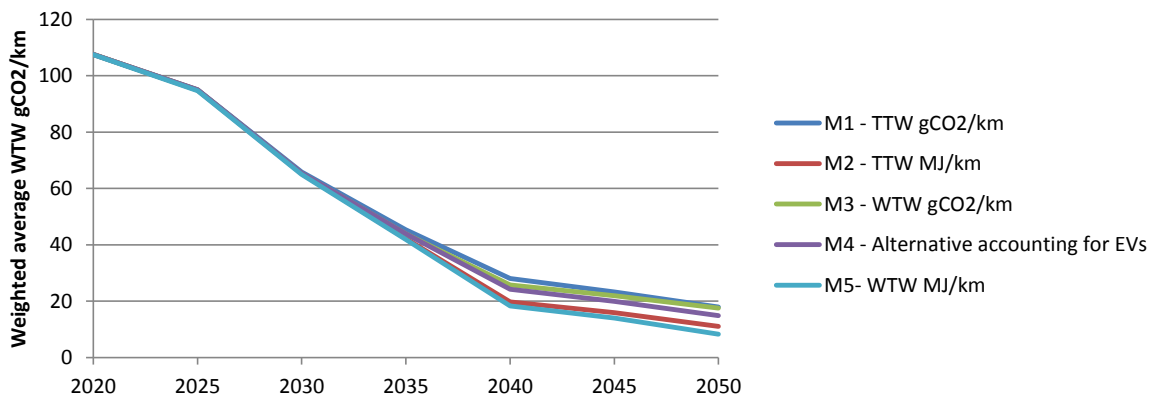

Figure 44   Weighted average WTW CO_2 emissions per kilometre for new vehicles for all metrics assessed (Scenario 2)
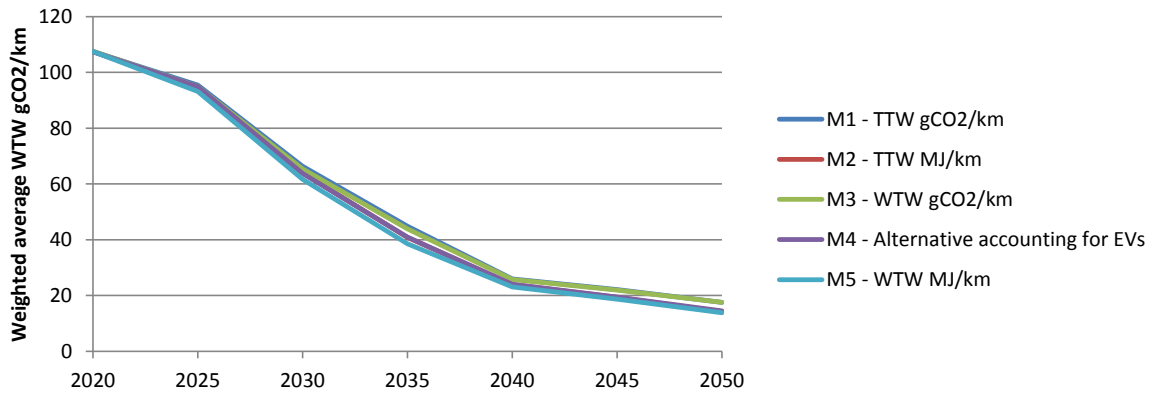
Figure 45   Weighted average WTW CO$_2$ emissions per kilometre for new vehicles for all metrics assessed (Scenario 3)
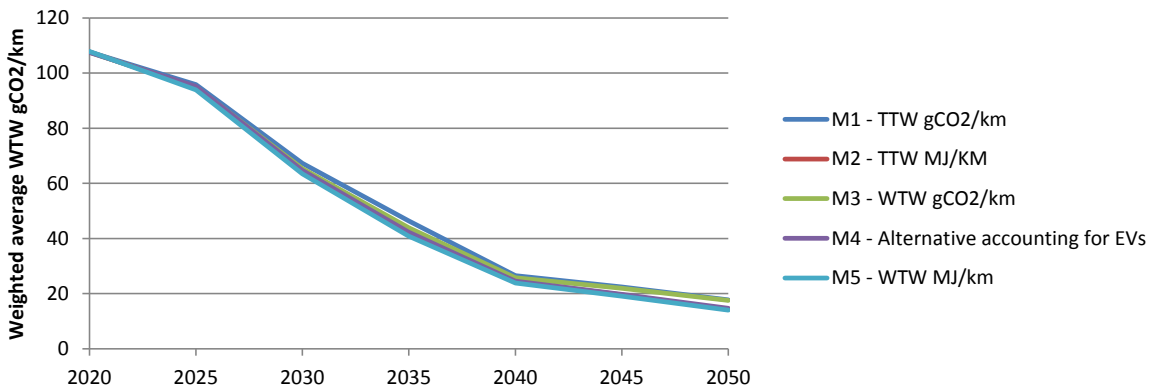

Figure 46   Weighted average WTW CO$_2$ emissions per kilometre for new vehicles for all metrics assessed (Scenario 4)

Scenario 1

As can be seen in Figure 43 and Table 16, in the Scenario 1 fleet the weighted average WTW CO$_2$ emissions per vehicle km for new vehicles are equal for all metrics assessed. The reason for this is that the equivalent targets for the alternative metrics have been derived using this scenario. As explained above, the trend of TTW CO$_2$ emissions is defined by reproducing the White Paper trend towards 2050. Equivalent trends to this TTW CO$_2$ emissions trend have been generated for the other metrics.

For the other fleet scenarios, the weighted average new vehicle WTW CO$_2$ emissions per vehicle km differ per metric because the trend per metric, as derived from the TTW CO$_2$ emissions given Scenario 1, are now to be met with another fleet composition. However, as can be seen in Figure 43 to Figure 46, the difference between difference metrics is rather limited for all scenario's assessed. This is mainly the result of the combination of high amounts of vehicles with a (partly) electric drive train and the significant decrease of CO$_2$ intensity of the electricity production. As a result, the overall emissions are reduced rather much for all scenario's. Nevertheless, when zooming in on the effects near 2050 conclusions can be drawn.

Scenario 2

As can be seen in the table below, the difference between different metrics is largest in Scenario 2, especially for the energy based metrics. This is the result of FCEVs requiring more energy per kilometre than BEVs. In case the hydrogen for the FCEVs is mainly produced by electrolysis, FCEVs would also emit more CO$_2$ WTW. In Scenario 2, the share of FCEVs is significantly larger than in Scenario1. In order to meet the equivalent trend based on Scenario 1, ICEVs would have to reduce more WTW CO$_2$ emissions. This results in relatively low WTW CO$_2$ emissions for energy based metrics.

FCEVs are expected to have higher annual mileages than BEVs. Since the total demand of vehicle kilometres travelled is conserved, the amount of FCEVs in Scenario 3 is lower than the amount of

BEVs in Scenario 1. This effect would allow higher WTW CO_2 emissions from ICEVs and is therefore contradictive to the effect resulting from the higher energy use of FCEVs compared to BEVs. Since this effect is smaller, the overall WTW CO_2 emissions are lower than in Scenario 1.

Scenario 3

Also in Scenario 3, the average WTW emissions per vehicle km are lower for the energy-based metrics than for the CO_2 related metrics. This is the result of the increased share of new electric vehicle registrations compared to Scenario 1. These electric vehicles use less energy per kilometre than the conventional vehicles on average use in Scenario 1. This allows conventional vehicles on fossil fuels to use more energy under a target based on a MJ/km metric. Since the electricity has a very low carbon intensity compared to the CO_2 emitted to generate the energy for the conventional vehicles, the WTW CO_2 emissions are lower for energy-based metrics than for CO_2 based metrics.

Scenario 3 includes more BEVs than Scenario 1. Given the used methodology, new ICEVs would be allowed higher TTW CO_2 emissions to still meet the TTW CO_2 emissions target. As a result it could be expected that the TTW CO_2 based metric would lead to higher WTW CO_2 emissions. In Table 16 it can be seen that this difference is very small. This is because the number of new ICEVs is diminutive in 2050. The only TTW CO_2 emissions for new vehicles in 2050 are from the PHEVs.

Scenario 4

In this scenario, the share of electric vehicles is equal to that in Scenario 3, while the share of biofuels is lower than in the other scenarios. Since the WTW CO_2 emissions of these biofuels are relatively low in 2050, a decrease in the share of biofuels has a negative effect on the weighted average WTW CO_2 emissions per vehicle for all metrics assessed. However, this effect is limited in 2050 because of the relative small decrease of the biofuels share in that year (as described in B) and the small remaining number of ICEVs.

Table 16   Weighted average WTW CO_2 emissions per newly registered vehicle in 2050

2050 weighted average WTW CO_2 emissions per vehicle [gCO_2/km]	Scenario 1	Scenario 2	Scenario 3	Scenario 4
M1 - TTW gCO_2/km	17.5	18.0	17.6	17.8
M2 - TTW MJ/km	17.5	11.0	14.2	14.3
M3 - WTW gCO_2/km	17.5	17.5	17.5	17.5
M4 – Alternative accounting for EVs	17.5	14.9	14.5	14.7
M5 - WTW MJ/km	17.5	8.3	13.8	14.0

Overall TTW CO_2 emissions

Figure 47   Overall TTW CO_2 emissions for all metrics assessed (Scenario 1)

Figure 48   Overall TTW CO$_2$ emissions for all metrics assessed (Scenario 2)
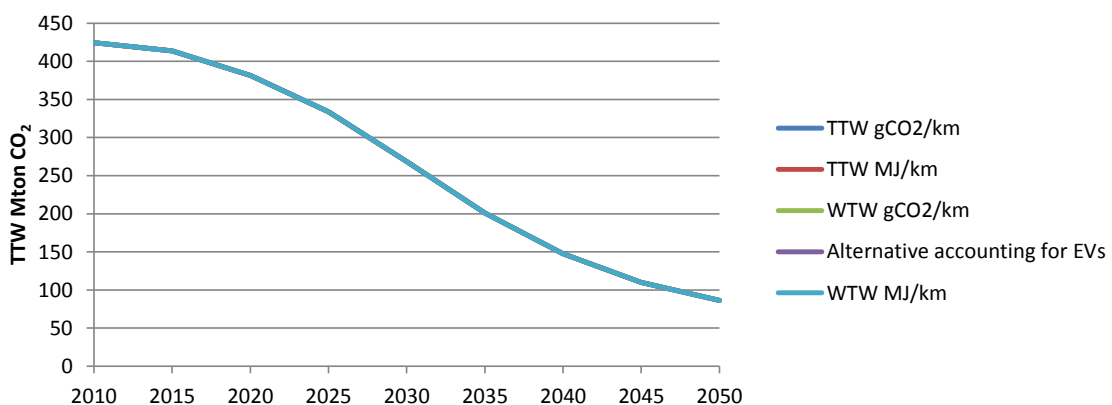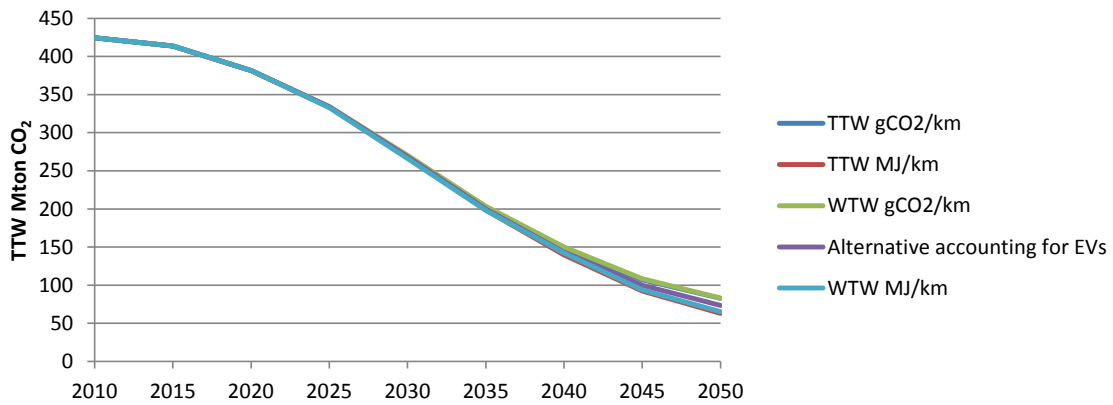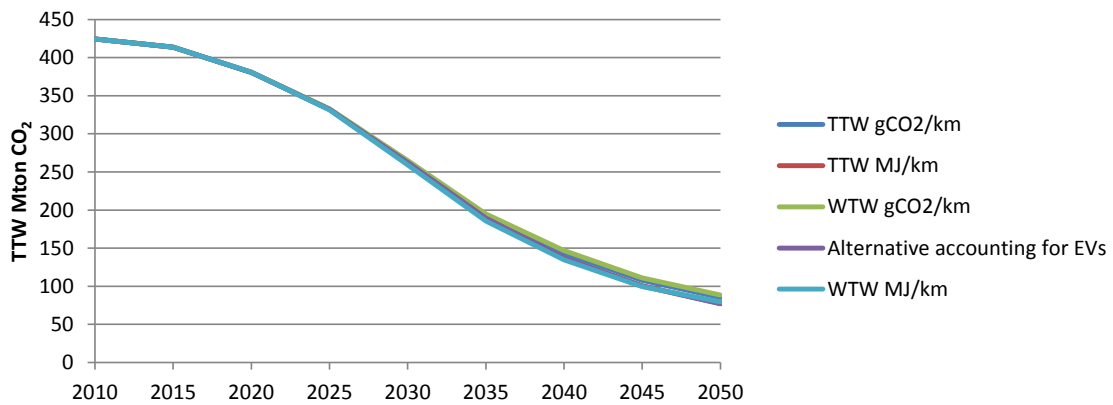

Figure 49   Overall TTW CO$_2$ emissions for all metrics assessed (Scenario 3)
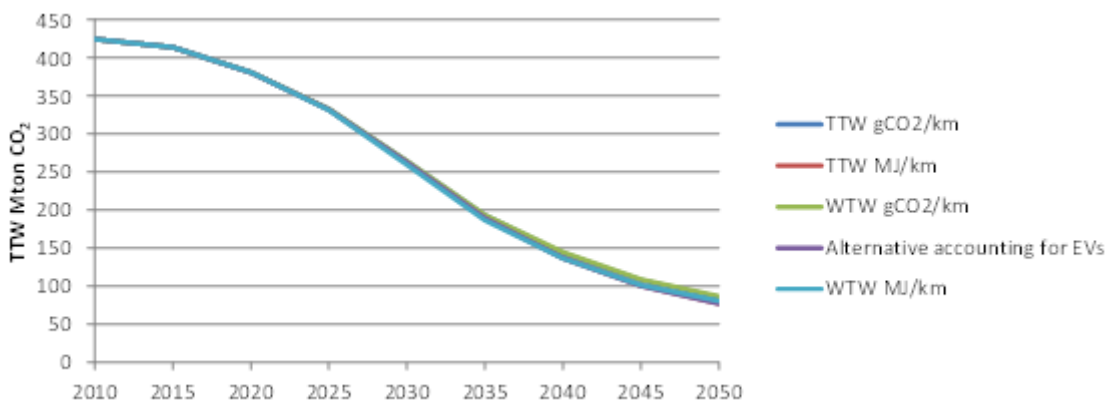
Figure 50   Overall TTW CO$_2$ emissions for all metrics assessed (Scenario 4)

<u>Scenario 1</u>
As can be seen in Figure 47, the overall TTW CO$_2$ emissions by the Scenario 1 fleet are equal for all metrics assessed. As explained above, this is the result of the equivalent trends for all metrics are based on this scenario. This was already explained in more detail in the assessment of the weighted average WTW CO$_2$ emissions per vehicle.

<u>Scenario 2 – Scenario 4</u>
For the other fleet scenarios, the overall TTW CO$_2$ emissions do differ more per metric. However, as can be seen in Figure 47 to Figure 50, the difference between different metrics is smaller than for the weighted average WTW CO$_2$ emissions per vehicle. This is the result of the CO$_2$ emissions represented in these figures being fleet based while the emissions in Figure 43 to Figure 46 are based on new vehicles. Since the fleet largely exists of vehicles that emit more than the emissions of the new registrations (i.e. older vehicles) differences are less pronounced.

Table 17   Overall TTW CO emissions for the whole vehicle fleet in 2050

2050 overall TTW fleet emissions [Mton]	Scenario 1	Scenario 2	Scenario 3	Scenario 4
M1 - TTW gCO$_2$/km	86	83	85	85
M2 - TTW MJ/km	86	63	77	77
M3 - WTW gCO$_2$/km	86	83	88	87
M4 – Alternative accounting for EVs	86	73	77	77
M5 - WTW MJ/km	86	65	80	81

5.6.2   Results for the case of electricity and hydrogen production with high carbon intensity

Results for the impact of different fleet composition scenarios on fleet-wide WTW CO$_2$ emissions in the case of high WTT emissions for alternative energy carriers are depicted in Figure 51 to Figure 55.

From Figure 51 to Figure 55 it can be concluded that, also based on higher GHG intensity electricity and hydrogen production, all metrics are only limitedly sensitive to changes in the fleet composition. In Table 18 can be seen that in 2050 the energy based metrics are most sensitive to the fleet composition.

Based on the higher GHG intensities compared to those used in section 5.6.1, the sensitivity of the metrics to changes in the fleet is less. This is the result of the WTW CO$_2$ emissions of BEVs and FCEVs being closer to those of conventional vehicles.

Overall WTW CO$_2$ emissions

Figure 51   Overall WTW CO$_2$ emissions for a TTW CO$_2$ based metric for the four assessed scenarios

Figure 52   Overall WTW CO$_2$ emissions for a TTW MJ based metric for the four assessed scenarios

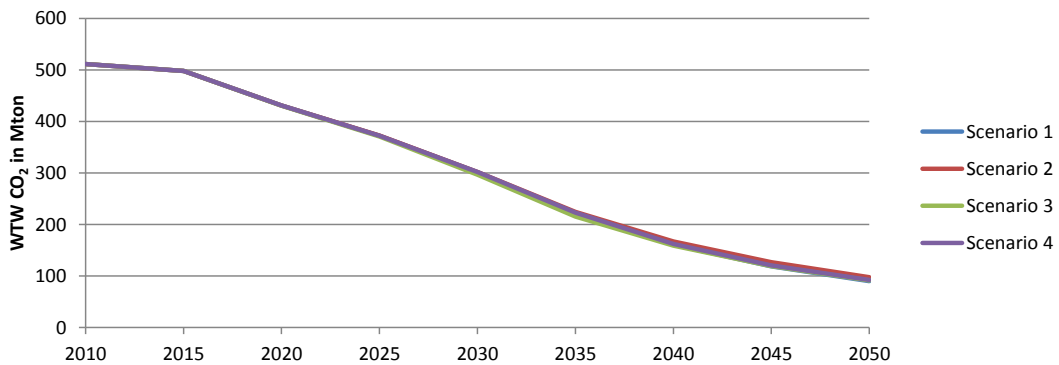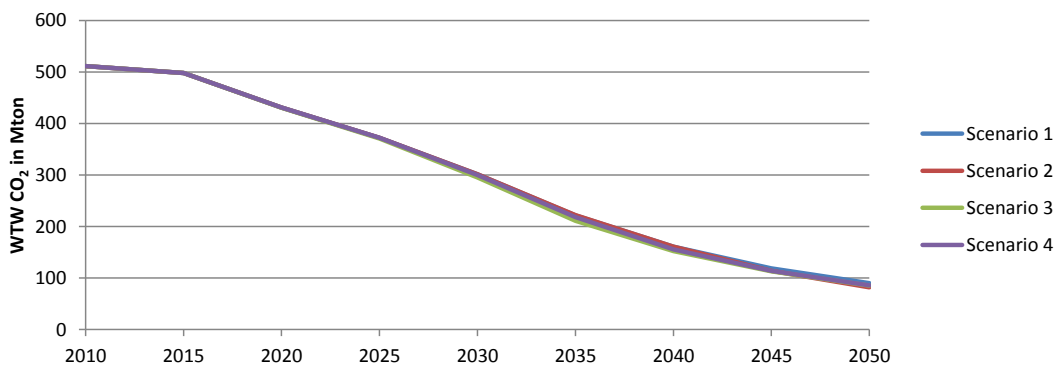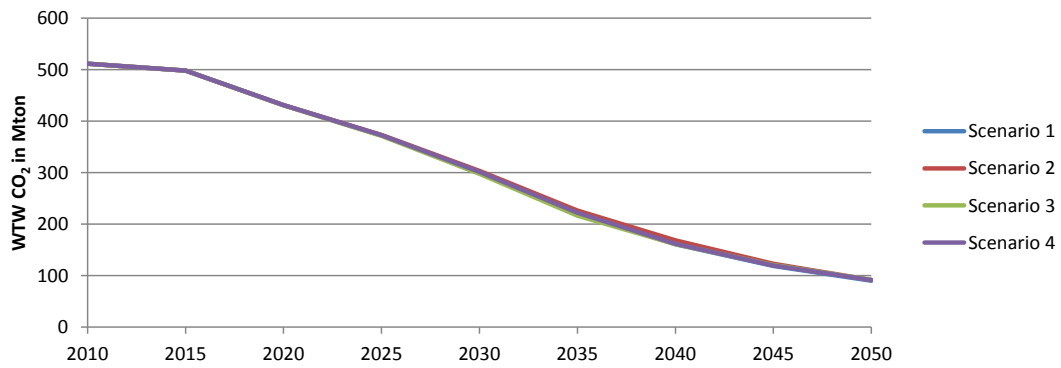Figure 53   Overall WTW CO_2 emissions for a WTW CO_2 based metric for the four assessed scenarios
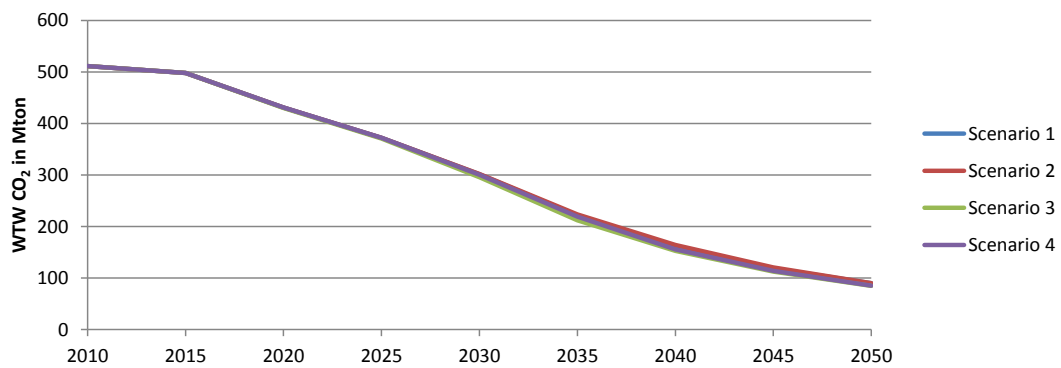
Figure 54   Overall WTW CO_2 emissions for a TTW CO_2 based metric corrected for emissions from BEVs
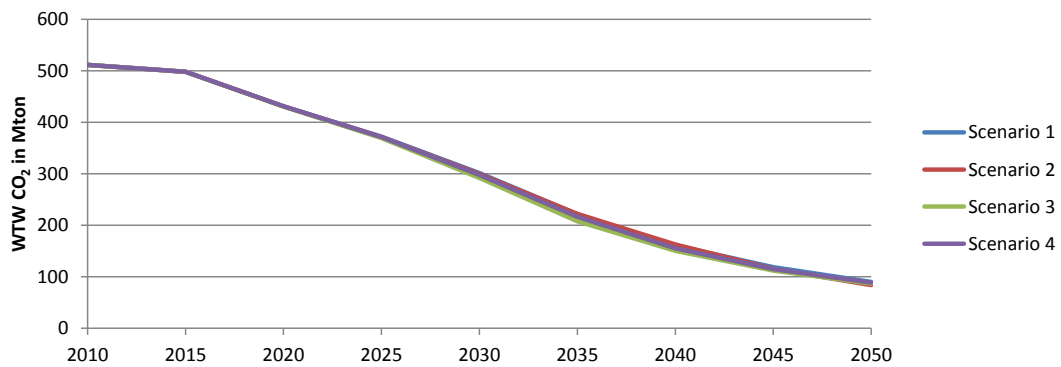
Figure 55   Overall WTW CO_2 emissions for a WTW MJ based metric for the four assessed scenarios

5.7   Conclusions

In chapter 4 it was shown that various metrics suffer from "WTW CO_2 leakage", i.e. that average WTW emissions of new vehicles increase with an increasing share of ZEVs in the new vehicle fleet. The assessments carried out in this chapter are intended to investigate whether this effect also significantly affects fleet-wide WTW CO_2 emissions in the medium and long term.

For the comparison of impacts of different metrics on fleet-wide WTW GHG emissions the definition of equivalent targets levels for the different metrics is crucial. The analysis in chapter 4 has also shown that for setting targets levels below what is technically feasible with ICEVs it is required to make assumptions on the share of alternative vehicles or ZEVs in the new vehicle sales in the target year. In case of a TTW CO_2 based target, the WTW CO_2 emissions and the TTW and WTW energy consumption of a new vehicle fleet meeting the TTW CO_2 target depend on the share of ZEVs, their energy efficiency and the WTT GHG emissions of the energy carriers for these ZEVs (specifically electricity and hydrogen).

Table 18   Overall WTW CO_2 emissions for the whole vehicle fleet in 2050 (based on a high carbon intensity scenario for electricity and hydrogen)

2050 overall WTW fleet emissions [Mton]	Scenario 1	Scenario 2	Scenario 3	Scenario 4
M1 - TTW gCO_2/km	89.9	97.9	91.6	92.4
M2 - TTW MJ/km	89.9	82.1	85.1	85.9
M3 - WTW gCO_2/km	89.9	91.3	92.0	91.5
M4 – Alternative accounting for EVs	89.9	90.3	84.8	85.5
M5 - WTW MJ/km	89.9	83.8	86.8	88.5

In this chapter the main policy scenario underlying the 2011 White Paper has been chosen as the starting point for defining equivalent targets. If the Commission's ambitions for GHG reduction are based on this scenario, the evolution over time of TTW and WTW CO_2 emissions and energy consumption of new vehicles and the entire fleet can be considered desired by or at least acceptable to the European Commission. For this reason the performance of the new vehicle fleet in this scenario on the different metrics was used to define equivalent targets for the various metrics.

The robustness of WTW GHG emissions under different metrics was tested by calculating these emissions for different fleet compositions meeting the target with a given metric. In the model the fuel efficiency of ICEVs (and of kms driven on the ICE by PHEVs) is adjusted in response to varying shares of ZEVs in the new vehicle fleet in such a way that the new fleet average remains on target.

Under a WTW CO_2 based metric the WTW CO_2 emissions of the new vehicle fleet, and as a result also of the entire fleet sufficiently long after introduction of the targets, are by definition not sensitive to changes in fleet composition. Given the assumptions made, however, the impact of changing fleet compositions on fleet-wide WTW GHG emissions was found to be very small also for the other metrics. This is not only the case when using WTT emission factors for electricity and hydrogen from the "decarbonisation scenario" that is part of the 2011 White Paper's main policy scenario, but also when significantly higher WTT emissions are assumed.

The limited sensitivity of fleet-wide WTW emissions in the long term is consistent with findings in chapter 4, that showed that in the long term WTT emissions of ZEVs become so low that an increase in the share of ZEVs can no longer lead to a significant increase in WTW emissions. The fact that sensitivity in the medium term is also small seems to contradict the results of chapter 4, although some dampening of the effect is to be expected due to the limited impact of changes in new vehicle emissions on the emissions of the entire fleet. The limited sensitivity in the medium term can be attributed to the fact that the scenario 1, which was chosen as a starting point for the assessments, assumes a very steep increase of the share of EVs and PHEVs in the period between 2025 and 2030. Significant changes in fleet composition (within the limitations set by a minimum feasible TTW CO_2 emission level of ICEVs and the requirement to meet the targets defined on the basis of scenario 1) can then only come from shifts between EVs, PHEVs and FCEVs. Such shifts may be expected to have less impact on fleet-wide WTW emissions than shifts between ICEV and ZEV shares.

In hindsight it would have been better to use a reference scenario with a less optimistic growth of ZEVs in the medium term as a starting point for the analysis. However, it was decided not to carry out additional analyses with the fleet model using alternative scenarios.

6 Pros & cons of different options

In this chapter the various metrics and other regulatory options, as listed in chapter 2, are evaluated by listing identified pros and cons (and relevant other comments) for each option individually. These pros and cons relate to the assessment criteria as specified in chapter 0, and are based on the results of analyses presented in chapters 4 to 8.

6.1 GHG emission based metrics

a.1 *Tailpipe CO_2 emissions as in existing Regulation (TTW gCO_2/km)*

Pros:
- Focus on CO_2 implies that the goal of contributing to CO_2 reductions is more likely to be achieved.
- Tight targets will stimulate the marketing of ZEVs (e.g. BEVs, PHEVs and FCEVs) and will thus promote a more rapid transition to alternative energy carriers with low or zero TTW emissions (electricity and hydrogen).
  - Depending on the marginal costs of reducing the last g/km in ICEVs and the additional costs of BEVs and other alternatives, this metric may also provide a cost incentive for manufacturers to market alternative vehicles.
    - The SR1 study [TNO 2011] estimates that the marginal costs for meeting 95 g/km are around € 90 per g/km. Under the 95 g/km target with a TTW CO_2-based metric selling one BEV allows 95 ICEVs to emit 1 g/km more. This saves € 8550 per BEV sold, which is of the same order of magnitude as the additional costs for manufacturing these vehicles.
    - This issue is explored in more detail in SR8 [TNO 2013].
- A similar approach is currently used in the US, Japan and other regions worldwide.
- This regulatory approach is currently generally accepted by vehicle manufacturers and automotive industry.

Cons:
- Not technology neutral (depending on the overall policy objective). If the overall goal is to reduce WTW emissions, this metric overstimulates vehicles with zero TTW emissions (ZEVs) in comparison with other, possibly more cost-effective CO_2 reduction options.
- Does not provide intrinsic credits for biofuel vehicles.
  - This could be fixed with additional provisions. TA CO_2 emissions could be corrected for the assumed impact of biofuels. This could be done by setting CO_2 emissions for the biofuel share to zero (IPCC definition and consistent with treatment of BEVs and FCEVs under this metric) or to a finite value that reflects the average net WTW GHG emission reduction potential.
- Upstream emissions continue to be ignored.
- Increasing the share of ZEVs (vehicles with zero TTW emissions) such as EVs and FCEVs to meet the TTW target leads to increase in WTW emissions compared to the situation where the target is met without zero TTW emission vehicles.
  - The same applies for PHEVs, though to lesser extent, depending on the shares of electric and ICE driving mixed in the test procedure resp. real world driving.
  - This effect was found to be most pronounced in the medium term when the share of ZEVs in the new vehicle sales may already be significant, while their energy carriers are still based on fossil energy to a large extent. In the short term the number of ZEVs is still very small, limiting the net effect of variations in the ZEV share on average WTW CO_2 emissions, while in the longer term the GHG intensity of the alternative energy carriers should become so low that even large shares of ZEVs lead to limited "WTW CO_2 leakage".
  - The problem goes away as soon as WTT emissions from electricity or hydrogen generation approach zero.
- For low TTW CO_2 targets, that will be necessary in the medium to long term, the TTW emissions of ICEVs required to meet the target become increasingly sensitive

to variations in the share of ZEVs. If the share of ZEVs in the fleet is smaller than assumed for setting the target, the required additional reductions in TTW CO_2 emissions of ICEVs may be beyond what is technically feasible.

- Provides no incentive for efficiency improvement for zero TTW emission vehicles,
    - It could be argued, however, that this is not necessary as, especially for EVs, high efficiency means large range and lower costs, so there is at least some intrinsic incentive for manufacturers to improve efficiency.

Other remarks: --

a.2 *Tailpipe CO_2 emissions for ICEVs with exclusion of Zero Emission Vehicles*

Pros:
- Targets for conventional vehicles are not compromised by introducing other technologies. This option avoids the leverage by zero-emission vehicles on the overall average WTW emissions as discussed for option a.1.
- Focus on CO_2 implies that the goal of contributing to CO_2 reductions is more likely to be achieved.

Cons:
- It is not a fundamental long term solution, if this means that the regulation stays limited to ICEVs.
    - This could be solved by setting separate efficiency standards for EVs and FCEVs, but then also CO_2 regulation for ICEVs could be replaced by an energy-based metric.
- Does not promote the transition to low-carbon or renewable energy carriers.
    - Additional policy instruments are necessary to promote the use of vehicles with low carbon energy carriers, such as BEVs and FCEVs, which are necessary to reach the long term GHG reduction targets.

Other remarks:
- No need to account for biofuels share in conventional fuels as ICEVs are not compared to alternative energy carrier technologies.
- In this metric TTW CO_2 emissions are a very good proxy for TTW energy consumption (or vehicle efficiency).

a.3 *Tailpipe CO_2 emissions with notional GHG intensity for Zero Emission Vehicles*

Pros:
- Focus on CO_2 implies that the goal of contributing to CO_2 reductions is more likely to be achieved.
- The use of a notional WTT factor for ZEVs can reduce the WTW CO_2 leakage resulting from introducing ZEVs, but this is only the case when the equivalent target is based on the assumption that the TTW target without notional WTT emission factors for ZEVs can be met with ICEVs only.
- Notional WTT and/or WTW/TTW factors do not need to be very exact (i.e. true WTT factors) and do not require a complex monitoring system.

Cons:
- For equivalent targets based on an assumed ICEVs/ZEVs mix for meeting the TTW-based target the target with notional WTT emission factors for ZEVs shifts with applied notional WTT factors, so that the WTW CO_2 leakage associated with a TTW CO_2 based metric is not affected.
- The required response in terms of adjusting the TTW emissions of ICEVs to variations in the ZEV share depends somewhat on the equivalent target setting (TTW target assumed to be met by ICEVs only or by a mix of ICEVs and ZEVs). In both cases, however, there is a strong sensitivity of required TTW emissions of ICEVs to variations in the actual share of ZEVs.
    - This sensitivity is of the same order as for a TTW GHG based target without notional GHG intensity for ZEVs.
    - Especially in the long term a smaller share of ZEVs than expected requires unrealistic improvements in efficiency of ICEVs.
    - Requires definition of, and agreement on notional WTT and/or WTW/TTW

factors.

- OEMs might oppose it arguing that they are not responsible for these WTT emissions.
  - But OEMs can be made responsible through providing incentives for making technology choices that contribute most effectively to meeting overall policy objectives by taking account of difference in upstream emissions.
- More frequent updates of notional WTT factors would make planning more difficult for OEMs.
  - To avoid regular "surprises", and the resulting planning uncertainty for OEMs, one could use a projected trajectory for the WTT factors. This assumed trajectory could be reviewed regularly to make trends visible. But legislation should only be adjusted infrequently.

Other remarks: --

a.4   *Tailpipe CO$_2$ emissions adjusted to take account of WTW emissions (WTW gCO$_2$/km)*

Pros:
- Focus on GHG emissions implies that the goal of contributing to GHG emission reductions is more likely to be achieved.
- Focus on the most important parameter with respect to world-wide climate impacts.
- Technology neutral, if main policy objective is to reduce WTW GHG emissions.
- Under a WTW GHG based target the WTW GHG emissions are obviously independent of the share of ZEVs and actual WTT factors for ICEVs and ZEVs.
- A WTW CO$_2$ based metric in the regulation would also allow national fiscal regimes to be based on WTW rather than TTW CO$_2$ emissions. This may improve their effectiveness towards the overall goal of reducing WTW GHG emissions.

Cons:
- The flexibility with respect to changes in the share of ZEVs (relative to the assumed share for determination of the equivalent WTW based target) appears rather limited and depends on the possibility for ICEVs to respond to a changing ZEV-share.
  - In case the equivalent WTW target is based on the assumption that the TTW target is met by a mix of ICEVs and ZEVs, the following can be concluded:
    - If the efficiency of ZEVs is assumed to be fixed, required changes in TTW MJ/km of ICEVs in response to a varying ZEV share appear feasible in the medium term. In the long term, however, the efficiency improvements of ICEVs, necessary to respond to a lower than expected share of ZEVs, become very large.
    - If the efficiency of ICEVs is assumed to be fixed, which is specifically likely in by 2030 and beyond when ICEV technologies may have reached their limits, the required energy efficiency of ZEVs is extremely sensitive to the ZEV share both in the medium and long term, and quickly moves beyond feasible values if realised ZEV shares are somewhat below the expected values.
  - In case the equivalent WTW target is based on the assumption that the TTW target can be met by ICEVs only, the efficiency of ZEVs does not need to be adjusted in response to a changing ZEV share, even when the efficiency of ICEVs is assumed constant. For longer term targets the assumption that the TTW target can be met with ICEVs only becomes very improbable. If one assumes that under a long term WTW target the TTW emissions of ICEVs are fixed to a value that is higher than the equivalent TTW target, the efficiency of ZEVs becomes very sensitive to changes in the share of ZEVs.
- Determining actual WTT and/or WTW emission factors requires a complex monitoring system.
  - For electricity and hydrogen an appropriate methodology is required. Different electricity mixes in different countries and the EU-ETS complicate matters.
- Using actual WTW or WTT emission factors, or very frequent updates of these factors, would make planning more difficult for OEMs.
  - To avoid this, one could use a projected WTT factor or glideslope and review regularly to give visibility of trends – but adjust legislation only infrequently.

- OEMs might oppose it arguing that they are not responsible for these WTT emissions.
  – But OEMs can be made responsible through providing incentives for making technology choices that contribute most effectively to meeting overall policy objectives by taking account of difference in upstream emissions.

Other remarks:
- A WTW CO_2 based metric might increase the interaction between the CO_2 regulation and other policy instruments such as the FQD, RED, and EU-ETS. As the interaction can be either complicating or beneficial (e.g. in the sense that the regulation may promote adoption of vehicle technologies that are necessary to achieve the targets w.r.t. energy carriers set in the FQD and RED), this is neither a pro nor a con.
- The option of having WTT emission factors taking into account estimated future progress to represent expected average value over the vehicle lifetime might be helpful, though note the risk of manipulation by "optimistic" forecasting.

6.2 Energy consumption based metrics

b.1   *Energy used in the vehicle per vehicle-km (TTW MJ/km)*

Pros:
- Reduces the overstimulation of electric and fuel cell vehicles and other vehicles with (partly) zero TTW emissions.
- A TTW energy based target can be considered to solve the problem of "WTW CO_2 leakage" as observed in a TTW CO_2 based metric, as WTW emissions decrease rather than increase with an increasing share of ZEVs if WTT emissions of these ZEVs are sufficiently low.
- Regulating vehicle efficiency rather than CO_2 emissions is apparently more consistent with the regulation of the carbon intensity of energy supplied to transport through the FQD/RED.

Cons:
- If reduction of WTW GHG emissions is the overall objective, this option is not technology neutral, due to intrinsic differences in the energy efficiency of various propulsion systems. Electric propulsion has about a factor of 3 better energy efficiency than conventional powertrain with internal combustion engine, but WTW GHG impact depends on upstream emissions.
- For a given share of ZEVs the WTW GHG emissions increase with increasing WTT emissions of ZEVs. The sensitivity of average WTW GHG emissions to variations in the WTT emissions of ZEVs is about the same as for a TTW CO_2 based metric
- Focus on energy efficiency could reduce effectiveness of achieving reduction goal with respect to WTW GHG emissions.

Other remarks:
- In the medium to long term equivalent targets for a TTW energy based target must be defined under the assumption that the original TTW CO_2 based target is met by a mix of ICEVs and ZEVs. If the target is translated under the assumption that the original TTW CO_2 based target is met by ICEVs only, the equivalent target ends up below the minimum feasible energy consumption of ICEVs and ZEVs.
  – This can, however, be considered a theoretical issue, as future targets for this metric would be based on what is considered feasible given an assumed share of ZEVs rather than on determining the equivalent of TTW GHG based target.

b.2   *Separate efficiency targets for different classes of propulsion systems*

Pros:
- Targets for conventional vehicles are not compromised by introducing other technologies. This option avoids the leverage by zero-emission vehicles on the overall average WTW emissions as discussed for option a.1.
- This option also sets efficiency targets for vehicles with zero TTW emissions.
- It is technology neutral provided that targets per technology are equally challenging.

Cons:	• Effort required for setting targets per class of propulsion systems based on evaluation of technical potential and cost effectiveness.
	• Does not promote the transition to low-carbon or renewable energy carriers.
	– Additional policy instruments are necessary to promote the use of vehicles with low carbon energy carriers, such as BEVs and FCEVs, which are necessary to reach the long term GHG reduction targets.

Other remarks: --

b.3 *Energy use per vehicle-km adjusted for WTW consumption (WTW MJ/km)*

Pros:
- Promotes overall resource efficiency.
- Improves impact relative to option b1 with respect to reducing the leverage of zero-emission vehicles.
  - WTW GHG emissions are moderately sensitive to variations in the actual WTT emission factor of ZEVs, but are quite sensitive to a varying ZEV share.
    - With targets getting lower in the medium to long term, the sensitivity to the ZEV share increases while the sensitivity of the average WTW GHG emissions to the WTT emissions of ZEVs further decreases;
    - In the short to medium term there is sufficient room for the TTW MJ/km of ICEVs to respond within a feasible bandwidth to variations in the share of ZEVs;
    - In the long term the sensitivity in terms of the required change in MJ/km of ZEVs or ICEVs in response to a changing ZEV share is much weaker than for a WTW CO_2 based metric.
- Promotes energy efficiency in vehicles running on alternative energy carriers.

Cons:
- Comparing primary energy use of fossil and renewable sources is an "apples & pears" comparison. Fossil sources are finite.
- WTW energy consumption does not correlate with WTW GHG emissions.
  - This would not be a problem if reduction of overall primary energy consumption is the goal. But the main goal of the policy strategy, of which the current vehicle CO_2 regulation is a part, is reduction of WTW GHG emissions and of GHG emissions attributed to the EU and Member States on the basis of IPCC rules.
- If reduction of WTW GHG emissions is the overall objective, this option is not technology neutral due to intrinsic differences in WTW energy efficiency of various propulsion systems.
- Focus on energy efficiency could reduce effectiveness of achieving reduction goal with respect to WTW GHG emissions.
- OEMs might oppose it arguing that they are not responsible for upstream / WTT energy consumption for the production of energy carriers.
  - But OEMs can be made responsible through providing incentives for making technology choices that contribute most effectively to meeting overall policy objectives by taking account of difference in upstream energy consumption.

Other remarks:
- The option of having WTT energy consumption factors taking into account estimated future progress to represent expected average value over the vehicle lifetime might be helpful, though note the risk of manipulation by "optimistic" forecasting.

6.3 Alternative options

6.3.1 Inclusion of road fuel use in EU ETS

c   *Inclusion of road fuel use in the EU ETS*

Pros:
- Theoretically economic instruments such as a cap & trade system promote the most cost effective reduction options.
- The advantage of a cap & trade system over a CO_2 tax is that the target is set and the CO_2 price follows from the reductions that are necessary to meet the target. With a CO_2 tax the tax level is a political choice.
- Technology neutral.
  - Large scale electricity and hydrogen generation plants are already part of the EU-ETS. The question is whether small-scale electricity and hydrogen generation, for use in vehicles or in general, should also be brought under EU-ETS in a future that has a significant share of decentralised energy generation.
- Inclusion of road fuel use in the EU ETS not only promotes the sales of less CO_2 emitting cars but also promotes a wide range of other technical and non-technical CO_2 reduction measures.

Cons:
- At current CO_2 prices under EU-ETS the impact of inclusion of road fuel use in the EU ETS on fuel prices is very small.
- A cap & trade system does not automatically stimulate timely action that is required to get longer term, transitional options (such as EVs) implemented.
- Current negative cost LDV CO_2 reductions suggest a degree of market imperfection that would hamper the use of a market based instrument.

Other remarks:
- It is essential to evaluate how much reduction in the road transport sector would be stimulated at different levels of the CO_2 price. The price differential between different technologies will furthermore depend on whether the existing taxes on various energy carriers remain unchanged or not.
- Effectiveness of a cap & trade system may be affected by the way in which emission credits are distributed.

6.3.2 A baseline & credit system for vehicle manufacturers

d   *A vehicle manufacturer based trading scheme based on lifetime vehicle GHG emissions*

Pros:
- A manufacturer based trading scheme has the advantage of allowing more cost effective distribution of reduction efforts over all new vehicles sold.
  - Previous studies such as [TNO 2006] and [IEEP 2007], however, have shown that the resulting average cost reduction per vehicle is limited.
- For the stricter post 2020 targets this option could become more interesting as trading allows setting target levels that cannot be met by all manufacturers within their own sales portfolio and technical capabilities.
- Adding lifetime mileage weighting to a manufacturer based trading system avoids that reduction on small vehicles with low annual mileage are one-to-one traded against equal reductions in larger vehicles with larger annual mileages.
- With respect to solving the problem of a TTW-based metric in relation to WTW impacts of ZEVs the pros are the same as for non-mileage weighted metrics that include WTT emissions.
- Lifetime mileage-weighting corrects for the fact that some technologies or size segments have longer vehicle lifetime and mileage than other, so that 1 g/km reduction in one segment has more/less impact on total GHG emissions than 1 g/km reduction in other segments Mileage weighting may thus lead to a more optimal distribution of reduction efforts and costs by manufacturers.

Cons:
- Allowing trading under a given target reduces incentives for investing in technologies that are needed for the longer term transition:
  - In the medium term, when large-scale application of ZEVs is not necessary for meeting the target, the option of trading may slow down their introduction compared to a target without trading, as it allows some manufacturers to avoid application of ZEVs for meeting the target and instead to buy credits from other manufacturers that have less difficulty in meeting their target by further improvements in ICEVs.
- Lifetime mileage figures need to be established. These are different per manufacturer, per country and vary over time. So it will be difficult to reach consensus.
- Lifetime mileages may also be different for different technologies, as e.g. EVs might be expected to be mainly used in urban applications with low annual mileage while diesel vehicles or FCEVs are expected to be used in applications with more long-distance driving and higher annual mileage.
  - If this is the case, the introduction of a given share of EVs or FCEVs may be expected to affect the average annual mileage of petrol and diesel vehicles. This adds further complexity and enhances the need to constantly monitor annual mileages of different vehicle categories.
- As with WTT emissions some may argue that manufacturers have no control over how much is driven with the cars they sell.
  - However, if this options is only based on default values this argument is irrelevant, similar to what was discussed for WTW based metrics.

Other remarks:
- The above pros and cons are based on the interpretation that this option is in addition to a manufacturer based target using a lifetime mileage weighted g/km metric, allowing manufacturers to trade excess emissions on the basis of lifetime GHG emissions = gCO_2/km x lifetime mileage, either on a TTW or WTW basis with default lifetime mileage values defined e.g. as function of the vehicle's utility value.

6.3.3   Cap & trade systems for vehicle manufacturers

e1   *A cap and trade system for vehicle manufacturers, of total CO_2 emissions of vehicles sold (expressed in g/km)*

Pros:
- Overall cap on total vehicle CO_2 introduces joint responsibility of OEMs and shared interest in reducing CO_2 emissions. This could encourage more collaboration.
  - But beyond pre-competitive research such collaboration may be difficult to arrange between competitors.
- Not only targets vehicle efficiency and CO_2 emissions but also total sales, and thus avoids market growth leading to increased emissions.

- Similar to option d, allowing trading under a given target reduces incentives for investing in technologies that are needed for the longer term transition
- Makes the engineering target for vehicle efficiency very dependent on economic / market fluctuations.
- Especially in the longer term there will be limited room to compensate growth in sales volumes by reduction of the average CO_2 emissions per vehicle kilometre. In the medium term fluctuations in sales volume might be compensated by changing the share of ZEVs in the new vehicle fleet. The room to manoeuvre depends on whether the cap is based on TTW or WTW CO_2 emissions.

Other remarks:
- In terms of the MJ/km based metric this option has many of the pros and cons also associated with options a.1 and a.3.

e2   *A cap and trade system for vehicle manufacturers, of total energy consumption of vehicles sold (expressed in MJ/km)*

Pros:
- Overall cap on total vehicle energy consumption introduces joint responsibility of OEMs and shared interest in reducing energy consumption. This could encourage more collaboration.
    - But beyond pre-competitive research such collaboration may be difficult to arrange between competitors.
- Not only targets vehicle efficiency but also total sales, and thus avoids market growth leading to increased energy consumption.

Cons:
- Similar to option d, allowing trading under a given target reduces incentives for investing in technologies that are needed for the longer term transition
- Makes engineering target for vehicle efficiency very dependent on economic / market fluctuations.
- Especially in the longer term there will be limited room to compensate growth in sales volumes by reduction of the average energy use per vehicle kilometre. In the medium term fluctuations in sales volume might be compensated by changing the share of EVs or FCEVs in the new vehicle fleet. The room to manoeuvre depends on whether the cap is based on TTW or WTW energy consumption.

Other remarks:
- In terms of the MJ/km based metric this option has many of the pros and cons also associated with options b.1 and b.3.

6.3.4   Inclusion of embedded emissions in WTW approaches

f   *Inclusion of embedded emissions in the WTW approaches listed above*

Pros:
- Provides an incentive for manufacturers to take account of differences in embedded emissions for different technologies in planning product portfolio.

Cons:
- This option requires an agreed and accountable methodology for determining life-cycle emissions of vehicles and components. This is a complex issue, especially if this method is also to be used to generate manufacturer-specific values.
- As with WTT emissions and lifetime mileage some may argue that OEMs do not have full control over embedded emissions.
    - This could be true for components they buy from suppliers, but even in that case OEMs can be assumed to take responsibility for chain management.

Other remarks:
- A 1st order approach with default values would suffice to cater for the main differences in embedded emissions when moving from ICEVs to e.g. EVs or FCEVs.
    - Default values would need to be updated regularly.

6.3.5   Combining different options with e.g. size-dependent mileage weighting

g   *Combining different options with e.g. size-dependent mileage weighting*

Pros:
- Lifetime mileage-weighting corrects for the fact that some technologies or size segments have longer vehicle lifetime and mileage than other, so that 1 g/km reduction in one segment has more/less impact on total GHG emissions than 1 g/km reduction in other segment.
    - As a result mileage weighting may thus lead to a more optimal distribution of reduction efforts and costs by manufacturers and would thereby improve the cost-effectiveness of the regulation.

Cons:	• Lifetime mileage figures need to be established. These are in principle different per manufacturer, per country and vary over time. So it will be difficult to reach consensus. Furthermore currently no reliable data are available at the EU level.
	• As with WTT emissions some may argue that manufacturers have no control over how much is driven with the cars they sell.
	– However, if this options is only based on default values this argument is irrelevant, similar to what was discussed for WTW based metrics.
Other remarks:	• The utility parameter used in the legislation is an obvious candidate for a size dependent mileage weighting. The most obvious implementations are in the form of a size- or mass-based mileage. The former is preferred as vehicle mass will be strongly affected by weight reduction measures in the next decades. Size could e.g. be parameterised as pan area (length x width) or footprint (wheelbase x track width).

7 Combining different options and inclusion of additional modalities

7.1 Introduction

As we see today, GHG emission policies in the EU consist of a whole package of different policies, each targeting different aspects and options of GHG reduction. For example, energy efficiency targets and policies are combined with renewable energy targets and policies, GHG intensity targets (FQD) as well as with an emission cap (ETS) and regulations for pricing policies. This can be a very useful and effective approach, because it provides targeted incentives to the various stakeholders involved and rectifies market failures.

To illustrate these effects, the potential effects of CO_2-based energy pricing policies or emission trading in transport can serve as an example. In theory, one might think that these economic instruments may lead to the most cost effective GHG emission reduction in the sector, as they set a price on CO_2, and both consumers and car manufacturers will automatically implement all CO_2 reduction measures that are cheaper than that price. However, this is not the case in practice, for example because consumers do not calculate cost over the lifetime of a vehicle but rather focus on short term cost, or because they cannot respond quickly to price: many of the potential CO_2 mitigation measures take many years to implement. Other policies are then necessary to promote these measures.

When looking at the GHG emission regulations for vehicles, either with or without inclusion of life cycle (upstream) emissions, it can be seen that these may interact with a number of other EU-level policies, in particular

- The EU ETS, which covers the GHG emissions of the electricity generated for electric cars and plug-in hybrids as well as of hydrogen production for fuel cell cars;
- The FQD[22], which aims to ensure that the average well-to-wheel CO_2 emissions of transport fuels and energy reduce over time;
- The RED[23], that sets a target for renewable energy in transport, and thus incentivises the use of renewable fuels and aims to ensure a minimum GHG reduction of biofuels - although the latter requires implementation of effective policies to include ILUC effects.

They also interact with several national and even regional or local policies, such as vehicle and fuel taxation, road charging, city access or parking restrictions or incentives, etc. These policies may also promote specific low-GHG technologies such as electric or CNG vehicles, or hydrogen cars, and thus support their deployment. This report, however, focusses on the interaction with EU policies.

7.2 Decarbonisation requires an integrated and timely approach

Scenarios for decarbonisation of the transport sector provide clear conclusions that the sector needs to implement most if not all GHG mitigation options available. An important feature of these scenarios is that the future transport system has to make large scale use of electricity from renewable sources to power rail and a significant part of road transport. Biofuels, possibly hydrogen and electricity and fossil fuels will have to power heavy duty vehicles (long range transport), maritime shipping and aviation. This is also confirmed in the White Paper for Transport, where development and deployment of new and sustainable fuels and propulsion systems is also considered to be one of the three key areas of focus.

Shifting from one energy source (the current oil-based fossil fuels) to other energy sources requires a significant change to the transport system as a whole. For many of these alternatives, engines and vehicles need to be developed, produced and brought on the market, the renewable energy (electricity,

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[22] DIRECTIVE 2009/30/EC, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009L0030:EN:NOT
[23] DIRECTIVE 2009/28/EC, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009L0028:en:NOT

hydrogen, biofuels) has to be generated and an infrastructure has to be built to charge or fill the vehicles. At the same time, consumers need to trust and accept the new technology, governments need to adapt their policies and fiscal systems, and industry has to build expertise and production capacity to support the new system.

Clearly, this type of transition requires time, and a coordinated approach between all parties involved. Some recent technological transitions, for example the large scale emergence of PCs, the internet and mobile phones have been driven mainly by the market itself. Governments played (and still play) a role in providing the right boundary conditions and prevent undesired impacts and market distortions, but the market uptake of these technologies was mainly driven by consumers willing to buy these products, and the industry responding by developing and supplying the products, building the necessary infrastructure, deciding on standards, developing attractive business models, etc.

This is, however, not a likely scenario in the case of vehicles with alternative fuels and drive trains. The new technologies may provide some advantages to consumers, e.g. electric vehicles can typically accelerate faster than the conventional cars, but these are limited compared to the disadvantages such as higher cost, limited driving range, lack of refuelling or charging infrastructure, long charging times, etc. A limited share of consumers is attracted by the new technology or the environmental benefits, but the majority of vehicle buyers is not expected to consider buying them as long as cost are higher and overall performance or ease-of-use is lower than of conventional cars.

It is generally expected that costs of the non-ICE alternative vehicles will not reduce sufficiently to become competitive, without quite far-reaching government support and incentives [CE Delft 2011]. Cost of e.g. electric vehicle batteries, or of hydrogen vehicles (incl. the fuel and infrastructure) are too high, and the advantages of conventional cars – in terms of cost, performance, etc. – are too large to be overcome by market forces itself. Investments in these new technologies are likely to remain limited unless the industry has confidence that consumers will indeed buy these cars. For that to happen coordinated government policies appear necessary.

7.2.1 Different actors all play an important role

As it is doubtful whether the market itself is capable to achieve this transition to sustainable fuels and propulsion systems on its own, policies need to ensure that all parties involved move in the right direction and take the right actions. For most alternative energy carriers, changes are required by quite a number of different parties, including vehicle and engine manufacturers and fuel producers and suppliers. This is illustrated in the following.

In case of biofuels:

- A biofuel producing industry needs to be developed that produces biofuels that are sustainable (in the broad sense, i.e. that they reduce GHG emissions over their life cycle, do not create significant indirect effects, do not cause other environmental or socio-economic problems). This includes the chain from feedstock cultivation or gathering/pre-processing to transportation, fuel production and distribution to end users or fuel suppliers.
- Depending on the biofuel, vehicles that are compatible with higher biofuel blends may need to be developed and put on the market.
- In case of bio-methane, vehicles need to be sold that can drive on this gas and a network of filling stations needs to be developed.

In case of electric transport:

- Battery industry, component suppliers and car manufacturers have to put efforts into the further development of batteries, electric powertrains and plug-in hybrids/range extenders, and increase the production capacity for these products
- The power sector (or related industries) needs to develop and put in place a sufficiently extensive charging network, preferably with a share of fast charging points or battery swap stations. This may require adaptations to the grid, development and implementation of smart charging, etc.. In any case it requires the development of standards, an IT infrastructure that enables roaming and new business models.

In case of hydrogen:

- Car manufacturers and related industries need to continue R&D into fuel cells, electric powertrains, on-board storage etc. to reduce cost, increase driving range, etc.
- Industry has to develop a hydrogen infrastructure, ranging from increasing production volumes (with a focus on production from renewable or low-carbon energy sources) to distribution to end consumers.

Apart from these main developments, many of which require significant investments, a whole range of smaller changes need to take place. For example, industry standards will have to be developed to ensure safety, compatibility between cars and charging/filling infrastructure, car maintenance engineers need to be trained, consumers need to be informed, etc.

Governments now need to develop robust policies that create effective incentives to promote these actions and investments. As many of these developments are interdependent, they will need to take place simultaneously – for example, bio-methane vehicles will only be developed and sold on a significant scale in regions where enough filling stations are available. This effectively means that a number of different actors need to be mobilized at the same time in order to promote a new fuel or energy type.

7.2.2   Timing of policies

All of the alternative fuels and propulsion systems require quite some time before they will be able to gain significant market shares. This is due to a number of reasons, such as:

- Research and development typically requires at least 10-15 years before it results in a marketable product that can be produced at larger scales.
- Production capacity needs to be built.
- Light duty vehicles have an average lifetime of around 15 years, which means that about 7% of the vehicle fleet is replaced annually. A new technology will first enter the market in small shares, which gradually increase if successful. This means that it may take at least 5-10 years and perhaps even several decades before a new technology can have replaced a significant share of the conventional cars in the fleet.
- Policies need to be developed, decided on and implemented. This also typically takes several years, especially on EU-level.
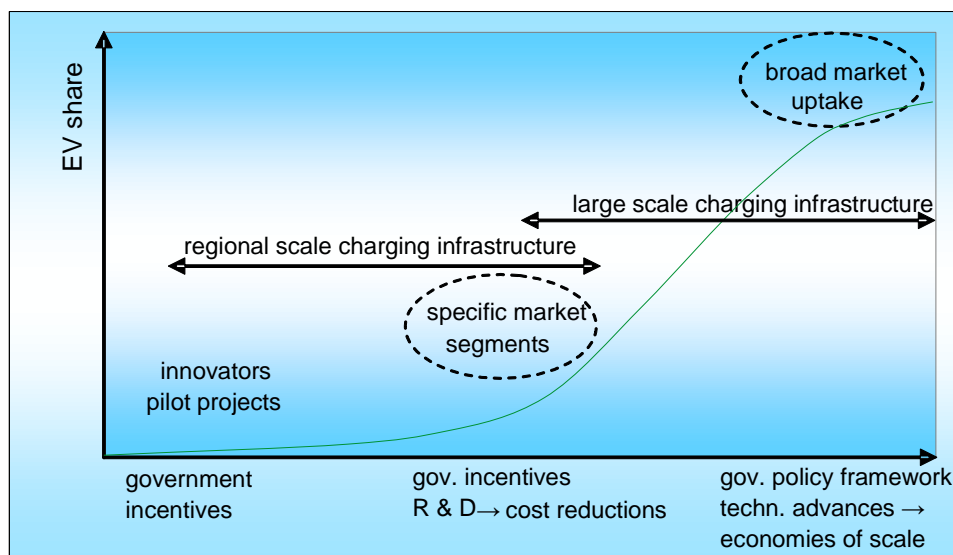

Figure 56   A schematic road map that illustrates how an increasing EV market share can be achieved [CE Delft 2011]

To illustrate this, a typical development curve that can be expected for electric vehicles (EVs) is shown in Figure 56. The market uptake will first be limited to innovators and pilot projects, to gain experience

nonewith the technology and provide feedback to the developers. If these projects are successful, EVs are likely to first be taken up in specific market segments, for example in urban transport and distribution, taxis, etc. At that time a regional scale charging infrastructure needs to be set up. As EV shares increase, this will gradually expand on a national/EU scale. During this whole period of transition, government policies should be adjusted to what is needed in each phase of the development.

The exact time scale is not indicated in this graph, as it depends on cost developments, success of R&D, the effectiveness of government incentives, etc. From the above list it becomes clear, however, that even in case of a successful development, this S-curve will take at least 25 years of development.

It can thus be concluded that as the aim is to have achieved significant shares of alternative cars and fuels in the vehicle fleet in 2030 (see goal no. 1 of the White Paper for Transport [EC 2011]), there is a clear need to promote their development and market uptake already in the coming years, and continue this, at least until costs have become competitive.

7.3 Consequences for policy: building an effective policy package

Effective policies should thus focus on achieving the right actions of all actors and stakeholders involved, ensuring that:

- The necessary **R&D investments and efforts** are being made, covering all the new technologies that are needed (i.e. fuels and energy carriers, vehicles and filling or charging infrastructure);
- The **low-carbon vehicles** are produced and marketed, at competitive prices;
- The production chains of the **low carbon fuels and energy carriers** are developed and production and marketing is increased (at competitive prices);
- Sufficient **filling and charging points** are available to consumers, i.e. a network of filling or charging stations is developed;
- **Consumers** are interested to buy these vehicles and fuels/energy carriers.

The first four bullet points are related to ensuring supply, the last point to demand.

Furthermore, policies should be timely, and aligned with the development phase of the technologies at hand.

As mentioned in the introduction of this chapter, the main EU policies directly related to the vehicle GHG emissions regulations are the following:

- The EU ETS covers the CO_2 emissions of large-scale electricity generation and hydrogen production which is mainly relevant for electric and hydrogen vehicles;
- The RED sets a target for renewable energy deployment, and thus provides incentives for biofuels, electric and (to some extent) hydrogen vehicles;
- The FQD sets a target for the GHG intensity of energy carriers used in the transport sector, and can thus provide incentives for low-carbon fossil fuels such as CNG and LNG, as well as for biofuels, electric and (depending on the production route of the hydrogen) hydrogen vehicles.

When combining these three with the vehicle CO_2 emission regulation, the EU policy package can cover part of the stakeholders involved in the transition to sustainable fuels. The stakeholders targeted by various policy instruments and their potential contribution to the transition to vehicles running on sustainable energy are listed in Table 19.

Table 19   Stakeholders targeted by various policy instruments and their potential contribution to the transition to vehicles running on sustainable energy

Policy	Actors targeted	Potential contribution to the transition to sustainable fuels and alternative drive trains
Vehicle emission regulation	Car manufacturers	Promote development and sales of cars that use low-carbon energy sources. Super-credits further strengthen this effect, albeit temporarily.
EU ETS	Electricity producers and fuel producers	Cap and reduce WTW CO2-emissions of electricity used in EVs
RED	Fuel suppliers and biofuels industry	Increase production and use of energy carriers from renewable energy sources (biofuels, electricity and hydrogen). Define sustainability criteria that biofuels have to meet. Double counting of biofuels from waste further promotes the use of these non-food biofuels.
FQD	Fuel suppliers (and, indirectly, biofuels industry)	Promote the use of low-carbon alternative energy sources, and define sustainability criteria that biofuels have to meet.

Important actors not directly targeted in this policy package are parties that develop and operate the infrastructure for electricity and hydrogen, and consumers – these policies focus on vehicle manufacturers and fuel/energy suppliers but do not drive the necessary changes further 'downstream', i.e. at the supply side of these developments.

This can be addressed in future policies, or, alternatively, in Member State, regional or local policies. Various EU countries already have policies in place aimed at this part of the transition:

- Fiscal measures (tax reductions), subsidies to promote the use of electric vehicles (and other vehicles with low emissions) are examples where national or regional/local policies are targeting consumers;
- Infrastructure developments, electric vehicle charging points, hydrogen filling points etc. are subsidized in various countries or regions/cities;
- A range of other advantages are in place throughout the EU, for example via green public procurement regulations, favourable treatment of specific technologies such as electric vehicles in parking policies, exemptions for vehicles with new propulsion systems, pilot projects, etc.

On EU level, the European Commission has recently published a proposal for a directive on the deployment of alternative fuels infrastructure (COM(2013) 18 /2), aiming to promote the development and rollout of the infrastructure of alternative fuels and energy carriers.

In addition, the EU provides funding to a number of R&D projects in this field, for example for the development of 2nd generation bioethanol processes and for various hydrogen demonstration and research projects. As was illustrated in Figure 56, this is typically a useful policy measure in the early phases of development.

This EU policy package thus addresses most of the actors involved in the transition, where some policies are already quite mature where others have only recently started to develop. Whether they are also effective, however, is more difficult to answer. For example, the on-going debate regarding ILUC in the sustainability criteria and GHG calculation tool significantly hampers the effectiveness of both the RED and the FQD, and has not yet led to many investments in biofuels from waste and residues production (except for some biodiesel production from used cooking oil). The EU ETS is still providing limited incentives to reduce CO_2 emissions of electricity, as EUA prices have been relatively low so far.

7.3.1 Specific benefits of combining other policies with vehicle emission regulations

Vehicle emissions regulations only regulate the emissions per kilometre driven. They do not cover overall emissions of these vehicles, as these also depend on other issues such as transport demand, i.e. on the total kilometres driven. Other policies are in place that control these:

- Fiscal policies of Member States, especially excise duties on fuels and electricity
- The EU ETS includes the CO_2 emissions of electricity produced for EVs and refinery emissions from the production of road fuels
- Other national policies such as road and congestion charging, spatial planning, etc.

In addition, as discussed extensively in this report, the current vehicle emission policies do not cover the upstream (well-to-tank) emissions of the fuels and energy carriers used.

On the other hand, the vehicle emission policy can be an effective means to address issues that other policies cannot address as effectively. The key benefit of this policy, compared to the others mentioned above, is that it can specifically aim to make the most use of the potential CO_2 mitigation options that require action by the car industry.

- Pricing policies such as vehicle and fuel taxes provide incentives to reduce fuel and energy use, and to buy fuel efficient cars. However, most consumers do not take the full lifetime costs of the vehicles they buy into account, so that they often do not realise that certain up-front investments in fuel efficient cars are recovered during the lifetime of the cars. This type of market failure results in the situation that consumers do not always chose the most cost-effective (also from an environmental view) option (See [Naturvårdsverket 2008] for a more detailed assessment of the pros and cons of combining fuel efficiency regulation with emissions trading in transport).
- The ETS, RED and FQD do not address car manufacturers, or give them incentives to invest in R&D for and production of new technologies for sustainable energy carriers. They will only do that when they anticipate that consumer demand for these vehicles will increase in the future. The impact of these policies on vehicle demand is, however, rather uncertain and probably very limited, as the future CO_2 price in the ETS effect is uncertain, the RED only targets Member States and the FQD is aimed at fuels suppliers and Member States[24].
- The ETS does not include life cycle CO_2 effects of energy carriers, but only includes end-of-pipe emissions. Bioenergy is taken to be zero-emission. Upstream emissions are thus not included in the CO_2 price, which will cause a bias towards energy sources that cause upstream emissions rather than direct emissions. The FQD aims to address this issue as it uses well-to-wheel GHG intensities. Some of the options for the vehicle emission regulation that are assessed in this study can also address this issue.

Looking broader than the RED, FQD and ETS, this development may also require a range of other supporting policies to speed up developments or prevent undesired impacts, for example the development of charging standards, battery recycling regulations, etc..

Combining different policies can also resolve potential issues of split responsibilities and incentives. Different actors are involved in the decarbonisation of transport, and all have their own circle of influence, responsibility and expertise. For example, the vehicle emissions regulation only affects vehicle manufacturers. If they sell more electric vehicles (EVs), they will get credits for the low GHG emissions of these vehicles. However, a shift to electric vehicles also requires action (i.e. investments) from potential providers of charging points and possibly battery swap stations, as availability of charging points is a requirement for EV market uptake. These are typically the responsibility and expertise of other industry sectors than the car industry. These split responsibilities may thus be a good reason to combine emission regulation with policies that promote the necessary, related actions in the other sectors.

As an example of split incentives, we can look at the benefits that low emission conventional (ICE) cars provide. First of all, they can reduce CO_2 emissions, which benefits society as a whole (by

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[24] The RED could encourage Member States to implement national policies to promote these new vehicle technologies, and thereby have an indirect impact on that industry. This would, however be only indirect and somewhat uncertain (as national policies tend to change over time), and it would not be a harmonized and coordinated approach within the EU.

reducing climate change impacts) and reduces the CO_2 mitigation to be achieved in other sectors to meet the overall CO_2 reduction goals. In addition, they provide financial benefits to car owners during use (lower cost per km), and they reduce the potential impacts of an increasing oil price on the economy. This example illustrates that whereas the car manufacturers may be faced with additional costs and investments to develop and market more fuel efficient cars, other stakeholders may benefit. Without a vehicle emission regulation, these benefits to others would not be considered by car manufacturers in their decision whether or not to reduce the CO_2 emissions of their vehicles.

Therefore, one of the key benefits from combining other policies with vehicle emission regulations is that it is difficult, if not impossible, to design one single policy that effectively promotes all different CO_2 mitigation options in transport. Every policy has its own pros and cons, focusses on a specific set of reduction options and is aimed at only part of the actors involved in the process. Only by combining different policy options effectively can the full playing field be covered.

7.4   Conclusions

The CO_2 regulation for passenger cars is part of a broader package of climate-related policies in transport. The EU-ETS, FQD and RED are the main EU-policies with which this regulation interacts. The recent Commission proposal for a directive on the deployment of alternative fuels infrastructure also has the potential to be an important addition to this package. On a national and even regional/local policy level there is a relationship with vehicle and fuel taxation, and in some cases with road charging, city access or parking policies.

Looking at the decarbonisation of transport, various reasons can be identified to have various related policies in place, rather than one overarching policy or several separate, unrelated policy measures. There are quite a number of stakeholders involved in this transition, and these all have to move towards the same direction, in a coordinated way. Some actions, for example R&D of batteries for electric or hybrid electric vehicles and biofuels production processes for woody biomass streams need to be carried out first, before an option is mature enough for large scale market take-up. Car manufacturers need to develop and market vehicles that run on these low-carbon energy carriers. The power sector (or local governments) will need to provide charging points, oil companies need to put new fuels on the market. Consumers will have to get used to the new technology. Governments (partly EU, partly national) will have to develop the necessary technical standards, and provide effective incentives to support these developments and a robust policy framework to provide the right boundary conditions for the market.

Vehicle emissions regulations specifically target the car manufacturers, and can thus be an effective means to drive developments in that sector and to make sure that efficient vehicles are offered. Combining this with a range of other policies, directed at other stakeholders and promoting the longer-term R&D efforts, can then make sure that required infrastructures are implemented in time and that customer demand is stimulated, thus increasing the longer term effectiveness of the emission regulations.

8 Interaction between CO_2 regulation and the FQD and EU-ETS

8.1 Introduction

As was discussed in chapter 0, the CO_2 regulation of cars is implemented in the context of a wider policy package aimed at reducing GHG emissions of the EU Member States. Looking at this package, there is some overlap between the current CO_2 regulation and the non-transport climate policies, specifically the ETS, but this is mainly limited to electric vehicles and possibly hydrogen (depending on the production method), and refinery emissions. All passenger cars contribute to the CO_2 reduction target of cars, as well as to the CO_2 reduction target for transport fuels as defined in the Fuel Quality Directive (FQD[25]) and to the renewable energy target for transport as defined in the Renewable Energy Directive (RED[26]). In addition, a shift to electricity in transport will impact on the EU Emission Trading System (ETS), as the electricity production is part of this system. As EV shares increase, effectively part of the road transport emissions are transferred from a non-capped sector to a capped sector. The share of electric cars is still very limited, but if it becomes significant in the future, the interaction between these policies will increase as well.

If a well-to-wheel emission approach would be chosen in a future CO_2 regulation, it can be expected that this interaction will increase further.

- The WTW emissions of fossil fuels are also regulated in the FQD. This means that the WTW emissions of the fuels of conventional cars can be expected to reduce over time.
- The WTW emissions of centralised (i.e. large scale) electricity generation is covered in the ETS[27]. The result is that the GHG intensity of the electricity used in transport is likely to reduce over time.
- The GHG emissions of hydrogen production for transport will also be covered by the ETS if this is done at centralised production sites (using gas reforming), or if it is produced from electricity from centralised power plants[28].
- Renewable energy and other types of energy with low GHG emission intensity are incentivised in the RED, the FQD and the ETS. If the CO2 regulation allows to take into account actual GHG emissions of the fuels and energy carriers, this policy can provide an additional incentive to renewable energy deployment.

Whereas chapter 0 discussed from a more top-down point of view how different policy instruments might work together to promote the transition to more sustainable vehicles and energy carriers, in this chapter the interactions between existing policy instruments will be discussed and assessed in further detail. It is assumed here that the FQD, ETS and RED policies are all extended beyond 2020, in the current form. It is not yet clear if this will indeed be the case, and any post-2020 targets are still unknown. Nevertheless, the pros and cons of these policy interactions can be assessed, in a qualitative way. The key issue of this analysis is whether the combination of the various regulatory approaches for the CO_2 regulation with these policies would lead to undesired side effects or impacts, or whether it will rather supplement and strengthen the existing regulations.

8.2 Interaction with the FQD (and RED)

The FQD and RED will affect the WTW CO_2 emissions of the fuels and energy carriers used in transport: both the average and the emissions of the individual fuels and energy carriers are likely to reduce over time due to these regulations, where some will reduce faster than others. This will impact the well-to-wheel CO_2 emissions of cars, and therefore will interact with the CO_2 regulation, if a WTW approach is implemented in the future.

Reverse impacts are also to be expected: if the CO_2 regulation results in increased shares of alternative fuel vehicles, the average WTW GHG intensity of the fuels, regulated in the FQD, is

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[25] DIRECTIVE 2009/30/EC, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009L0030:EN:NOT
[26] DIRECTIVE 2009/28/EC, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009L0028:en:NOT
[27] Strictly speaking, only the electricity production emissions are covered in the ETS, not the upstream emissions due to e.g. gas production or coal mining. These are about 5% of production emissions in case of electricity from fossil sources.
[28] Small-scale, decentralised hydrogen production may not be part of the ETS, as it only covers larger industries and electricity production.

affected – even in the current CO_2 regulation where GHG intensity is not taken into account. For example, a shift from conventional to battery electric vehicles will cause a shift from diesel or petrol (currently with an average GHG intensity of 88.3 gCO_{2eq}/MJ) to electricity. Electricity is currently included as zero emission in the CO_2 regulation, but the European Commission's FQD draft proposal of October 2011 suggested that the actual WTW emission factors of the Member States are used in the FQD. When these are lower than the values for conventional fuels, this shift will contribute to meeting the CO_2 reduction target of the FQD.

This interaction is illustrated in Figure 57 below. This figure shows rough estimates of the reduction of the WTW GHG intensity of transport fuels for increasing shares of battery electric vehicles, in 2030 in the EU. Emission factors of fossil fuels and electricity are taken from section A.2, and it is assumed that the energy efficiency of electric vehicles is about 2.5 times that of conventional vehicles. For simplicity, we only look at full EVs here, i.e. not plug-in hybrid electric vehicles or EREVs – the effects of these vehicles will be similar in general terms, but GHG intensity reductions will be less.

In Figure 57, the GHG intensity of fuels for the passenger car fleet is shown, for varying shares of these EVs. As the emission factor of electric cars (per MJ) in 2030 is predicted to be about 35% of that of fossil fuels, a 50% share of EVs would result in about 43% GHG reduction. The contribution of these cars to the GHG intensity of all road transport fuels (for which the FQD target applies) is, however, less. When we assume a share of about 52% of passenger cars in the total road transport energy use in 2030, we get the results shown by the blue line in Figure 57: a 50% share of electric passenger cars in the EU fleet would contribute to a reduced GHG intensity of energy for transport by about 22%.
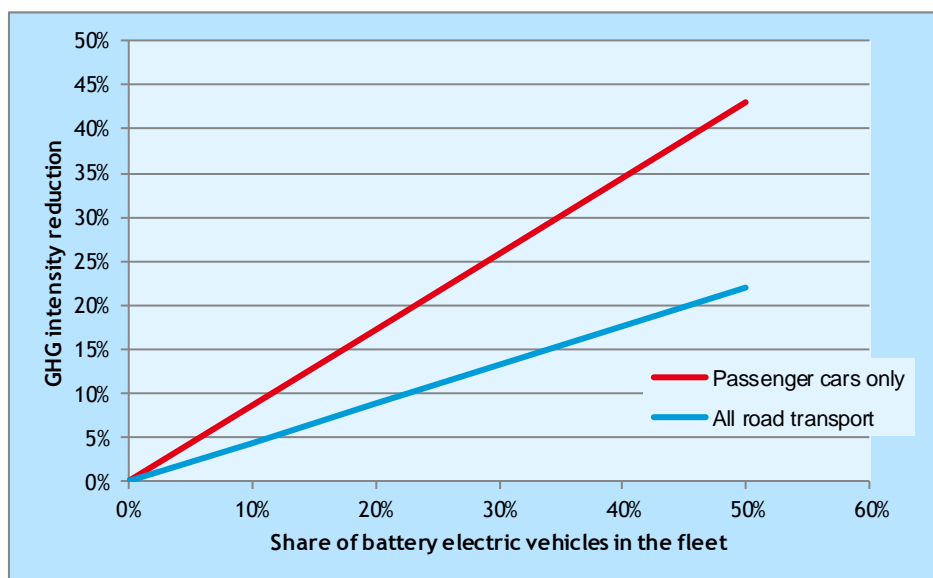
Figure 57   Potential impact of an increasing share of battery electric vehicles in the passenger car fleet on the **GHG intensity of the transport fuels for passenger cars** and on the **GHG intensity of all fuels for road transport** in 2030

Similar effects will occur with other fuels or energy carriers with low WTW emissions, such as hydrogen from renewable energy or methane (CNG or LNG). If the CO_2 regulation causes a shift towards vehicles that run on these energy sources, the WTW GHG intensity of transport fuels will reduce. The lower the GHG emissions of the alternative energy carriers, the stronger this effect will be.

8.3   Interaction with the EU ETS

CO_2 that is emitted due to electricity production for use in electric vehicles will be part of the EU ETS. This means that it is included under the emission cap of the ETS system and CO_2 emission allowances have to be submitted for each ton of CO_2 emitted additionally as a result of the additional electricity generation. As the emission cap reduces over time, this also means that the emissions of

electricity production are likely to reduce over time[29]. Together with the renewable energy targets of the RED, this can lead to the reduction trend of the CO_2 intensity of electricity production that is shown in section A.2, Table 59.

In addition, the EU ETS may have an impact on the passenger cars market and the uptake of EVs, as it adds a CO_2-price to the electricity and thus increases electricity costs (it does the same to a lesser degree to fuel costs). This increases the TCO of EVs, and makes them somewhat less competitive with conventional vehicles. However, this effect is currently very small, as the price of an emission allowance is relatively low (about 4-5 €/ton CO_2, status June 2013[30]). The price of emission allowances is predicted to increase in the future, but the decarbonisation scenarios of the Roadmap 2050 illustrate that the electricity price will depend only partly on ETS price, next to cost of renewable energy and CCS, and high fuel prices [EC 2011]. To illustrate this: In the Baseline 2009 [EC 2010], the ETS auction payments account for 9.4% of the average pre-tax electricity price. However, the more investments in renewable energy, the less CO_2 allowances have to be bought. In the more recent decarbonisation scenarios of the Energy Roadmap 2050 (EC, 2011), the impact of ETS allowances on electricity prices remains limited, as significant efforts are put into decarbonisation of the sector. In all these scenarios, the costs related to ETS auction payments decrease substantially after 2030 – in fact, electricity prices are predicted to decrease after 2030 in all but one decarbonisation scenario.

Looking at these assessments, we conclude that the impact of the ETS on the TCO of electric cars (and thus on the uptake of these cars) will be very limited. Decarbonisation measures may first increase cost of electricity in the period until 2030, after which prices are expected to reduce again [CE 2011].

The potential impact of the CO_2 regulation on the ETS, however, could be quite significant, when electricity demand from the sector increases and the ETS is not adapted to compensate for electrification of transport. Once the electricity demand increases, the price of CO_2 emission allowances will increase as the CO_2 emissions in the ETS are capped. This will have a positive effect on implementation of CO_2 reducing measures – more costly measures will become competitive. However, it may have a negative impact on the industries within the ETS, especially on those that compete with industries outside the EU. This impact could be reduced by increasing the emission cap (i.e. the number of allowances) accordingly (CE Delft, 2011). In the short to medium term, however, the additional electricity demand from the transport sector is negligible and therefore also the impact on the ETS and the price of emission allowances.

If the cap is not increased, the additional CO_2 emissions resulting from electricity production for electric vehicles will have to be compensated by CO_2 reductions elsewhere in the ETS, or with JI or CDM measures (assuming that these are effective, and continued after 2020). However, if the cap is increased as a response to electrification of transport – a likely scenario for the future – and/or JI and CDM are not fully effective, the upstream emissions of the electricity generation cannot be considered to be zero (an assertion that is in any case debateable as discussed in section 3.3.1).

In addition, the CO_2 regulation could reduce the potential impact of transport electrification on the ETS allowance price, if it increases energy efficiency of electric cars, and thus reduce the additional electricity demand. This will be the case in the WTW CO_2-based approach and the energy-based approaches discussed in this report.

Whether or not the CO_2 regulation is adapted to a WTW GHG or energy-based approach does not significantly affect these mechanisms, but some impacts can be identified. Firstly, the various approaches explored in this report may lead to different shares of electric vehicles. In general, it can be concluded that the larger the share of EVs, the more electricity will be used, and the more the potential impact on the ETS will be. Secondly, as mentioned above, regulatory options that improve the energy efficiency of the vehicles that drive on electricity will reduce this additional electricity demand, and therefore the impacts on the ETS[31].

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[29] The reductions may also take place in other industries under the EU ETS or using mechanisms such as CDM and JIP, but is it generally expected that the electricity sector will contribute significantly to these reductions.
[30] Source: www.eex.com
[31] Provided potential rebound effects are addressed, so that efficiency improvements do not lead to an increase of total car transport demand, see chapter 13.

8.4 Other policy interactions

Besides the EU policies described above, CO_2 regulation of passenger cars is also related to a number of fiscal policies on EU and (especially) Member State level:

- passenger car taxation such as registration tax, circulation tax, road and congestion charging, company and lease car taxation, etc.;
- fuel taxation.

In an increasing number of EU Member States vehicle taxes are directly related to the CO_2 emission of cars as measured on the type approval test. This has proven to be an effective means to promote the sales of more fuel efficient cars and to reduce national CO_2 emissions, and it is also a strong support to the car industry's efforts to meet the CO_2 targets set by the regulation. Implementing a well-to-wheel approach to the CO_2 regulation and thus the type approval system will then also result in a WTW approach of the vehicle taxation systems, assuming they will remain to be linked to the type approval emissions. This can be expected to have a positive impact on CO_2 emissions, assuming that the changes in the CO_2 reduction will lead to a more realistic representation and control of the of real-life, well-to-wheel emissions of vehicles.

In some EU countries, fuel taxation is partly based on CO_2 emissions, but this is not yet a very common approach. This might change in the coming years, however, as the European Commission has issued a proposal which would oblige Member States to differentiate fuel excise duties to CO_2 emissions, to some extent. The approach taken in that proposal would be in line with most of the approaches studied in this report, as it would take WTW emissions into account, not just vehicle emissions.

8.5 Double counting and double regulations

When designing a policy package, there is often some debate about whether it is justified and effective to have a number of policy measures in place to regulate a specific part of the market. The issues discussed are often related to two potential issues: double counting and double regulations.

The first issue is a concern that certain emissions (or emission reduction efforts) are counted towards various goals and targets, and are thus 'counted double'. For example, the emissions of electric cars are already part of the EU ETS, and count towards the emissions of the electricity sector. In addition, they are counted towards the FQD target for GHG emission reductions of transport fuels. Would it then be fair to also count them in CO2 regulations for cars?

Double counting is an issue if this occurs in one regulation, or in a calculation methodology for one single target. For example, care should be taken that the electric vehicle emissions and energy use are not counted twice in national or EU emission and energy inventories. This could happen when they are included in inventories for both the transport and the electricity sectors.

However, the EU ETS and the FQD targets are separate targets and policy measures, and all are aimed at different goals and stakeholders. Therefore, there is no problem including these emissions in all of them. As discussed earlier, in chapter 0, it can increase the effectiveness of this policy package if all stakeholders are subject to related but separate policy measures, which all point towards the same direction (in this case, decarbonisation of the transport sector and the overall energy system).

Double regulation can become an issue if specific stakeholders are faced with two related but different policy measures and targets. An example would be the FQD target for fuel suppliers (a measure on EU-level), in combination with a renewable energy or biofuels obligation for fuel suppliers (a policy measure implemented by various EU Member States, in their aim to meet their RED target for transport). These policy measures both relate to road transport fuels, and increasing the share of renewable energy in their fuels will contribute to both targets. They also set the same minimum sustainability criteria for biofuels to count towards these targets. However, both directives look at different characteristics of the biofuels: the renewable energy or biofuel obligations sets effectively a volume target (within the boundary conditions of the sustainability criteria), whereas the FQD also takes WTW CO_2 emissions of the energy carriers into account. Furthermore, both directives use different calculation methodologies as a basis, for example biofuels from waste and residues count

double towards the RED target, but not towards the FQD target. This combination of two related but different policies makes it quite complex for fuel suppliers to find the most cost effective way to meet both obligations.

In this example it may, however, also be argued that both policies aim to contribute to two different goals: one is to promote the use of renewable energy, the other is to reduce the WTW GHG emissions of the fuel. These are both crucial parts of the decarbonisation efforts, linked but not the same. If only one of these would be implemented, the other might not develop as much as needed to meet the future goals of the sector.

It can thus be concluded that a WTW approach of the CO_2 regulation would not create risks regarding double counting or double regulations, if the right boundary conditions are taken into account.

- A whole package of EU and national policies is in place that relate to and interact with the CO_2 regulation. However, modifying the metrics of the regulation would affect car manufacturers only and does not directly interact with other EU policies that affect this group of stakeholders. It may increase the interaction between this policy and the ETS, FQD and RED, but as these have separate targets it is not expected that this will create problematic double counting or double regulation issues,
- Care should be taken, however, that in national and EU statistics, the well-to-tank emissions and energy use of the transport fuels and energy carriers are not counted towards more than one sector. For example, the emissions of power production for electric vehicles should not be counted towards both the transport sector and the power production statistics. The same holds for the well-to-tank emissions of petrol and diesel: these are typically also included in the emission data of refineries, shipping, crude production, etc.

8.6   Conclusions

There is an interaction between the CO_2 regulation for cars and vans and other EU policies, and this interaction is likely to increase if WTW emissions of the fuels and other energy carriers are to be included in the regulation. Especially the FQD, RED and EU ETS are relevant policies in this respect. First of all, these policies have an impact on the WTW emissions of the various energy carriers, as they can be expected to reduce these emissions over time. In addition, the FQD and RED both provide additional incentives for electric cars, although this impact is currently considered to be very limited. The ETS may hamper the uptake of electric cars to some extent, as it adds a CO_2 price on electricity production. If electricity demand of the transport sector increases, there is a risk that this will increase the CO2-price if the emission cap of the ETS is not adapted accordingly. This impact is, however, considered to be limited.

Alternatively the emission regulation will also impact these policies, as it may help to bring the vehicles on the market that use low-carbon energy carriers such as electric cars. This will contribute to both the FQD and the RED targets. It will also impact the ETS, as it may increase the price of CO_2 emission allowances once the electricity demand increases, unless the ETS cap is increased accordingly over time. In the short to medium term, these impacts are expected to remain very limited.

In addition, it is worth noting that if the metric in the vehicle regulation is changed, a number of national policies can be adapted as well. For example, vehicle taxation is often based on the CO_2 emissions of cars as measured during type approval. If these would be based on WTW emissions of the energy carriers, their effectiveness would improve.

Regarding potential issues of double counting or double regulations, it is concluded that a WTW approach of the CO_2 regulation would not create significant risks or negative side effects. This policy would affect car manufacturers only and does not interact with other policies that affect this group of stakeholders. Care should be taken, though, that in national and EU statistics, the well-to-tank emissions and energy use of the transport fuels and energy carriers are not counted towards more than one sector.

9 Greenhouse gases to be included

9.1 Introduction

9.1.1 Objectives and aims of this chapter

The purpose of this chapter is to assess whether there is a need to include greenhouse gases (GHGs) other than CO_2 in the coverage of the regulatory approach. This assessment has been undertaken for the different regulatory approaches.

A summary of the different regulatory approaches, described in chapter 2 and analysed in chapters 0 to 6 is given in Table 20.

Table 20   Summary of the different regulatory approaches considered in this project

General approach	Details of variant	Type of approach
a) Vehicle CO_2 emissions	a.1 Tailpipe CO_2 emissions as in existing Regulation (= TTW CO_2 emissions)	Regulatory approach with metric based on CO_2 emissions
	a.2 Tailpipe CO_2 emissions for ICEVs with exclusion of zero emission vehicles	
	a.3 Tailpipe CO_2 emissions with notional GHG intensity for zero emission vehicles	
	a.4 Tailpipe CO_2 emissions adjusted to take account of WTW emissions (= WTW CO_2 emissions)	
b) Vehicle energy use	b.1 Energy used by the vehicle per vehicle/km (= TTW energy consumption)	Regulatory approach with metric based on energy used
	b.2 Energy use per vehicle/km adjusted for WTW consumption (WTW energy consumption)	
c) Inclusion of road fuel use in EU ETS		Economic instrument
d) A vehicle manufacturer based trading scheme based on lifetime vehicle GHG emissions	trading scheme associated with a vehicle-based target	Regulatory approach
e) A cap and trade system for vehicle manufacturers, of total CO_2 emissions of vehicles sold (expressed in g/km)		Regulatory approach
f) The possibility to include embedded emissions in the WTW approaches listed above will also be assessed		Regulatory approach
g) Combining different options with mileage weighting		Regulatory approach

Given the possible metrics above, this study considered for a range of different powertrain options and energy carriers, the following types of greenhouse gas emissions:

- Tailpipe (i.e. tank-to-wheel, TTW) emissions of CO_2

- linked to energy consumption for vehicles with ICE, but not for those using external electricity (BEV, PHEV, etc.) or non-hydrocarbon fuels (e.g. FCEV)
- Tailpipe (i.e. TTW) emissions of other GHG gases
- Upstream (i.e. well-to-tank, WTT) GHG emissions
  - which, when combined with TTW emissions, give the well to wheel (WTW) emissions
  - linked to energy consumption for all vehicles.

Coolants used in mobile air conditioners (MACs) are also powerful greenhouse gases. These are excluded here as they are not directly related to the propulsion of the vehicle and are covered by existing regulation[32].

9.1.2   Delimitations

The undertaking of a life cycle assessment (LCA) to calculate the greenhouse gases emitted by a vehicle when it is driven, is a vast technical area. Much research into LCA has been completed and published, and more is continuing. Hence there are a considerable number of relevant authoritative papers in the public domain. This study draws on these to undertake the assessment defined in the study's objective, rather than to undertake further original LCA research.

9.1.3   Structure of this chapter

Following this introductory section the chapter is structured to address:

- the overall methodology, and the IPCC guidance on the preparation of GHG inventories from road transport;
- the scope of the study, in terms of the range of powertrains and energy carriers to be considered;
- the tank-to-wheel (TTW) GHG emissions for different powertrains and energy carriers;
- the well-to-tank (WTT) GHG emissions for different powertrains and energy carriers;
- the well-to-wheel (WTW) GHG emissions for new technologies, and
- then provides some conclusions and recommendations.

9.2   Approach

9.2.1   Overall methodology

The opening paragraph of EU Regulation 510/2011, and the second paragraph of EC Regulation 443/2009 sets the context for the emissions performance standards by stating: "*The United Nations Framework Convention on Climate Change seeks to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.*"

The use of light duty vehicles generates greenhouse gases. These can be quantified using a whole life cycle assessment. For fossil fuels this involves the extraction, refining, distribution and end use of the petroleum products. For other energy carriers there are analogous whole life cycle assessments. This whole life assessment is often referred to as the **Well-to-Wheel** (WTW) life cycle. For vehicles this can be divided into the **Well-to-Tank** (WTT) component (comprising the extraction, refining and distribution for fossil fuels) and the **Tank-to-Wheel** (TTW) component (comprising the tailpipe emissions). The current light duty vehicle regulations only relate to the **Tank-to-Wheel CO_2 emissions**. In this section we assess whether this focus on CO_2 only will remain appropriate after 2020, when additional powertrains and energy carriers become more important in the fleet in addition to the current dominance of fossil fuelled internal combustion engines and when the metric could possibly be changed from Tank-to-Wheel to Well-to-Wheel.

9.2.2   IPCC definitions of GHG and their global warming potential

The IPCC summarise the long-lived greenhouse gases (LLGHGs), and their current concentrations, as shown in Table 21[33].

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[32] MAC Directive 2006/40/EC and further regulation in preparation.
[33] Copied directly from Table 2.1 of IPCC Fourth Assessment report on Climate Change 2007 (AR4) Chapter 2, available from http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf

The same quantity (mass) of different greenhouse gases leads to different amounts of global warming (or different climate forcing). This is related to the relative amounts of radiation that they absorb, reflect and/or radiate back from the earth's surface, and the period of time over which this typically occurs. For example, for road transport two of the greenhouse gases emitted by vehicles are methane and CO_2. Methane absorbs more radiation than CO_2. However, methane also reacts in the atmosphere, being oxidised to CO_2 and water vapour, whereas CO_2 does not react, though it is involved in the carbon cycle which sustains life on earth. Consequently, the relative impact of a quantity of methane when assessed over a short period of time is greater than its longer term impact, because its concentration diminishes. The IPCC recommendation on the appropriate methodology to use when comparing different greenhouse gases is to use their **global warming potential (GWP)** relative to CO_2, when assessed over 100 years. Some key GWPs are given in Table 22.

Table 21   Summary of IPCC listed LLGHGs with their present day concentrations and radiative forcing parameters (at the given 2005 concentration levels)

Species[a]	Concentrations[b] and their changes[c]		Radiative Forcing[d]	
	2005	Change since 1998	2005 (W m^{-2})	Change since 1998 (%)
CO_2	379 ± 0.65 ppm	+13 ppm	1.66	+13
CH_4	1,774 ± 1.8 ppb	+11 ppb	0.48	-
N_2O	319 ± 0.12 ppb	+5 ppb	0.16	+11
	ppt	ppt		
CFC-11	251 ± 0.36	−13	0.063	−5
CFC-12	538 ± 0.18	+4	0.17	+1
CFC-113	79 ± 0.064	−4	0.024	−5
HCFC-22	169 ± 1.0	+38	0.033	+29
HCFC-141b	18 ± 0.068	+9	0.0025	+93
HCFC-142b	15 ± 0.13	+6	0.0031	+57
CH_3CCl_3	19 ± 0.47	−47	0.0011	−72
CCl_4	93 ± 0.17	−7	0.012	−7
HFC-125	3.7 ± 0.10[e]	+2.6[f]	0.0009	+234
HFC-134a	35 ± 0.73	+27	0.0055	+349
HFC-152a	3.9 ± 0.11[e]	+2.4[f]	0.0004	+151
HFC-23	18 ± 0.12[g,h]	+4	0.0033	+29
SF_6	5.6 ± 0.038[i]	+1.5	0.0029	+36
CF_4 (PFC-14)	74 ± 1.6[i]	-	0.0034	-
C_2F_6 (PFC-116)	2.9 ± 0.025[g,h]	+0.5	0.0008	+22

Table 22   Lifetimes and direct global warming potentials (GWPs) relative to CO_2 for important GHGs for transport[34]

Species	Chemical formula	Lifetime (years)	100-yr global warming potential
Carbon dioxide	CO_2	Complex function[35]	1 (by definition)
Methane	CH4	12	25
Nitrous oxide	N_2O	114	298

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[34] Taken from Table 2.14 of IPCC Fourth Assessment report on Climate Change 2007 (AR4) Chapter 2, available from http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf

[35] Note a to this table in the IPCC guidebook states:

   a   The CO_2 response function used in this report is based on the revised version of the Bern Carbon cycle model used in Chapter 10 of this report (Bern2.5CC; Joos et al. 2001) using a background CO_2 concentration value of 378 ppm. The decay of a pulse of CO_2 with time t is given by

$$a_0 + \sum_{i=1}^{3} a_i \cdot e^{-t/\tau_i}$$

Where $a_0 = 0.217$, $a_1 = 0.259$, $a_2 = 0.338$, $a_3 = 0.186$, $\tau_1 = 172.9$ years, $\tau_2 = 18.51$ years, and $\tau_3 = 1.186$ years.

The GWP compares GHGs by mass, such that from the table above 1 kg of methane is equivalent to 25 kg of carbon dioxide, and 1 kg of nitrous oxide is equivalent to 298 kg of carbon dioxide.

9.2.3   GHGs important for road transport

The 2006 IPCC guidelines for the preparation of national greenhouse gas inventories from the combustion of fuels for mobile applications are given in Chapter 3 of Volume 2 (Energy)[36]. The opening sentence of the overview is: "*Mobile sources produce direct greenhouse gas emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from the combustion of various fuel types, as well as several other pollutants such as carbon monoxide (CO), Non-Methane Volatile Organic Compounds (NMVOCs), sulphur dioxide (SO_2), particulate matter (PM) and oxides of nitrate (NOx), which cause or contribute to local or regional air pollution.*" It also comments, in the opening paragraph: "*This chapter does not address non-energy emissions from mobile air conditioning, which is covered by the IPPU Volume (Volume 3, Chapter 7).*"

The IPCC methodologies for calculating the CO_2, CH_4 and N_2O emissions cover **only the tank-to-wheel contribution from analysis of the tailpipe emissions**. However, this does not mean that the well-to-tank contribution is omitted from national inventories. These emissions are included in the various appropriate industrial and other sectors, for example in petroleum extraction and refining, or in electricity production. The emissions caused by the delivery of petroleum products is accounted for in the mobile transport section of the inventory.

9.3   Scope of this study

9.3.1   Species included

From the IPCC guidelines discussed in Section 9.2.3 the three GHGs focused on in this study are:

- carbon dioxide (CO_2)
- methane (CH_4) and
- nitrous oxide (N_2O).

Recent research is uncovering the importance of "black carbon" to climate change. This is also known as soot, or elemental carbon. There are two different mechanisms, one involving direct absorption of radiation by aerosol black carbon, and the other involving the change in albedo of snow and ice, which is particularly important for polar-regions. Vehicles are a significant source of black carbon emissions. The principal objective of this task is to consider greenhouse gases to be included and the methodology principally assesses the current IPPC guidelines for quantifying GHG emissions from road vehicles. At present this does not include black carbon. It is therefore suggested that whilst this is an important species that potentially could be included, until either it is included in GHG inventories or there is a consensus methodology developing regarding its inclusion, it is not considered as a climate forcing emission from vehicles that should be regulated at the current time.

Emissions of GHG compounds used in mobile air conditioning (MAC) are not covered. This is not because these are deemed unimportant but because currently it is not expected that changes to the mix of powertrain / primary energy carrier technologies used by vehicles post 2020, will affect the types of MAC systems used. Consequently, it is expected that the GHG emissions from MAC systems will evolve, irrespective of the powertrains/energy carriers of the future, and, as mentioned above they are covered by a different piece of legislation.

9.3.2   Range of powertrains included

This study involves assessing the GHG emissions for different powertrains. Those considered are:

- Conventional ICE vehicles
- Hybrid ICE vehicles, including two main classes
    - o   charge sustaining hybrids

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[36] Chapter 3 of Volume 2 (Energy) of 2006 IPCC Guidelines for National GHG Inventories is available from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf

   o   plug-in electric hybrid vehicles (PHEV) and extended range electric vehicles (EREV)
- Full electric vehicles
- Fuel cell vehicles

In practice there will be a number of additional powertrain developments in various of these categories, specifically including improved ICE efficiency caused by any one of a number of advanced technologies. However, the GHG emissions from these are generally covered within the four powertrain types listed above The only exception to this generality is where "improvements" in ICE efficiency (which can be viewed as a reduction in fuel consumption for the same mobility) lead to a different ratio of CO_2, N_2O, and CH_4 tailpipe emissions. This possibility is covered in Section 9.6.

9.3.3   Different energy carriers included

This study assesses the GHG emissions for the following energy carriers:

- Mainstream fossil fuels, petrol and diesel
- Alternative fossil fuels: LPG and natural gas as CNG or LNG
- Biofuels
- Electricity
- Hydrogen

In Section 9.2 it was noted that the current inventory methodologies for "mobile combustion" calculate the direct emissions of CO_2, CH_4 and N_2O emissions for the tank-to-wheel emissions. To provide a quantification of the life-cycle GHG impact of different types of vehicles this study will also consider the emissions arising before the energy carrier reaches the vehicle, the well-to-tank emissions. This provides an assessment of the consequences of only including the TTW CO_2 emissions in the coverage of the regulatory approach.

9.4   Tank to wheel (TTW) GHG emissions for different powertrains and energy carriers

The current regulatory metric for assessing the GHG emissions from light duty vehicles is the tank-to-wheel (TTW) CO_2 emissions from the vehicle. The principal focus of this section is to quantify the emissions of all GHGs that the IPCC guidelines say should be included, for the range of powertrains and energy carriers considered, and to assess whether there is a need to include the GHG other than CO_2 in the coverage of the regulatory approach. This assessment will be based on the ratio of the total GHG emissions (expressed in CO_2 equivalents) divided by the CO_2 emissions.

9.4.1   Mainstream fossil fuels: petrol and diesel, LPG and natural gas as CNG or LNG used in ICEVs

The methodology specified by the IPCC in their "Guidelines for national GHG inventories" for CO_2, assumes the quantitative conversion of fuel to CO_2. Hence its quantification requires the measurement of the fuel consumed. Alternatively, the CO_2 + CO + hydrocarbons can be quantified and all converted into the equivalent CO_2 emissions.

For calculating the CH_4 and N_2O emissions different methodologies are specified. These are to use either a fuel based (known as Tier 1) or a technology stratified (known as Tier 2) methodology.

The Tier 1 approach requires knowledge of the total fuel used. Emission factors, expressed in terms of mass of GHG species per TJ (10^{12} J) fuel used enable the emissions of GHGs to be calculated from the total fuel used. Emission factors are given in the IPCC handbook for gasoline, diesel, LPG and natural gas (methane) fuels when used in "average" ICEs[37]. Whilst this is not helpful to those compiling inventories from vehicle km data, the relative values, when combined with the GWP of each species, do enable the relative importance of the three species to be assessed. These data are summarised in Table 23.

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[37] See Table 3.2.1 of Chapter 3 of Volume 2 (Energy) of 2006 IPCC Guidelines for National GHG Inventories.

Table 23   IPCC Tier 1 emission factors for the three important GHGs from transport, their sum and ratio relative to the CO_2 emissions

Fuel	Emission factors (from IPCC guidelines)			Emission factors for CH_4 and N_2O as CO_2 equivalents			RATIO
	CO_2 kg/TJ	CH_4 kg/TJ	N_2O kg/TJ	CH_4 kg CO_2e/TJ	N_2O kg CO_2e/TJ	TOTAL CO_2e kg/TJ	Total CO_2e emissions / CO_2 emissions
Gasoline	69,300	25	8	625	2,384	72,309	104.34%
Diesel	74,100	3.9	3.9	97.5	1,162.2	75,360	101.70%
LPG	63,100	62	0.2	1,550	59.6	64,710	102.55%
CNG & LNG	56,100	92	3	2,300	894	59,294	105.69%

The Tier 2 emission factors for CH_4 and N_2O are given for the same fuels, but with values being specified for urban, rural and highway driving, and for vehicles built to meet pre-Euro, Euro 1, 2, 3 and 4 emission standards. Hence, the average emission factors used in the Tier 1 methodology are disaggregated according to type of driving and vehicle technology. In addition, different values are provided for cold and hot start urban driving[38]. The weighted average emission factors for this study were calculated using:

Average emissions = 10% cold start ECE value + 30% hot start ECE value + 60% EUDC value

This was chosen as being a moderately accurate proxy for the NEDC regulatory cycle. The composition of the NEDC is approximately 4 km urban driving, the ECE cycle, and 7 km rural driving, the EUDC cycle. Also, the average trip length is taken as around 10km for the UK inventory, i.e. one cold start occurs around every 10 km driven.

Data for the emissions of nitrous oxide and methane for gasoline passenger cars built to comply with five different emissions standards, for the four drive cycles are given in Table 24.

Table 24   IPCC Tier 2 emission factors for N_2O and CH_4 for gasoline fuelled passenger cars meeting different emission standards, when driven over different drive cycles

Vehicle emissions standard	Nitrous oxide (N_2O) emissions in mg/km				Methane (CH_4) emissions in mg/km			
	Cold ECE	Hot ECE	Rural	Highway	Cold ECE	Hot ECE	Rural	Highway
pre-Euro	10	10	6.5	6.5	201	131	86	41
Euro 1	38	22	17	8	45	26	16	14
Euro 2	24	11	4.5	2.5	94	17	13	11
Euro 3	12	3	2	1.5	83	3	2	4
Euro 4	6	2	0.8	0.7	57	2	2	0

From these, using the weighted average calculation given above, the GWP of Table 22 and the methodology illustrated in Table 23, the emissions can be calculated, expressed as CO_2 equivalents. If the estimated CO_2 emissions are 130 g CO_2/km for these gasoline vehicles, then these other GHG emissions can be expressed as a ratio to the CO_2 emissions. The 130 gCO_2/km in this example was chosen as this is the 2015 EC target for passenger cars. This is shown in Table 25.

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[38] See Table 3.2.5 of Chapter 3 of Volume 2 (Energy) of 2006 IPCC Guidelines for National GHG Inventories.

Table 25   GHG emissions calculated from IPCC Tier 2 emission factors of N_2O and CH_4 emitted from gasoline fuelled passenger cars meeting different emission standards, and the ratio of these to the CO_2 emissions

Vehicle emissions standard	Weighted avg N_2O emissions (mg/km)	Weighted avg CH_4 emissions (mg/km)	$N_2O + CH_4$ emissions gCO_2e/km	Estimated CO_2 emissions gCO_2e/km	Ratio of $(N_2O+CH_4)/CO_2$ emissions
pre-Euro	7.9	111	5.13	130	3.95%
Euro 1	20.6	21.9	6.69	130	5.14%
Euro 2	8.4	22.3	3.06	130	2.35%
Euro 3	3.3	10.4	1.24	130	0.96%
Euro 4	1.68	7.5	0.69	130	0.53%

From the table, as anticipated, the ratio of the non-CO_2 GHG emissions to the CO_2 emissions is found to be technology dependent. However, what is also noticeable is that the emissions of the two key compounds reduce with less polluting (higher Euro standard) vehicles. Since any future GHG regulations will apply only to new vehicles, the key relevant data are for Euro 3 and 4 standard vehicles, rather than the historical fleet. For modern gasoline passenger cars Table 25 shows that the contributions from N_2O and methane to overall TTW GHG emission are less than 1%.

This methodology was used to calculate the emissions of N_2O and CH_4 for Euro 3 and 4 vehicles (expressed as CO_2e) for different fuels, and the ratio of this relative to the CO_2. These are given in Table 26. Emission factors for natural gas (methane) fuelled light duty vehicles are not given in the IPCC Tier 2 emission factor tables.

Table 26   GHG emissions calculated from IPCC Tier 2 emission factors for N_2O and CH_4 for vehicles meeting Euro 3 & 4 emission standards, and the ratio of this to the CO_2 emissions

Fuel - vehicle	Estimated CO_2 emissions gCO_2e/km	Euro 3		Euro 4	
		$N_2O + CH_4$ emissions gCO_2e/km	Ratio of $(N_2O+CH_4)/CO_2$ emissions	$N_2O + CH_4$ emissions gCO_2e/km	Ratio of $(N_2O+CH_4)/CO_2$ emissions
Gasoline cars	130	1.24	0.96%	0.69	0.53%
Diesel cars	120	2.01	1.67%	1.97	1.64%
LPG cars	120	2.40	2.00%	2.40	2.00%
Gasoline vans	190	2.01	1.06%	2.01	1.06%
Diesel vans	190	2.01	1.06%	1.97	1.04%

In addition to the Tier 2 methodology described in the IPCC guidelines for national inventories, another often used methodology is yet more sophisticated, and is known as a Tier 3 approach. This uses vehicle-km data, disaggregated by road type and vehicle type and emissions standard. Whereas the Tier 2 methodology used an average emission factor per road type, for example in units of mg CH_4/km, the Tier 3 methodology uses emission factors that are expressed as a function of speed.

Within Europe the calculation tool used most often to compile inventories is known as COPERT 4 (4 being the current version number). This software tool calculates air pollutant and greenhouse gas emissions from road transport. Its development is coordinated by the European Environment Agency. It was last updated in January 2009, and its methodology is totally consistent with that described in the 2006 revision of the IPCC guidelines for national inventories. However, it does draw on a wider range of databases, and it the most contemporary and sophisticated general GHG inventory tool available. Its predictions of the methane and nitrous oxide (GHG) emissions, relative to CO_2 emissions, were evaluated to see if they differed markedly from the Tier 2 data above.

Table 27 GHG emissions calculated using COPERT 4 model to calculate emissions of N_2O and CH_4 for vehicles meeting Euro 3 & 4 emission standards, and the ratio of this to the CO_2 emissions

Fuel - vehicle	Euro 3			Euro 4		
	Estimated CO_2 emissions gCO_2e/km	$N_2O + CH_4$ emissions gCO_2e/km	Ratio of $(N_2O+CH_4)/$ CO_2 emissions	Estimated CO_2 emissions gCO_2e/km	$N_2O + CH_4$ emissions gCO_2e/km	Ratio of $(N_2O+CH_4)/$ CO_2 emissions
Gasoline cars	191	0.68	0.35%	204	0.56	0.27%
Diesel cars	181	2.01	1.11%	181	1.98	1.09%
LPG cars	120	1.33	1.10%	120	1.33	1.10%
Gasoline vans	336	1.46	0.44%	336	0.59	0.18%
Diesel vans	239	2.01	0.84%	239	1.98	0.83%

These data do show systematic differences from the data in Table 26 in the following respects:

- The sum of the emissions of N_2O and CH_4 from gasoline and LPG fuelled vehicles when calculated by the COPERT 4 methodology is less than that calculated using the IPCC Tier 2 methodology by around two thirds;
- The sum of the emissions of N_2O and CH_4 from diesel vehicles when calculated by the COPERT 4 methodology is virtually identical to that obtained when calculated using the IPCC Tier 2 methodology;
- The CO_2 emitted, and hence fuel consumed, when calculated by the COPERT 4 methodology is around 40% higher to that obtained when calculated using the IPCC Tier 2 methodology.

Furthermore it should be noted that the CO_2 emission value for LPG, as calculated above, is unrealistically low. For equivalent petrol and LPG vehicles one expects the CO_2 emissions of the LPG variant to be 10% lower at best due to the lower C/H ratio of the fuel.

These factors combine to make the ratio of the non-CO_2 greenhouse gas emissions to the CO_2 greenhouse gas emissions calculated by the COPERT 4 methodology around 60% of those calculated by the IPCC Tier 2 methodology. For gasoline and diesel cars and vans, and LPG cars (5 fuel – vehicle type combinations) the average of the non-CO_2 GHG / CO_2 emissions ratio for Euro 4 vehicles is 0.7% from the COPERT 4 methodology and 1.25% from the IPCC methodology.

9.4.2 Use of biofuels in ICE powertrains

As for fossil fuels, the principles for assessing GHG emissions from biofuels are laid down by the IPCC. However, the methodologies for the accounting of GHG emissions from the use of biofuels differ from those for fossil fuels. In summary, biofuels are categorised as biogenic carbon sources, but their production as an anthropogenic activity. Consequently, tailpipe CO_2 emissions from the combustion of biofuels in mobile combustion are **not** included in national totals. However, the combustion of biofuels in mobile combustion **does produce** anthropogenic N_2O and CH_4 tailpipe emissions. These are included in the inventory for mobile combustion. This is summarised in the table below.

Table 28 The GHG emissions included in the inventory for the production of, and subsequent use of, biofuels (from IPCC guidelines)

Activity	Relevant IPCC Guidelines	CO_2	CH_4	N_2O
Crop production growing, and fuel production (Well-to-Tank portion of WTW)	Volume 4 Agriculture, forestry and other land use, and Volume 3 Industrial processes	√	√	√
Biofuel use in vehicles (Tank-to-wheel portion of WTW)	Volume 2 Energy, Chapter 3 Mobile combustion	X	√	√

In terms of emission factors, to first approximation the emissions of N_2O and CH_4 from vehicles using biofuels can be taken to be the same as when running on fossil fuels. These factors are given in Table 26 and Table 27.

9.4.3   Hybrids

The addition of hybrid technology improves the overall fuel efficiency of the vehicle, though by an amount that is drive cycle dependent. To a first approximation it can be assumed that the tailpipe emissions of N_2O and CH_4 from hybrid vehicles scale with the fuel usage and CO_2 emissions. Consequently, the contribution of non-CO_2 species to the GHG footprint, as a proportion of the CO_2 emissions **remains unaltered by the use of hybrid technology.**

9.4.4   Electric vehicles

The tank-to-wheel emissions from electric vehicles are zero – there being no tailpipe emissions. This applies to all three GHG gases, CO_2, N_2O and CH_4. Therefore, there is no need to include the TTW emission of non-CO_2 greenhouse gases in the coverage of the regulatory approach for electric vehicles. The impact of including well-to-tank emissions is discussed in the next section.

9.4.5   Hydrogen fuel cell vehicles

The absence of carbon in the hydrogen fuel leads to there being no CO_2 or CH_4 emissions from vehicles using hydrogen fuel cells. An assessment by CONCAWE, EUCAR and EC JRC [JEC 2011] says there are no N_2O emissions either[39]. Therefore, as for electric vehicles, there is no need to include the TTW emission of non-CO_2 greenhouse gases in the coverage of the regulatory approach for vehicles with a hydrogen fuel cell power source.

This would not apply to fuel cell vehicles running on hydrocarbons, e.g. methanol, by using an on-board reformer or direct reforming in the fuel cell. Currently however, such systems are not foreseen for passenger cars and vans.

9.4.6   Plug-in hybrid and extended range electric vehicles

Both plug-in hybrid electric vehicles and extended range electric vehicles use two energy carriers, a fuel for their ICEs and electricity from the grid. From Sections 9.4.1 and 9.4.4 it is seen that these have very different TTW GHG (and CO_2) emissions (typically around 80 – 150 g/km for ICE driving and 0 g/km for electric driving). The emissions from PHEVs and EREVs depend on the proportions of their use that are powered by these two different energy carriers. To a first approximation their TTW GHG emissions will be a weighted average of these. However, since the TTW GHG emissions from the EV portion is zero, this reduces to the following equations for the emissions of CH_4 and N_2O:

TTW GHG emissions (PHEV or EREV) = amount of carbon liquid fuel consumed x
             appropriate emission factor per unit fuel

or equivalently

TTW GHG emissions (PHEV or EREV) = amount of CO_2 emitted x
             appropriate emission factor per unit CO_2

The appropriate emission factors can be derived from those of comparable ICEVs, by dividing their CH_4 and N_2O emission factors by the fuel consumption per km or the CO_2 emission per km.

There may be some very small, subtle deviation from this because extended range EVs tend to only use a restricted region of the engine speed/power map relative to that used for a standard ICE powered vehicle. Therefore whilst the CO_2 emissions remain correctly accounted for from knowledge of the amount of carbon liquid fuel consumed, the same may not be true for the N_2O and CH_4 emissions. However, because these are such a small proportion of the whole GHG emissions these subtle deviations are unlikely to be significant.

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[39] Well to wheels analysis of future automotive fuels and powertrains in the European context, CONCAWE EUCAR and EC JRC, Tank to Wheels report (Version 3) October 2008, Table 5.3.5-1 (p36/43)

9.4.7   Summary

The GHG TTW emissions for different power train options, and different energy carriers have been is assessed for the direct CO_2, N_2O CH_4 tailpipe emissions. These are summarised in Table 29 and shown diagrammatically in Figure 58. The source of the key emissions data are also given.

Table 29   Tank-to-wheel CO_2 and non-CO_2 GHG emissions (and their ratio) for different powertrains and energy carriers according to IPCC guidelines

Fuel	Assumed CO_2 emissions /km gCO2/km	Resulting N_2O + CH_4 emissions gCO2e/km	Ratio of N_2O + CH_4 emissions (CO2e) / CO_2	Details
Conventional ICE and hybrid ICE power trains				
Petrol	130 (Note 1)	0.82 (Note 2)	0.63%	Table 27
Diesel	120 (Note 1)	2.00 (Note 2)	1.67%	Table 27
LPG	120 (Note 1)	1.33 (Note 2)	1.11%	Table 27
Methane as CNG or LNG	108 (Note 1)	6.16 (Note 3)	5.7%	
Petrol & electricity in PHEV/EREV	50 (Note 4)	0.32 (Note 4)	0.63%	
Bioethanol	0	0.82 (Note 5)	N/A	From petrol ICE
Biodiesel	0	2.00 (Note 5)	N/A	From diesel ICE
Biomethane	0	6.16	N/A	From methane ICE
Full electric vehicles and fuel cell vehicles				
Electricity	0	0	N/A	Section 9.4.4
Hydrogen	0	0	N/A	Section 9.4.5

Note 1   Taken as a representative value for the current passenger car fleet
Note 2   Average for vehicles meeting Euro 3 and 4 emission standards as calculated from COPERT 4 methodology
Note 3   From IPCC Tier 1
Note 4   Scaled Petrol emissions
Note 5   Same as for the fossil fuel the biofuel is replacing

The key findings from this study are:

- generally the emissions of both methane and nitrous oxide (expressed as CO_2 equivalents to take account of their higher global warming potential) are small, <2%.
- These emissions are technology dependent, and have reduced together with other pollutants for vehicles built to meet successive Euro standards.

Other important factors are:

- Any new GHG regulatory standards would not be introduced until after the Euro 6 standards are in place, and the emissions of non-CO_2 GHGs are most probably going to reduce further, rather than increase.
- Currently, type approval Euro 5/6 legislation contains THC and non-methane HC (NMHC) limits for all vehicles, and methane emissions are measured on all vehicles during the Type I test. The Euro 6 limit for THC is 100 mg/km. Since they emit very little NMHC this could be close to 100 mg/km methane, i.e. 2.5 g/km CO_2 equivalents, which is 2.6% of the 95 g/km CO_2 total 2020 target. Therefore exhaust methane emissions could easily be incorporated in the TTW GHG emissions as part of any post 2020 regulation.
- There is currently not a type approval test protocol for nitrous oxide, and often it is not measured. Consequently, any change to regulate N_2O emissions using vehicle test data would require further measurements to be taken.
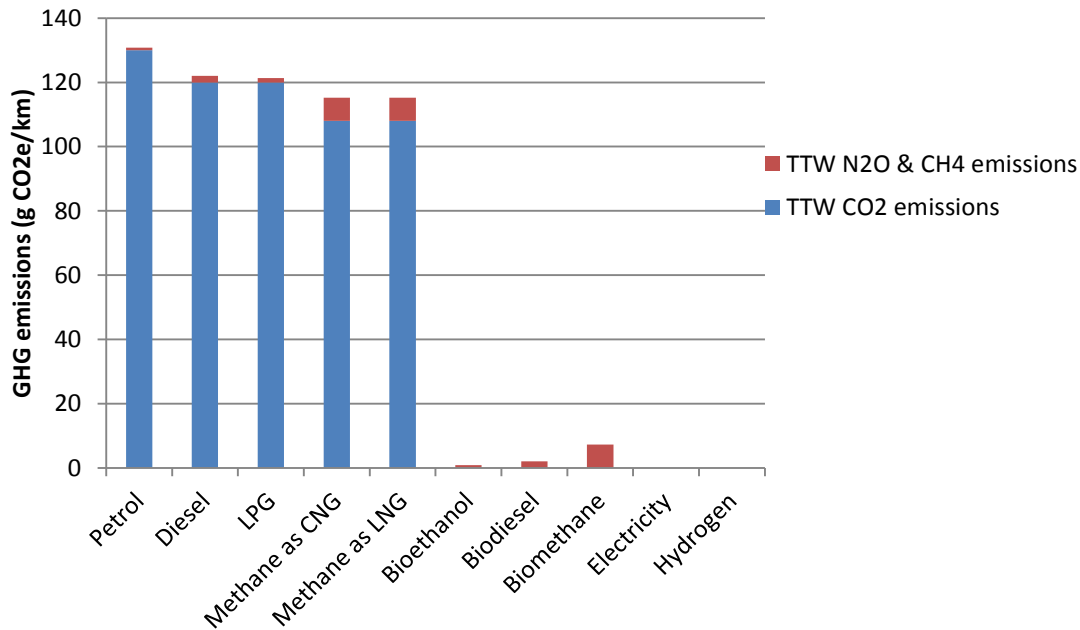
Figure 58   TTW GHG emissions for a range of energy carriers

The two exceptions to this are:

- For vehicles using methane as a fuel, the higher GWP of methane relative to CO_2 (25 relative to 1) and the potential high emissions of methane lead to these vehicles having higher than average non-CO_2 GHG emissions;

- For pure biofuels where the tank-to-wheel CO_2 emissions are deemed biogenic, and set at zero, the small amount of non-CO_2 species emitted is the only contribution to tank-to-wheel GHG emissions according to IPCC definitions. Under the existing CO_2 legislation direct emissions from combustion of biofuel (as (part of the) reference fuel used in the type approval test) are counted and are of the same order of magnitude as those when tested on 100% fossil fuel.

9.5   Well to tank (WTT) GHG emissions for different energy carriers

The current regulatory metric for assessing the GHG emissions from light duty vehicles is the TTW CO_2 emissions from the vehicle. An alternative metric could be based on WTW GHG emissions. Because the driving principal behind the light duty vehicle CO_2 regulations is the stabilisation of GHG emissions, a regulatory approach based on WTW emissions, would be more directly related to the vehicle's in use GHG footprint.

The WTW GHG emissions can be expressed as:

well-to-wheel (WTW) GHG emissions =   well-to-tank (WTT) GHG emissions +
tank-to-wheel (TTW) GHG emissions

The previous section of this chapter focussed on TTW emissions for the range of powertrains and energy carriers considered. Therefore, to quantify the WTW emissions, the focus of this section is on the WTT GHG emissions.

Quantification of the well-to-tank emissions for different energy carriers is a complex subject. It will vary from energy carrier to energy carrier, and depends on the detailed production route for a given energy carrier. It is the subject of a large amount of other EC funded research. For example, the GHG emissions arising from the relatively straight forward step of extracting a tonne of petroleum varies by more than a factor of 5 because of:

- the location of the well (land, shallow water or deep sea wells);

- the amount of flaring that is associated with the extraction well;
- fugitive emissions from the well (often of methane, which has a 100 year GWP of 25 relative to CO_2).

It is already common usage to include all GHGs in inventories of WTT and WTW emissions of energy carriers. The purpose of this section is to obtain authoritative data for the WTT GHG emissions that complement the TTW GHG emissions summarised in Table 29 of section 9.4.6.

The primary source of information reported here is the on-going "Well to wheels analysis of future automotive fuels and powertrains in the European Context" study, being undertaken by CONCAWE, EUCAR and EC JRC [JRC 2011]. The latest version of this study was published on the JRC EC Europa website on 27th October 2011, and is Version 3[40].

It should also be noted that WTT GHG emissions are relevant to the production of the fuel, not the efficiency with which it is used. Consequently, in this chapter only the different energy carriers are considered, not the different power train options.

9.5.1 Mainstream fossil fuels: petrol and diesel, LPG and natural gas as CNG or LNG

The CONCAWE, EUCAR and EC JRC report contains the detailed energy and GHG balances of a large number of fuel pathways. It focuses on total energy expended (MJ_{xt}), i.e. all the energy, regardless of its origin, that needs to be used to produce the desired fuel, *after discounting the energy content of the fuel itself*. The unit used is

$$MJ_{xt}/MJ_f = MJ \text{ expended total energy per MJ finished fuel (LHV basis)}$$

For example a figure of 0.5 means that making the fuel requires 50% of the energy that it can produce when burned. This total energy figure gives a truly comparable picture of the various pathways in terms of their ability to use energy efficiently. The data given below is taken from Appendix 2 of the WTT Version 3 report.

Table 30   The GHG emissions included in the WTT chain of conventional / fossil fuels [JEC 2011]

Pathway	Pathway code	WTT energy expended MJ_{WTT}/MJ_f	WTT GHG gCO_2e/MJ_f	GHG breakdown into components	Reference in Appendix 2 of WWT v3 report
Crude oil to **gasoline**	COG1	0.17	14.2	100% CO2	App2, p10 (402/545)
Crude oil to diesel	COD1	0.19	15.9	100% CO2	App2, p10 (402/545)
Gas field condensate to LPG	LRLP1	0.12	8.0	94% CO2, 6% CH4	
Natural gas to CNG	GMCG1	0.12	8.7	63% CO2, 37% CH4	App2, p13 (404/545), Note 1
LNG to CNG from import	GRCG1	0.31	20.2	65% CO2, 35% CH4	App2, p13 (404/545), Note 1

Note 1   assumed pipeline length 1,000 km, rises from 0.12 to 0.30 for 7,000 km pipeline

The WTT emissions from the energy chain scale with the TTW energy consumed. Therefore WTT GHG emissions in g/km to be attributed to a vehicle scale directly with the vehicle's energy use, and are thus reduced if vehicle efficiency is improved. For example, if the application of advanced engine technologies leads to a vehicle only needing 80% of the fuel to complete a drive cycle relative to a "standard" engine, then the TTW emissions are only 80% of that for the vehicle with the "standard"

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[40] "Well-to wheels analysis of future automotive fuels and powertrains in the European Context", partners Joint Research Centre of the European Commission, EUCAR and CONCAWE. Version 3 is an update of their joint evaluation of the well-to-wheels energy use and greenhouse gas emissions for a wide range of potential future fuel and powertrain options. This document reports on the third release of this study replacing Version 2c published in March 2007. The original version was published in December 2003. Available from http://publications.jrc.ec.europa.eu/repository/handle/111111111/22590

engine. Similarly, if only 80% of the fuel is needed, then only 80% of the energy is required to generate this fuel. Hence, an 80% TTW requirement also implies a 80% WTW requirement.

9.5.2   Use of biofuels in ICE powertrains

It was noted in section 9.4.2 that when compiling GHG inventories for biofuels their use (TTW) is categorised as a biogenic carbon source, but their production (WTT) as an anthropogenic activity. Consequently, whilst the CO_2 emissions from the combustion of biofuels are taken as 0 (for accounting under the Kyoto protocol), their WTT GHG emissions are important. The WTT emissions from the production pathway does depend on:

- the crop or waste stream used to produce the biofuel;
- agricultural processes for producing biomass crop;
- indirect emissions associated with the production of fertilizers and pesticides;
- the production process for converting biomass into biofuel and the associated process energies used;
- the utilisation of co-or by-products, which may e.g. be used in CHP plant, or biomass products used as animal feeds.

Especially for the WTT emissions of biofuels taking account of other GHGs than CO_2 is of paramount importance. This is illustrated in Table 31 for two biofuels compared to some example pathways for conventional fuels and electricity and hydrogen.

Table 31   Share of different GHGs in the CO_2-equivalent WTT emissions of some examples of conventional and alternative energy carriers, taken from [JEC 2011] (excl. ILUC).

		CO_2	CH_4	NO_2	CO_2	CH_4	NO_2
		g/MJ_{fuel}	g/MJ_{fuel}	g/MJ_{fuel}	share in CO_2-equivalents		
petrol	COG1 Crude oil to gasoline	14.1	0	0	100.0%	0.0%	0.0%
diesel	COD1 Crude oil to diesel	15.8	0	0	100.0%	0.0%	0.0%
LPG	LRLP1 LPG from gas field (remote)	7.5	0.02	0	93.8%	6.3%	0.0%
CNG	GPCG1b Piped NG, 4000 km	9.2	0.2	0	64.8%	35.2%	0.0%
ethanol	SCET1b EtOH from sugar cane (Brazil), no credit for excess bagasse	13.4	0.16	0.025	53.9%	16.1%	30.0%
biodiesel	ROFA1 RME, glycerine as chemical, meal as animal feed	16.9	0.06	0.079	40.3%	3.6%	56.1%
electricity	GPEL1a Piped NG, 7000 km, CCGT	125.6	0.55	0.006	89.0%	9.7%	1.3%
electricity	KOEL1 Coal, state-of-the-art conventional technology	242.6	0.91	0.012	90.2%	8.5%	1.3%
H_2	GPCH1a Piped NG, 7000 km, on-site reforming	98.4	0.42	0.001	90.1%	9.6%	0.3%

Growing biomass emits significant quantities of N_2O, while e.g. soil conversion can lead to large emissions of CH_4. On the other hand, biogas production from fermentation of manure can also avoid direct emissions of CH_4 to the air, which may partly or fully compensate the CO_2 emissions occurring in the well-to-tank chain.

In this respect not only emissions from the land directly used for biomass cultivation are relevant, but also impacts of indirect land-use change (ILUC). The increased production of biofuels, even when it takes place on existing agricultural land, is found to contribute to the conversion of land such as forests and wetlands into agricultural land. This leads to increased CO_2 and CH_4 emissions from oxidation or fermentation of carbon that is stored in the soil. These emissions from indirect land use change (ILUC)

can significantly counteract the greenhouse gas savings from biofuels[41]. Food-based biofuels and bioliquids often contribute to land conversion. To account for this, in October 2012 the European Commission proposed amending the Fuel Quality Directive to include ILUC factors in the reporting of the greenhouse gas emission savings from biofuels under the directive.

It is common practice in WTT and WTW analyses to take non-CO_2 GHGs into account. This is also the case in the CONCAWE EUCAR JRC study [JEC 2011] and in the typical and default WTT emission factors listed in the FQD and RED. The amendments to EC Renewable Energy Directive (2009/29/EC) and the Fuel Quality Directive (2009/29/EC) summarise the typical greenhouse gas emissions giving total GHG emissions (g CO_2e/MJ) for the cultivation, processing, transport and distribution of biofuels. Data for key biofuel production pathways are given in Table 32.

ILUC emissions are currently not included in WTT emission assessments such as [JEC 2011] and the WTT emission factors included in the FQD and RED.

Table 32   The GHG emissions from the cultivation, processing, transport and distribution of crops to produce biofuels, as defined in the FQD and RED, expressed as CO_2-equivalents including N_2O and CH_4 emissions (excl. ILUC).

Biofuel	Production pathway	Typical GHG emissions gCO$_2$e/MJ$_{fuel}$[42]
Bioethanol	From sugar beet	33
	From wheat, using NG as process fuel with 50% in CHP plant	43
	From sugar cane	24
Bioethanol	Average from the three pathways	33
Biodiesel	From rape seed	46
	From sunflower	35
	From soya bean	50
	From palm oil	54
	From waste vegetable or animal oil	10
Biodiesel	Average from rape seed, sunflower and waste vegetable or animal oil	31
Compressed biomethane	From municipal organic waste	17
	From wet manure	13
Compressed biomethane	Average from both the above pathways	15

The average values for bioethanol, biodiesel and compressed biomethane given in Table 32 are those used the subsequent analysis in this report.

9.5.3   Electricity (used in electric and plug-in hybrid vehicles)

Whilst the tank-to-wheel emissions from electric vehicles are zero, there being no tailpipe emissions, the same is not true for the WTT component since there are GHG emissions from the generation of electricity and its delivery to the vehicles' batteries.

It is difficult to swiftly obtain an average GHG emissions for the generation and delivery of a quantity of electrical power. This arises because of:

- The range of different energy sources used (e.g. coal, petroleum, biofuels, nuclear, renewables);
- The range of plant efficiencies for plants using each fuel (e.g. coal through conventional boilers, the use of fluidised bed combustion, the use in CHP plant, etc.);

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[41] See: http://ec.europa.eu/clima/policies/transport/fuel/studies_en.htm for recent studies on this subject for the European Commission
[42] The typical GHG emissions are taken from table D: Disaggregated default values for biofuels, for cultivation, processing, transport and distribution listed on page 112 of 140 of the Official Journal of the European Union, published on 5th June 2009.
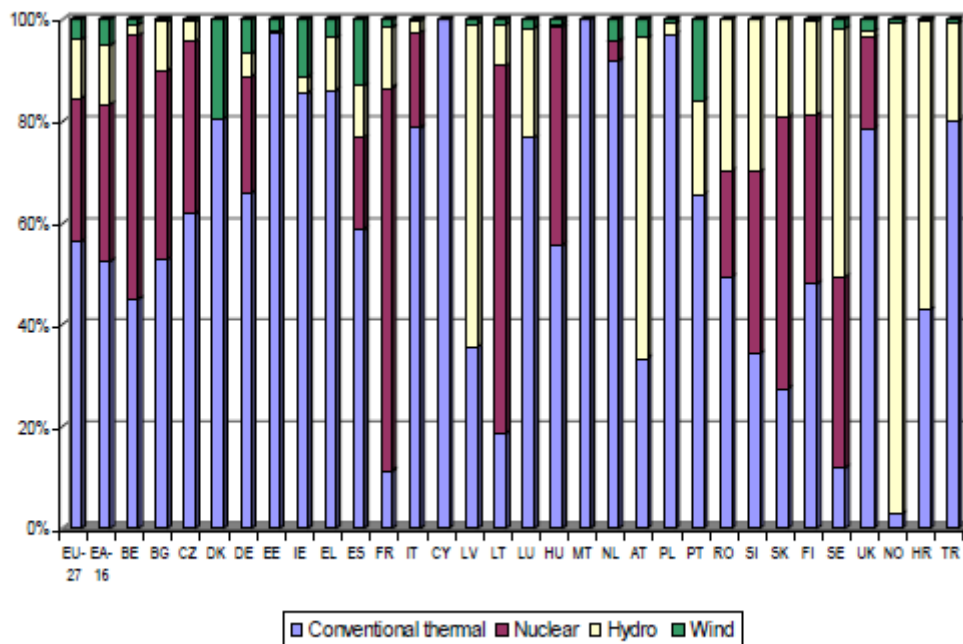
- The changing electricity generation mix caused by economics of fuels and demand,
- methodological issues related to attributing emissions to electricity consumers (see section 3.3.1 and Annex A.1).

It is common practice in WTT and WTW analyses to take non-CO_2 GHGs into account. This is also the case for the data on electricity in the CONCAWE EUCAR JRC study [JEC 2011]. Some GHG emission figures for different types of power generation, in units of gCO_2e/MJ_{elec} provided in Annex 2 of the CONCAWE EUCAR EC JRC report are given in Table 33. The previous Table 31 shows that non-CO_2 GHGs make up about 10% of the CO_2-equivalent emissions of electricity from natural gas or coal-fired power plants.

Table 33   The GHG emissions associated with electricity generation for different power generation plant for generation in 2008

Fuel	Type of plant	GHG emissions (gCO_2e/MJ_{elec})
Coal	Conventional thermal	269
Natural gas	Combined cycle gas turbine	126
Nuclear	Not specified	4.4
Wind turbine	All types	0
EU Mix	All types	130

Figure 59 shows the mix in terms of conventional thermal, nuclear, hydro and wind power sources[43] for the average of the EU 27 and for each Member State.

Source: Eurostat (nrg_105m, nrg_105a)

Figure 59   Electricity generation mix for the EU 27 average and each of the Member States for 2009[43]

It can be seen this varies widely between countries. Hence, the GHG emissions for generating electricity in France, with its large nuclear component, and Germany, the Netherlands or the UK, with their large conventional thermal components, are quite different. Furthermore, for Germany and the UK, which have modest (e.g. around 20%) nuclear generation capability, the generation mix changes throughout the day. This leads to the GHG emissions from each MJ electricity varying throughout the

[43] data taken from Eurostat, via http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-QA-10-014/EN/KS-QA-10-014-EN.PDF

day, and being lower or higher at night when, traditionally, many electric vehicles would be recharged, depending on whether base load is largely provided by nuclear or coal-fired plants.

The consequence of the above is that there is no simple answer to the question of what are the GHG emissions from generating 1 MJ of electricity. The figure used in this section is the Eurostat value of 130 gCO₂e/MJ for the average Europe mix[43].

However, to convert this figure into GHG emissions (per km driven) it needs to be multiplied by the energy required to travel an average kilometre. A recent trial, run by the RAC Foundation compared the fuel consumption of three types of vehicle: pure electric; hybrids, including plug-ins and hydrogen fuel cells; and internal combustion engines emitting no more than 110 gCO₂/km[44]. Electric vehicles on average consumed 0.61 MJ_e/km (megajoules per kilometre). However, this figure doesn't take into account the efficiency losses from the point of generation of the electricity to the vehicle's battery. If the transmission efficiency of the energy taken from the point of production to where energy gets stored in the vehicles' battery is estimated to be 80%, then the overall WTT energy requirements would be 0.76 MJ/km, and the WTT (and WTW) GHG emissions would be 99 gCO₂e/km for such an electric vehicle, using the average Europe mix for electricity generation. This is the figure used later for comparison with other energy carriers.

Decarbonisation of the electricity generation would lead to a direct, and equivalent, decarbonisation of the electric vehicle WTW GHG emissions.

9.5.4   Hydrogen (used in fuel cell vehicles)

As for electric vehicles, whilst the tank-to-wheel emissions from hydrogen fuel cell vehicles is zero the production of the hydrogen does lead to GHG emissions. Also, as for electric vehicles there are a multitude of different fuel production pathways, most of which do have GHG emissions. Four representative fossil fuel derived pathways for hydrogen production are summarised in Table 34. As an example, Table 31 shows that non-CO₂ GHGs make up some 10% of the CO₂-equivalent emissions of hydrogen production from natural gas.

Table 34   The GHG emissions associated with the production of hydrogen for different production pathways[45]

Hydrogen production route	Type of plant	Pathway code	GHG emissions (gCO₂e/MJ$_{fuel}$)[45]
Steam reforming of natural gas (methane)	On-site reformer	GPCH1B	112
Steam reforming of natural gas (methane)	Central reformer	GPCH2B	99
Coal	Not specified	KOCH1	234
Electricity from EU Mix	Electrolysis	EMEL1/ CH1	209

It is common practice in WTT and WTW analyses to take non-CO₂ GHGs into account. This is also the case for the data on hydrogen in the CONCAWE EUCAR JRC study [JEC 2011].

Generally it is seen that the WTT emissions per MJ hydrogen are 100 gCO₂e or greater. However, this can be very significantly reduced if:

- instead of using fossil natural gas biomethane is used, or
- hydrogen is produced through electrolysis using electricity originating from renewable sources.

To convert the GHG emissions per MJ$_{fuel}$ figure into GHG emissions (per km driven) the energy content of the hydrogen consumed when travelling an average kilometre is required. The CONCAWE EUCAR EC JRC well-to-wheel report gives a GHG emission of around 95 gCO₂e/km for a compressed

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[44] See report on "Which low-carbon cars are the most eco-friendly" from the RAC Foundation, dated May 2011, available from
http://www.lowcvp.org.uk/assets/reports/Shades%20of%20green%20future%20car%20challenge%20booklet%20-%20lytton%20-%20050511.pdf
[45] Data taken from Appendix 2 of CONCAWE EURCAR JRC Well to tank (WTT) report v3c, July 2011

hydrogen fuel cell vehicle fuelled with hydrogen made from steam reforming natural gas using a central reformer[46]. This is the figure used is this summary further on.

9.5.5 Summary

Non-CO_2 GHGs are a negligible fraction of the WTT emissions for petrol and diesel, but contribute significantly to the WTT emissions of alternative energy carriers. For natural gas pathways, CH_4 can be about 35% of the CO_2-equivalent WTT emissions. For biofuels both CH_4 and N_2O are important with shares of around 50% in the CO_2-equivalent WTT emissions. For electricity and hydrogen from fossil sources the share of non-CO_2 GHGs is typically of the order of 10%.

The GHG WTT emissions for different energy carriers have been is assessed, expressing the total emissions of CO_2, N_2O and CH_4 in CO_2-equivalents on the basis of the global warming potentials of the different GHGs. Overall results are summarised in Figure 60.
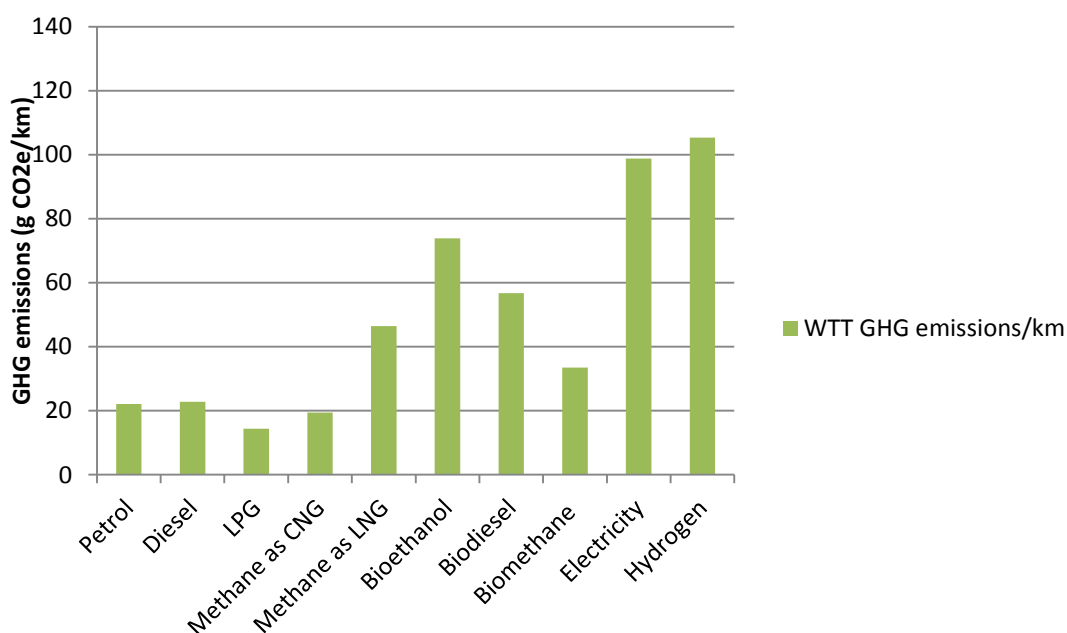

Figure 60   WTT GHG emissions for a range of energy carriers

9.6   WTW GHG emissions for new technologies

The study so far has considered the powertrain technology and energy carrier options listed in section 9.3. In addition to these there are some additional, more advanced powertrain and automotive technologies that are worth mentioning briefly.

9.6.1 Homogeneous charge compression ignition engines

This type of engine is a hybrid of the traditional spark ignition and the compression ignition processes. In an HCCI engine a homogeneous (instead of stratified) mixture of air and fuel is created which is ignited by compression. The defining characteristic of HCCI is that the ignition occurs at several places at a time. This creates a low temperature and flameless release of energy throughout the chamber, burning all the fuel simultaneously. The primary benefit of this technology is very low NO_x and PM emissions (a consequence of the lower combustion temperature of a premixed charge) relative to conventional diesel, compression ignition, engines. Interestingly, although HCCI can be viewed as being derived from petrol engines, its overall CO_2 emissions are less than those from an analogous diesel engine – so this technology has the potential to provide CO_2 emissions reductions relative to the current diesel light duty vehicles.

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[46] Data given in Figure 6.4.1 – 1a/b of the CONCAWE EUCAR EC JRC Well to Wheel (WTW) report v3c, dated July 2011

REDUCING SOOT AND NOx EMISSIONS

In HCCI and petrol engines, the fuel and air are mixed before combustion, preventing the soot emissions of diesel engines. Only HCCI engines have multiple ignition points throughout the chamber. This plus their lean burn keeps temperatures low, preventing formation of nitrogen oxides (NOx)
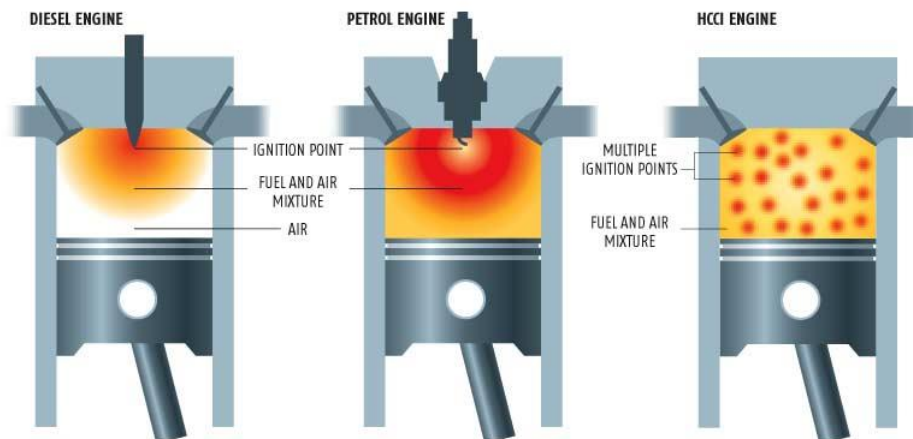

Figure 61   Working principle of HCCI (*Source:* from New Scientist magazine, January 2006)

For petrol (spark ignition) engines the HCCI concept is sometimes known as Controlled Auto Ignition (CAI).

The technology is not yet ready for commercial production, but functioning prototypes have been produced and universities, laboratories and car makers are working on the technology as control software still needs to be fully developed. This software is needed to improve the control of the engine, as the engines are currently not reliable with changes in conditions, as the combustion method needs more composition and compression control than standard engines.

In terms of this type of engine's emissions of GHGs, there are currently very little data. The technology has the potential to use "lower grade" fuels, i.e. ethanol – water mixtures.

- TTW changes – this technology may produce a different CO_2 / CH_4 / N_2O ratio
- WTT changes – this technology may change the required energy to produce fuel, e.g. a reduction in the energy intensive final dehydration step in the production of bioethanol.

However, overall there are insufficient data of the GHG footprint for this new technology to allow a meaningful estimation of either its overall GHG emissions or its breakdown into CO_2 and non-CO_2 components.

9.6.2   Exhaust after-treatment technologies

The two pollutant species of principal concern for air quality and health are oxides of nitrogen and PM. This leads to a dilemma: CI (diesel) engines are generally more thermodynamically efficient than SI (petrol) engines because of their higher compression ratio leading to lower GHG emissions. However, these combustion characteristics also lead to higher emissions of NO_x. Automotive industry is increasingly using exhaust after-treatment systems on diesel engines to reduce post engine NO_x concentrations. The systems used may change the CO_2 / CH_4 / N_2O ratio.

Because of the relatively high GWP of N_2O, any exhaust after-treatment technology that, as an unintended side effect, increases N_2O emissions could be reversing the advantage of the reduced CO_2 emissions through the use of a higher engine efficiency.

For three-way catalysts it is known that they tend to increase the share of N_2O in the exhaust gas. This mainly occurs under cold start conditions. In general all systems with a platinum-based catalyst, including e.g. Diesel Particulate Filters (DPF), oxidation catalysts and Continuously Regenerating Traps (CTR), could potentially lead to increased N_2O emissions. There are indications that this is the case for oxidation catalysts [Graham et al. 2008] and Selective Catalytic Reduction (SCR) [Riemersma et al. 2003], but currently insufficient data are available to quantify the situation for modern vehicles, let

alone Euro 6 production vehicles which are only now coming to the market. In principle proper design and management of the catalyst can prevent increased N_2O emissions.

The conclusion from the two sections above is that these technologies are insufficiently characterised for an authoritative assessment to be completed. It seems justified, however, to review these technologies again, when they become more widespread and measurement data become available.

9.7 Conclusions and recommendations

9.7.1 The importance of including TTW emission of GHGs other than CO_2 in the regulatory approach

The current regulatory metric is tailpipe (i.e. tank to wheel, TTW) CO_2 emissions. The principal focus of this part of the assessment is to quantify the emissions of all GHGs that the IPCC recommend should be included in the GHG inventory, for a range of powertrains and energy carriers. From the ratio of the GHG emissions/ CO_2 emissions it was assessed whether there is a need to include the GHGs other than CO_2 in the coverage of the regulatory approach.

The GHGs included in the study were:

- carbon dioxide (CO_2) because it is the metric for the current regulatory approach, and
- nitrous oxide (N_2O) and methane (CH_4) because the IPCC guidelines for national GHG inventories specify that these are the species that are important and should be included.

Emissions of GHG compounds used in mobile air conditioning (MAC) are excluded because it is expected that changes to the powertrain/primary energy carrier technology mix will not affect the MAC systems used. Also reduction of refrigerant emissions from MACs is already covered in dedicated legislation. Consequently, there is **no need** for the coverage of the regulatory approach post 2020 to include the GHGs used within MAC unless it is found that changes to the powertrain / primary energy carrier technology mix do change the MAC systems used or their performance.

The range of powertrain and primary energy carrier technologies included are listed in Table 35:

Table 35   Range of powertrain and primary energy carrier technologies included

	Powertrains	Energy carriers
Primary powertrains	Conventional ICE	Mainstream fossil fuels
	Full (battery) electric vehicles	Biofuels
	Hydrogen fuel cell vehicles	Electricity
Linked powertrains	Plug-in hybrid electric vehicles	(using electricity and carbon liquid fuels)
	Extended range electric vehicles Improved efficiency ICE (including hybrid vehicles)	(using electricity and carbon liquid fuels)

The TTW emissions of the three IPCC specified GHGs were calculated using peer reviewed standard emission factors obtained from:

- IPCC guidelines for national GHG inventories, Tier 1 emission factors
- IPCC guidelines for national GHG inventories, Tier 2 emission factors
- COPERT IV model, equivalent to IPCC Tier 3 emission factors.

The emissions given by these different methodologies, and the ratio of the non-CO_2 emissions to total GHG emissions are given in Table 23 to Table 27. There are some differences, though these do not affect the overall conclusions reached, and are explicable in terms of the different approaches. These are as follows:

- For standard fossil fuels the ratio of non-CO_2 emissions to total GHG emissions never exceeds 6%.

- The non-CO_2 emissions to total GHG emissions ratio is vehicle technology dependent and reduces for the modern less polluting vehicles.
- For light duty vehicles meeting Euro 3 and Euro 4 emissions standards the ratio never exceeds 2% except for natural gas (methane) fuelled vehicles.
- For biofuels the IPCC deem the tailpipe CO_2 emissions are biogenic in origin, and therefore equal to zero. However these vehicles do generate small quantities of N_2O and CH_4 from their biofuel of similar magnitudes as the N_2O and CH_4 emissions from vehicles running on petrol or diesel.
- For electricity and hydrogen powered vehicles the tailpipe emissions are zero (as long as the H_2 is not used in an ICE), as too are the tailpipe emissions of N_2O and CH_4.

Figure 62, below, summarises these data, showing the TTW emissions of CO_2 and of $N_2O + CH_4$ for the different energy carriers.
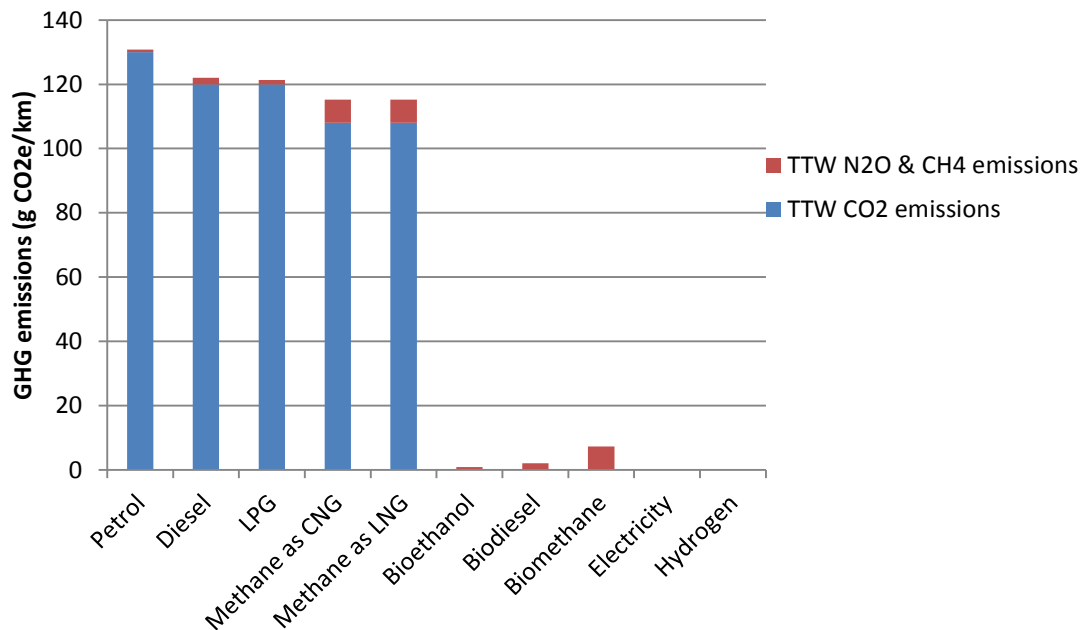

Figure 62   TTW GHG emissions for a range of energy carriers

The emissions of the non-CO_2 GHGs generally occur together with CO_2 emissions. Their ratio remains virtually constant for a given vehicle principal powertrain technology and exhaust clean-up combination. Consequently, improvements in the efficiency of the ICE, or the addition of hybrid technology, is in first order expected to lead to equivalent reductions in both the CO_2 emissions and the non-CO_2 emissions.

For vehicles using a combination of energy carriers, i.e. plug-in hybrid and extended range electric vehicles, their emissions are considered to be an average of the emissions of each energy carrier weighted by the shares of the different energy carriers used. However, this varies according to the pattern of usage. Hence the emissions from a plug-in hybrid electric vehicle that is never attached to the mains (i.e. the electric power used is zero) is that for an equivalent (non plug-in) hybrid vehicle, whereas the emissions from an extended range electric vehicle that only uses electric power are zero, equivalent to that for a battery electric vehicle.

The assessment did show that methane fuelled vehicles do have higher than a 2% non-CO_2 GHG emission, because of the increased emissions of methane and because each unit of methane has a global warming potential of 25 times that of CO_2. Further, fugitive emissions (leakage from compressed fuel cylinders, or boil-off from liquid methane tanks) could cause this to be greater. The actual methane emissions and fugitive losses will change as the vehicle technology develops, hopefully reducing.

This assessment also considered two new technologies that may become important vehicle technologies in the future, but are currently immature. These are homogeneous charge compression ignition(HCCI) engines, which potentially are a more efficient and less polluting ICE concept, and

advance selective catalytic reduction, potentially used in the future to further reduce the emissions of nitrogen oxides. Both of these new technologies are currently insufficiently mature for a meaningful assessment of the non-CO_2 GHG emissions from likely in-use vehicles to be undertaken.

It is also noted that the current vehicle type approval testing procedures do not specify the measurement of nitrous oxide and current practice is not to measure this species. For test cells with FTIR instruments, augmenting the current vehicle emissions instrumentation, estimates of nitrous oxide emissions can be made. Consequently, any requirement that nitrous oxide becomes included in the regulatory approach post 2020 would involve an additional test burden and instrumentation.

The main conclusions from this analysis regarding TTW non-CO_2 GHG emissions can be summarized as follows:

- There is no need for the coverage of the regulatory approach post 2020 to include the GHGs used in MACS unless it is found that changes to the powertrain / primary energy carrier technology mix would change the MAC systems used or their performance.
- There is no need for the coverage of the regulatory approach post 2020 to include TTW emissions of non-CO_2 GHGs from ICEVs using carbon-based liquid fuels because they are a small fraction of CO_2 emissions (<2% for Euro 4) and are potentially going to reduce further following the introduction of the Euro 6 emission standards.
- However, for Euro 6 the methane measurement provisions are already part of the test procedure, and the emissions standards permit around 2.5 g CO_2 equivalents methane emissions per kilometre (2.6% of the 2020 95 g/km average target). This argument is especially relevant for natural gas (methane) fuelled vehicles, to ensure that the additional potential GHG emissions of methane are not a significant proportion of the CO_2 emissions. Including methane emissions in the regulation of TTW GHGs could thus be justified.
- In modern passenger cars N_2O emissions are not expected to exceed 1 g CO_2-equivalents per kilometre on average. Therefore inclusion of N_2O is not necessary.
- The need to extend the regulatory approach post 2020 to include non-CO_2 GHGs from vehicles using either HCCI or high levels of SCR should be reviewed if, or when, the technology becomes more widespread.

9.7.2 WTT and WTW GHG emissions for different vehicle technologies and energy carriers

The above considerations relate to the TTW emissions of vehicles. If the metric for future CO_2 regulation would be changed to cover WTW CO_2 emissions, the inclusion of non-CO_2 is definitely necessary, as for some fuels (e.g. biofuels) these constitute a significant share of the WTT GHG emissions. In energy chain analyses (WTT or WTW analyses) it is, however, already common practice to include all relevant GHGs.

In support of this potential regulatory option the TTW GHG emissions, discussed above, have been augmented with the WTT GHG emissions for a range different and energy carriers. This was assessed by drawing on authoritative published literature, principally the CONCAWE EURCAR JRC well-to-wheels study, and information in the annexes of the EC's Renewable Energy Directive and Fuel Quality Directive. The results from this assessment are summarised in Table 36, and shown graphically in Figure 63.

These data are for the current technologies. Improvements in vehicle efficiencies lead to a direct equivalent reduction in all GHG emissions. For example, a 25% improvement in the efficiency of ICE engines would, by definition, lead to 25% less fuel use to travel the same distance. This would reduce:

- the TTW CO_2 emissions by 25%;
- the TTW non-CO_2 GHG emissions by 25% based on the previous evidence that non-CO_2 GHG emissions follow CO_2 emissions and
- all WTT GHG emissions by 25% because only 25% of the fuel needs to be produced.

This applies for all such innovations, e.g. improved engine efficiency, adding hybrid technology, and fuel economy improvements caused by light weighting or improved aerodynamics.

Table 36   The WTW GHG emissions for modern vehicles with a range of different energy carriers

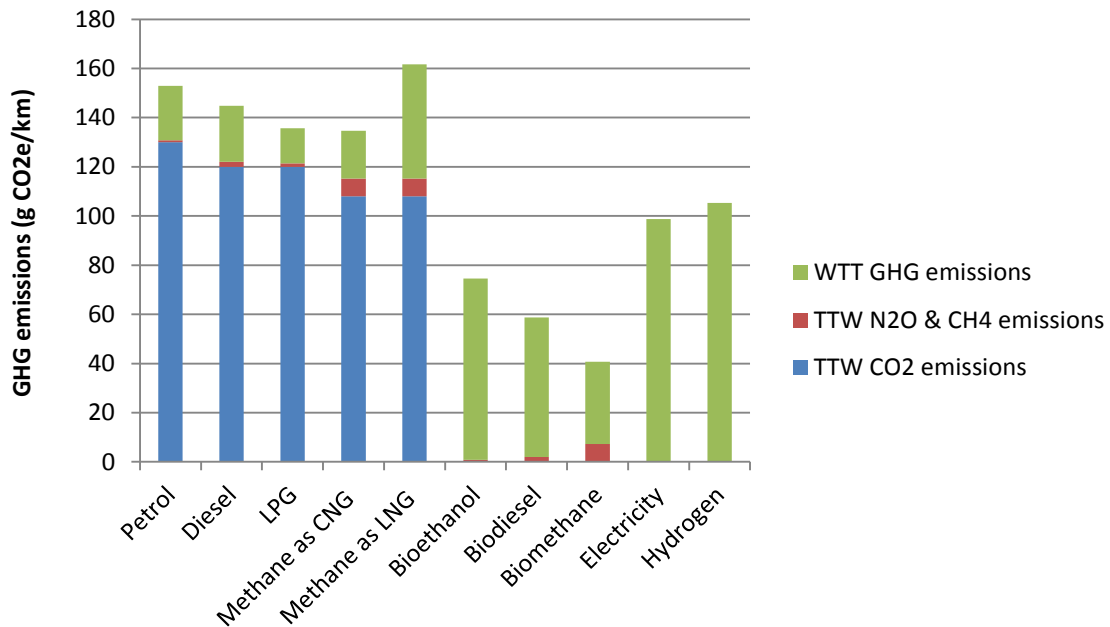| Fuel	TTW CO_2 emissions /km g CO_2/km	TTW N_2O + CH_4 emissions g CO_2e/km	WTT GHG emissions g CO_2e/km	WTW GHG emissions g CO_2e/km
Conventional ICE and hybrid ICE power trains				
Petrol	130	0.82	22.1	152.9
Diesel	120	2.00	22.8	144.8
LPG	120	1.33	14.4	135.7
Methane as CNG	108	6.16	19.4	134.6
Methane as LNG	108	6.16	46.4	161.6
Biofuels				
Bioethanol	0	0.82	73.8	74.6
Biodiesel	0	2.00	56.7	58.7
Biomethane	0	6.16	33.5	40.74
Full electric vehicles and fuel cell vehicles				
Electricity	0	0	98.8	98.8
Hydrogen	0	0	105.3	105.3

Figure 63   WTW GHG emissions for a range of energy carriers for 2010 with TTW and WTT emissions according to IPCC definition

For vehicles using a combination of energy carriers, i.e. plug-in hybrid and extended range electric vehicles, as for their TTW emissions, their WTT emissions are a weighted average of the emissions of each energy carrier. As noted in the previous section, this varies according to the pattern of usage.

Some observations on the WTW data, relative to the TTW data, and in particular the TTW CO_2 emissions, are:

- For the fossil fuels, the WTT component for LNG is the largest of all the fossil fuels, reflecting the energy intensive nature of liquefying methane.
- For Kyoto accounting, in which the TTW CO_2 emissions from biofuels are taken as 0, the WTW approach enables the overall GHG emissions of biofuels to be shown.
- The WTW data also enables the overall GHG impact of using electric vehicles, or hydrogen vehicles to be demonstrated.

The WTT data for electricity and hydrogen are based on current status and practices, i.e. the EU-27 electricity generation mix, and the production of hydrogen by the steam reforming of **fossil natural gas**. The decarbonising of these generation/production routes would be the key to decarbonising the GHG footprint of these energy carriers. Also, at present the TTW emissions for these energy carriers are taken as zero. It is also noted that the carbon footprint of these energy carriers is outside the direct control of the vehicle manufacturers, and their suppliers.

Overall it is concluded that for proper accounting of WTT emissions the inclusion of non-CO_2 GHGs is essential, as these constitute a significant part of these emissions. CH_4 and N_2O are the relevant species. It is already common practice to include these emissions in WTT and WTW analyses and to express them in CO_2-equivalents based on their global warming potential (GWP). Current WTW analyses of biofuels generally do not include GHG emissions associated with Indirect Land-Use Change (ILUC). As these can be significant for various biofuels, it is recommended that ILUC emissions are included.

10 Implications with regard to vehicle testing and certification procedures

10.1 Introduction

This section will identify any implications for the vehicle testing and certification procedures of each of the options for the regulatory approach and metrics for road vehicle CO_2 as identified in chapter 2 of this study. This review will consider what changes or amendments may be required to the current test and/or certification procedures to accommodate these different regulatory approaches.

For light duty vehicles, work is currently well underway to reach agreement on a new set of regulations known as the Worldwide harmonized Light vehicles Test Procedures (WLTP). The objective of the WLTP is to provide a world-wide harmonised method for determining the levels of gaseous and particulate emissions, CO_2 emissions, fuel consumption, electric energy consumption and electric range from light-duty vehicles in a repeatable and reproducible manner which is representative of real world vehicle operation. Implementing any potential changes to the testing and certification procedures for light duty vehicles post 2020 would require further consideration concerning how the changes could be incorporated into the WLTP or any other applicable European legislation.

10.2 Current test procedure

The term 'current test procedure' means the type approval procedure required for Euro 5 or Euro 6 vehicle CO_2 emissions measurement – applicable regulations are UNECE R101 and UNECE R83. The test procedure involves driving a representative vehicle on a chassis dynamometer over a test cycle defined in UNECE R83 Annex 4a. This test cycle is known as the Type I test or New European Drive Cycle (NEDC). Throughout the test measurements are taken, using a constant volume sampling system, of tailpipe gaseous and particulate emissions, including CO_2.

The calculation for a plug in hybrid electric vehicle (PHEV) is a weighted result based on two verification tests – one test is performed starting with a fully charged battery, and one test is performed starting with a fully discharged battery. The test procedure and calculation method is specified in UNECE R101 Annex 8. The results from the two vehicle tests are combined with the vehicle's electric range, and a parameter that can be interpreted as the assumed distance between opportunities to recharge (25km), to get an overall CO_2 result. The calculation does not take into account the CO_2 used to generate the electricity utilised during plug-in recharging. Electrical energy consumption is reported separately to cycle

For non plug-in hybrid vehicles, corrected CO_2 results for Part One (Urban) and Part Two (Extra-Urban) phases of the Type I test are calculated for zero battery energy balance (no storage). This calculation uses a correction coefficient that can be determined from carrying out a number of vehicle tests and calculating the change in battery energy content during each test from measurements of the electricity balance Q. The vehicle test results used must include at least one test with the battery state of charge depleting, and one test with the state of charge increasing.

10.3 Options for review

Consequence for the test procedure need to be reviewed for all options described in chapter 2.

a.   regulating vehicle CO_2 emissions
   - tailpipe CO_2 emissions as in existing Regulation (= TTW CO_2 emissions)
   - tailpipe CO_2 emissions for ICEs with exclusion of Zero Emission Vehicles
   - tailpipe CO_2 emissions with notional GHG intensity for Zero Emission Vehicles
   - tailpipe CO_2 emissions adjusted to take account of WTW emissions (= WTW GHG emissions)

b.   regulating vehicle energy use

   - energy used in the vehicle per vehicle-km (= TTW energy consumption)
   - energy use per vehicle-km adjusted for WTW consumption (= WTW energy consumption)

c.   inclusion of road fuel use in the EU ETS

d.   a vehicle manufacturer based trading scheme based on lifetime vehicle GHG emissions.

e.   a cap and trade system for vehicle manufacturers, of total CO_2 emissions of vehicles sold (expressed in g/km)

f.   inclusion of embedded emissions in the WTW approaches listed above

g.   combining different options with e.g. size dependent mileage weighting

10.4   Options summary table

Table 37 presents each option along with its associated measurement parameters and required input data. Any modifications required to the test procedure are also listed.

It can be concluded from this table that overall no modifications to the test procedure are necessary. Measurement of fuel consumption, electric energy consumption and CO_2 emissions are already included in the existing test procedures.

10.5   Measurement parameters

All of the options presented require the measurement of certain key parameters. These measurement parameters are then combined with other external input data into the relevant calculation. This 'post test' calculation can be dealt with separately to the test procedure itself.

The key test-related measurement parameters are:

1. Tailpipe CO_2
2. Fuel consumption
3. Battery electrical balance (from measuring battery electrical current during test)
4. Electrical energy consumption

The methodology for the measurement of tailpipe CO_2 is already well established under the current test procedure, as is measurement of fuel consumption based on emissions data. Measurement of battery state of charge is also covered by existing procedures for hybrid vehicles.

In view of what has been discussed in chapter 9, modifications of the emission measurement method might be needed if it was decided to include direct emissions of other greenhouse gases in the regulation. While CH_4 is already measured in the existing procedure, N_2O emissions are not.

Measurement of electrical energy consumption appears unlikely to pose particular issues under any of the options considered. Procedures for this are already defined and applied to the homologation of plug-in vehicles under current legislation, and may possibly be carried over without significant changes.

However the weighting calculation currently applied in the certification of plug-in hybrid vehicles assumes a particular proportion of electric vs. non-electric driving as function of the vehicle's electric range. This may benefit from review in the light of the increasing amount of available data on the actual usage of these vehicles, and given its significant influence on the overall test result.

The potential inclusion of non-usage-based factors (such as well-to-tank energy carrier and vehicle production impacts) in vehicle homologation metrics does not have implications for the test and certification procedures themselves. WTT factors can be included by multiplying the vehicle's TTW energy consumption with the WTT emissions or energy use per unit of final energy. Vehicle production impacts would have to be established by means of an assessment procedure that is separate from the certification testing.

Table 37   Summary table comparing measurement parameters and input data requirements for different options

Option	Measurement Parameters				external input data	test procedure modifications
	CO_2	fuel consumption (FC)	battery electrical balance	electrical energy consumed		
	g/km	l/100km	V	Wh/km		
Tailpipe CO_2. existing measurement	Y	Y (from CO_2)	PHEV and HEV only	EV and PHEV only	No extra data beyond current requirements	No modifications required
Tailpipe CO_2 for ICEV but exclude zero emissions vehicles	Y	Y (from CO_2)	PHEV and HEV only	PHEV only	No extra data beyond current requirements	No modifications required
Tailpipe CO_2, with notional 'GHG intensity' for zero emissions vehicles	Y	Y (from CO_2)	PHEV and HEV only	EV and PHEV only	'GHG intensity' conversion data required	No modifications required
Tailpipe CO_2 adjusted for WTW emissions	Y	Y (from CO_2)	PHEV and HEV only	EV and PHEV only	WTT conversion data required (TTW already covered)	No modifications required
Tailpipe CO_2 adjusted for WTW emissions via efficiency factors	Y	Y (from CO_2)	PHEV and HEV only	EV and PHEV only	WTT conversion data required (TTW already covered)	No modifications required
Vehicle energy use per vehicle km	Y (to derive FC)	Y (from CO_2)	PHEV and HEV only	EV and PHEV only	No extra data beyond current requirements	No modifications required
Vehicle energy use per vehicle km adjusted for WTW	Y (to derive FC)	Y (from CO_2)	PHEV and HEV only	EV and PHEV only	WTT input data required, expressed per unit FC	No modifications required
Inclusion of road fuel usage in EU ETS	Y (to derive FC)	Y (from CO_2)	PHEV and HEV only	EV and PHEV only	ETS calculations required	No modifications required
Manufacturer based trading scheme based on lifetime GHG emissions	Y	Y (from CO_2)	PHEV and HEV only	EV and PHEV only	Lifetime mileage required per vehicle	No modifications required
Cap & trade system for all OEMs of total CO_2 emissions of vehicles sold (g/km)	Y	Y (from CO_2)	PHEV and HEV only	EV and PHEV only	Vehicle sales data for all vehicles	No modifications required
Including embedded emissions in WTW approach	Y	Y (from CO_2)	PHEV and HEV only	EV and PHEV only	Embedded emissions data and WTT input data required	No modifications required
Combining different options with e.g. size dependent mileage weighting	Y	Y (from CO_2)	PHEV and HEV only	EV and PHEV only	Additional vehicle data may be required	May need to test more vehicle variants

Other data required for the assessment of lifecycle impacts would need to be made available for use in the certification procedure. This data is likely to come from external sources, such as assessments of the energy or GHG emissions involved in manufacturing the vehicle (embedded emissions), or of the energy or GHG emissions involved in the fuel or electricity production and supply processes. It is assumed that this external data would be provided for use in the certification process, perhaps with regular updates for changing values (e.g. assumed typical values for WTT emissions associated with particular fuel types). Instead of including WTT aspects in the certification procedure, they could also be added to the vehicle data in the monitoring programme that assesses compliance with the targets.

The quantity and nature of the fuel consumed in the test takes on a further level of significance in this case. A metric that characterises in some way the WTW fuel consumption impacts of a vehicle for certification must consider the type of fuel used and its characteristics. The degree to which the reference fuels used for certification testing are representative of fuels available on the open market should also be considered, as variations may have a significant effect on the overall lifecycle impact.

Hydrogen fuel in particular may need to be considered at a future point in relation to these metrics. There are already certification and testing regulations in place to cover vehicles fitted with internal combustion engines burning hydrogen (both mono and dual fuel applications) as well as hydrogen fuel cell powered vehicles. The testing regulations are based on or analogous to the regulations for other types of motor vehicle given in UN/ECE Regulation No. 101. Even if CO_2 emissions are not produced there is still a requirement to report fuel consumption. These amendments are detailed in EU Regulation No. 630/2012 which gives guidelines for both H_2 and H_2NG fuelled vehicles. For vehicles fitted with an internal combustion engine burning pure hydrogen, gaseous emissions of NOx must still be considered.

The considerations specific to hydrogen fuel include how to measure the fuel consumption, given that hydrogen combustion does not produce CO_2 emissions at the tailpipe. Methods available include measuring tailpipe H_2O and H_2 or measuring fuel tank metrics before and after testing.

11 Choice of utility parameter

11.1 Introduction

The objective of this section is to critically review the assessments carried out under previous service requests with regard to the choice of utility parameter for the period up to 2020, and to assess whether changes that may occur post 2020 affect the conclusions reached. The assessment will take into account the vehicle technologies that may be deployed, and other relevant factors.

It is emphasised that unlike the studies regarding the optimum utility parameters undertaken as part of Service Requests 1 on passenger cars [TNO 2011] Service Request 3 on light commercial vehicles [TNO 2012], this study will not involve any further analysis of the new vehicle sales databases. Rather, it will draw on the earlier analyses, and consider trends resulting from the principal CO_2 emissions reduction technologies that may be employed post 2020. It will then assess whether the changes, that are anticipated post 2020, affect the conclusions reached in the earlier studies.

11.2 Summary review of utility parameters studies from SR#1 – Passenger cars

11.2.1 Introduction

This summary is taken from [TNO 2011]. Whilst mass and footprint were emphasised in the proposal and inception report for SR#1, Subtask 2.3 was entitled "transport utility" and involved the wider investigation of possibilities for using alternative utility parameters for CO_2 limit functions. The approach used was to generate a long list of potential utility parameters, to undertake a preliminary, essentially qualitative analysis against a number of criteria, and to see which potential utility parameters looked promising.

11.2.2 Long list of utility parameters assessed

The inception report originally suggested the following nine database parameters should be assessed:

1. Wheelbase (mm)
2. Front track (mm)
3. Rear track (mm)
4. Total authorised weight (kg)
5. Weight without load (kg)
6. Reference mass
7. Number of seats
8. Overall height (mm)
9. Trunk space / loading space (litre)

Preliminary analysis showed that these were not optimal. For example, the average of the front and rear track multiplied by the wheelbase, to give the vehicles footprint, was chosen as a combination of the first three. Similarly, the weight without load and reference mass are not independent. Consequently a revised list was created and contained the following revised potential utility parameters:

- Pan area (vehicle length x vehicle width)
- Wheelbase
- Number of seats
- Trunk volume
- Payload
- Price
- Mass in running order
- Footprint (wheelbase x average track width
- Footprint x height (as a proxy for internal volume)

11.2.3   Assessment criteria and assessment

The evaluation criteria for the revised list of potential utility parameters included:

- Measurability
- Objectivity of the measurement
- Possibilities/incentives for gaming[47]
- Correlation with CO_2 emissions
- Relation with CO_2 reduction options
- Use in CO_2 legislation in other regions

The revised version of the "long list" of utility parameters was assessed against the evaluation criteria. The conclusions reached are summarised in the table below.

Table 38   Pros and cons of the potential utility parameters

Utility parameter	Pros	Cons
Pan area (length x width)		Footprint is superior to pan area with respect to all criteria, therefore discarded
Wheelbase		Footprint is superior to wheelbase with respect to all criteria, therefore discarded.
Number of seats	One of the true measures of "utility"	Difficult to measure objectively; has poor correlation with CO_2 emissions and provides many possibilities for gaming. Therefore discarded.
Trunk volume	One of the true measures of "utility"	Difficult to measure objectively, has poor correlation with CO_2 emissions and provides many possibilities for gaming. Therefore discarded.
Payload		Payload is a declared value rather than a measured value and because of poor correlation with CO_2 discarded.
Price		Price is not a measure of functional utility. It has a very uneven distribution around its average value, and cannot be objectively measured or verified. Furthermore it promotes gaming and gives credit to high performance cars. Therefore discarded
Footprint x height	A proxy for interior volume which is one the true measures of "utility"	Rewards higher vehicles like SUVs
Mass in running order	Given in more detail in Table 39	Given in more detail in Table 39
Footprint	Given in more detail in Table 40	Given in more detail in Table 40

The pros and cons tables for mass in running order and footprint were considered in greater detail, and the conclusions reached are summarised in the two tables below.

Table 39   Pros and cons of reference mass as utility parameter

Reference mass	
Pros	**Cons**
Easily / objectively measured	Not a direct measure of utility
Accepted by industry (continuity with current legislation)	Possibilities for gaming depend on slope of limit function
Good correlation with CO_2 emissions	Easy options for gaming: "Brick in the boot"
Used in other jurisdictions	Makes weight reduction as CO_2 reduction measure much less attractive

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[47] i.e. bringing a vehicle closer to its target by changing the value of the utility, rather than applying CO_2 reducing measures

Table 40   Pros and cons of footprint as utility parameter

Footprint	
Pros	▪ **Cons**
Easily / objectively measured	Relatively tough on compact / high cars (e.g. MPVs)
Gaming is considered relatively difficult due to required changes in structural design of vehicle and associated consequences for mass and vehicle CO_2 emissions	May promote tendency towards larger cars unless compensated for such autonomous footprint increase
Better proxy for utility than mass	
Used in US legislation	
Good correlation with CO_2 emissions	

In addition to the qualitative assessment given above, a quantitative assessment was made regarding the goodness of fit to a linear correlation between CO_2 emissions and various potential utility parameters. This was undertaken for some of the revised utility parameters, or combinations of these, for example, normalised footprint + mass in running order. The number of registrations (sales) from the database that could be included in the analysis, and the goodness of fit, as determined by the R-squared parameter, was noted. These are given in Table 41.

Table 41   Value of R-squared (coefficient of determination) for CO_2 emissions - utility parameter correlations

linear regression (y= carbon emission) y=ax+b	registrations	R^2 (registration weighted)
x = mass in running order	10,137,144	0.497
x = normalised footprint + mass in running order	9,98,3603	0.462
x = price (Euro)	10,922,232	0.447
x = footprint * height	10,519,775	0.382
x = footprint	10,519,775	0.320
x = wheelbase	10,887,735	0.305
x= normalised (payload + number of seats + trunk volume + mass + footprint)		0.259
x = payload	9,641,401	0.141
x = normalised sum of payload and number of seats (quantity) + trunk volume	9,253,732	0.123
x= normalised number of seats (quantity) + trunk volume	10,453,958	0.094
x= number of seats (volume) + trunk volume	10,453,958	0.059

From this assessment four potential utility parameters have an R^2 value above 0.35, though it is noted none have an $R^2 > 0.5$, and no single potential utility parameter stands out as being significantly superior on the criterion of its correlation with CO_2 emissions. In this context it must be noted that for a parameter to qualify as a useful utility parameter for differentiating CO_2 targets the correlation between the parameter and CO_2 should not be perfect. Some level of correlation is necessary, because otherwise there would be no ground for differentiating the target. But a less than perfect correlation suggests that there is potential to reduce CO_2 while preserving utility. The intention of the legislation is to stimulate manufacturers to make more efficient cars, not necessarily smaller or lighter cars.

It was concluded in SR#1 that this preliminary evaluation did not provide a clear favourite. Three utility parameters were highlighted as being "reasonable candidates" for a regulatory utility parameter:

• Mass in running order
• Footprint (wheelbase x average track width
• Footprint x height (as a proxy for internal volume).

11.2.4   Other considerations with respect to the choice of utility parameter

The SR#1 final report also contains some further analysis which had the potential to provide a steer as to which was the optimum utility parameter.

Comparison of reference mass and footprint based on additional manufacturer cost - The results of the cost assessment and distributional impacts did not significantly contribute to the selection of the preferred utility parameter. Differences in cost and distributional impacts were found to be too small to motivate the choice. It should be noted here that the initial cost assessment for reference mass as utility parameter ignored the fact that under a mass-based target the cost effectiveness of weight reduction as a CO_2 reduction option is reduced as it not only lowers CO_2 emissions but also leads to a lower target. In [TNO 2012b] it was analysed that accounting for this reduced cost-effectiveness would lead to 3% higher costs for meeting a 95 g/km target with mass as utility parameter. This effect works in favour of footprint as utility parameter as footprint fully rewards the impacts of weight reduction on a manufacturer's average CO_2 emissions.

Comparison of reference mass and footprint based on impacts of the penetration of low emitting vehicles – The impact on cost for meeting the target from a finite market penetration of (PH)EVS in 2020 is very similar for both utility parameters. For scenarios with different levels of EV penetration the differences between the additional manufacturer costs based on either mass or footprint as the utility parameter are below 0.6%. This difference also seems too small to motivate the choice of the favourable utility parameter.

Comparison of reference mass and footprint in the context of applying an additional vehicle-based CO_2 limit – It was concluded that the option to apply a vehicle-based limit in addition to the target function provided no ground to decide upon a favourable utility parameter either.

11.2.5   Choice of favourable utility parameter

The paragraphs below are taken directly from the Executive Summary of the SR#1 final report [TNO 2011]. They conclude that overall footprint "seems" to be the favourable utility parameter. However, it also concedes that there are not compelling arguments to clearly comment footprint over mass in running order:

"Since no obviously favourable utility parameter arises from the cost assessments, the choice will need to be based on general pros and cons as discussed above. From these pros and cons two potential effects of the utility parameter choice seem more important than other ones.

Firstly, a relevant argument is that mass reduction will be an important measure for future CO_2 reduction beyond 130 g/km. If mass is used as a utility parameter, applying this measure is made unattractive, since it would lead to a stricter CO_2 target for a manufacturer. The European Commission has the possibility to adjust the limit function when changes in average mass are observed, and for the case of mass reduction this would lead to higher specific targets per manufacturer for given utility values. This would compensate the reduced effectiveness of weight reduction as CO_2 reducing measure in relation to a mass-based limit function. Nevertheless mass as utility parameter provides a first-mover dilemma to individual manufacturers. Since the choice for footprint as a utility parameter would not influence the CO_2 target of a manufacturer in case of light weighting its vehicles, this parameter seems favourable from this perspective.

As mentioned above, [TNO 2012b] estimates the reduced cost-effectiveness of weight reduction under a CO_2 regulation with mass as utility parameter would lead to 3% higher costs for meeting a 95 g/km target. This estimate is based on the costs for weight reduction as assessed in [TNO 2011]. Recent studies by EPA and ICCT (see e.g. [ICCT 2013]) suggest that costs of weight reduction are much lower than the estimates used in [TNO 2011]. This would imply that weight reduction would already be a cost effective option at lower CO_2 reduction levels and as a consequence would lead to an increase in the additional costs for meeting a given target under a mass-based regulation as compared to a footprint-based system.

Moreover the argument that footprint is a better measure for utility is a valid one from a consumer perspective. Consumers tend to buy certain vehicles because of their size, e.g. to transport more people or goods or to transport people with more legroom and comfort, while they do not purchase a

certain car because it is heavy. Since footprint is a much better proxy for vehicle size and resulting utility than mass, footprint seems favourable from a consumer perspective and might increase the acceptance of legislation and other measures (e.g. CO_2 labelling or taxation schemes) based on this utility parameter.

As a result of these arguments, footprint seems to be the favourable utility parameter.

A risk of changing the utility parameter could be that European policy making on cars and CO_2 is perceived by stakeholders as inconsistent, and might make critical stakeholders wonder what changes are to be expected for a next generation standard beyond 2020. The evaluation of alternative utility parameters, however, has made clear that other options generally do not provide any significant advantages compared to footprint but usually do have disadvantages and aspects that make them less practical or even unfeasible in practice. Whereas mass was chosen for the 2015 target, partly because the at least equally attractive alternative of footprint was not available due to the absence of data in the Monitoring Mechanism, there are no alternatives in view now that are potentially better than footprint or mass but cannot be applied yet for practical reasons."

11.3 Summary review of utility parameters studies from SR#3 - Vans

11.3.1 Introduction

This summary is taken from [TNO 2012]. This study built on the findings from SR#1, and avoided inappropriate duplication. The analysis of potential utility parameters for passenger cars had both considered a wide range of potential parameters and excluded the majority based on their assessment against the criteria listed in Section 2.3. The reasons for discarding some potential utility parameters for cars, e.g. price or footprint x height, are equally relevant to vans. Therefore these potential utility parameters were not assessed again in the context of van CO_2 emissions. Other potential parameters, e.g. number of seats, or "trunk" space are not applicable to vans. Therefore, these potential utility parameters also were not considered in SR#3.

11.3.2 List of utility parameters assessed

SR#3 focussed on footprint, payload and mass as potentially utility parameters for light commercial vehicles. It did not extend to the longer list described in Section 2.2 for passenger cars. The mass in running order is the utility parameter used in the current regulation (EU 510/2011).

11.3.3 Assessment criteria

For each of these three possible utility parameters the following sections were covered in the LCV utility parameter study:

- The size of the sample that was analysed. This was to assess the extent to which the quantitative analysis was representative of all light commercial vehicle sales.
- An analysis of the sales weighted average CO_2 emissions as a function of each utility parameter. This quantified:
  - the average values of CO_2 emissions and of the utility parameter being considered;
  - the 100% slope relationship between the two parameters based on a sales weighted least squares fit;
  - the goodness of the fit, using the R^2 parameter of the 2010 (JATO) sales database.
- An analysis of the sales weighted average CO_2 emissions as a function of each utility parameter undertaken for the six light commercial vehicle segments, which comprise the three weight classes for the two principal engine types (i.e. spark ignition and compression ignition). This potentially highlights similarities and differences for the different light commercial vehicle segments.
- An analysis of the sales weighted CO_2 emissions as a function of each potential utility parameter for the individual vehicle manufacturers.

11.3.4 Quantitative assessment

For the light commercial vehicles sales as a whole the studies gave the results summarised in Table 42.

Table 42   Summary of analysis data for light commercial vehicles

Aspect	Mass in running order	Footprint	Payload
Coverage (see note 1)	98.28%	92.79%	95.43%
Average CO_2 emissions	181.4 gCO_2/km	180.3 gCO_2/km	182.7 gCO_2/km
Average value of the utility parameter	1,654 kg	7.08 m_2	928 kg
100% slope line based on JATO 2010 sales database	$CO_2 = 0.118\ M - 14.0$ gCO_2/km	$CO_2 = 17.3\ FP + 57.5$ gCO_2/km	$CO_2 = 0.100\ PL + 90.0$ gCO_2/km
Goodness of fit (R2)	0.81	0.58	0.68

Note 1: Defined as the number of sales for which both CO_2 emissions and the utility parameter are specified in the database, divided by the number of valid, hydrocarbon fuelled light commercial vehicles in the whole dataset.

This quantitative assessment suggests, based on the values of R^2, that the choice of utility parameter attractiveness is:

mass in running order > payload > footprint

11.3.5   Qualitative assessment

The quantitative assessment was undertaken on the assumption that **the relationship between the utility parameter and CO_2 emissions is best described as being linear.** The relative attractiveness of the potential utility parameters was determined on this basis. However, examination of the mass in running order and footprint – CO_2 emissions graphs, Figure 64, shows that this assumption is probably not optimal.

For footprint there appears to be a knee in the data at around 8 m^2. Some reasons for this were discussed in SR#3 report, and arise from subtleties in the testing procedure. A non-linear utility function comprising two linear portions appears to be an attractive alternative better describing the relationship between footprint and CO_2 emissions.

It is, however, likely that this issue will go away with adoption of the WLTP, due to the removal of the upper limit for the mass setting of the chassis dynamometer. In that case it would not be an issue for post 2020 regulation.
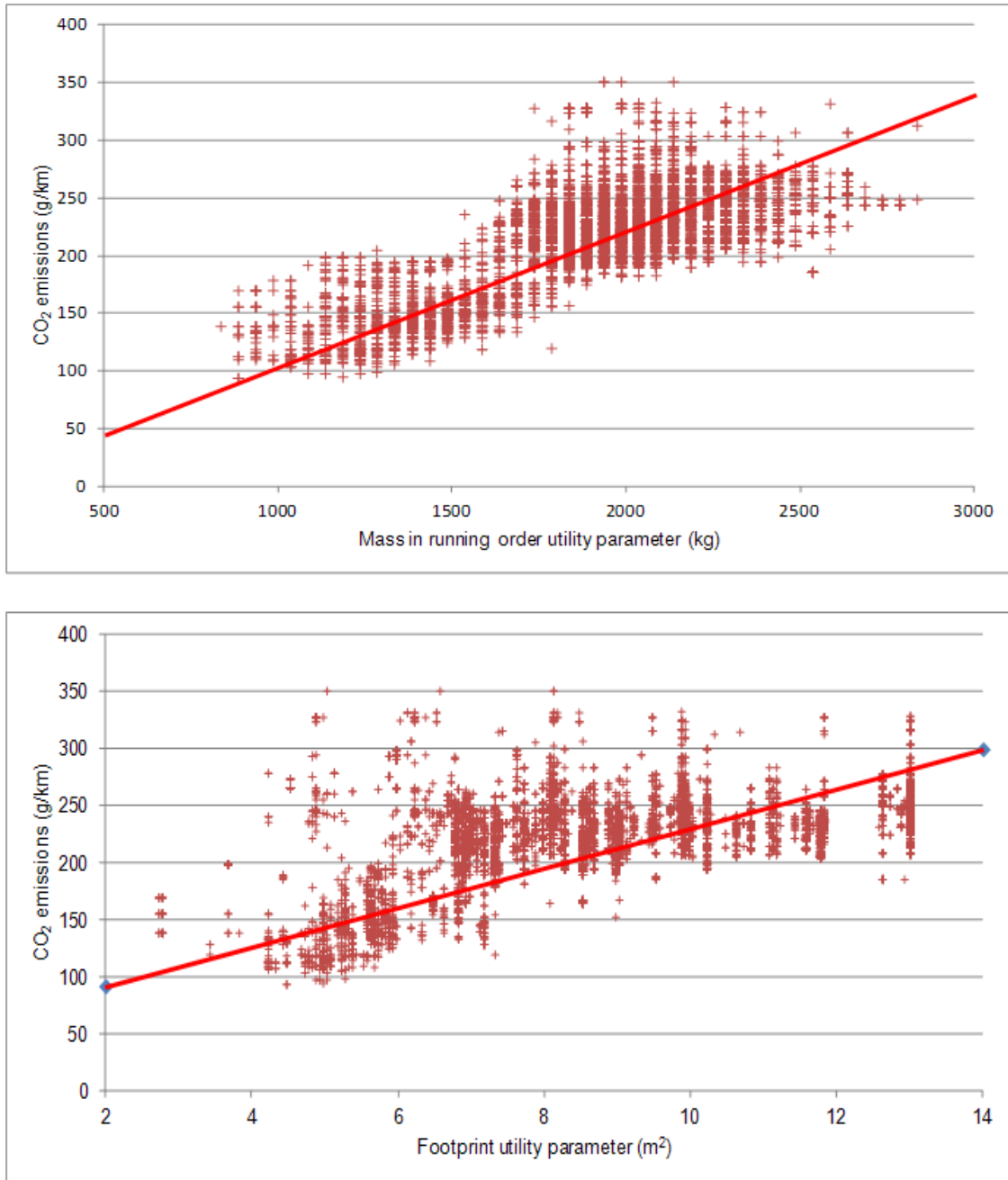
Figure 64 CO_2 and mass in running order resp. footprint values of LCV sales in 2010, and the sales weighted least squares fits through the data

Table 43   Summary of aspects of the different potential utility parameters for light commercial vehicles

	Mass in running order	Footprint	Payload
Regulatory status	Is defined as part of the vehicle specification	Traditionally there are no requirements to define, or record its components (track widths and wheel base). This was the parameter with the largest number of "no data available" in the database. However, this is changed in the new provisions for the Monitoring Mechanism.	Can be inferred. However, whilst the kerb-weight (mass in running order) can be measured, the gross vehicle weight is a declared value. Both values are recorded as part of the vehicle specification.
Utility parameter as a function of LCV purpose	Not directly linked to either of the key utility parameters of LCVs (their ability to move weight and volume). However, given the 3,500 kg upper limit for N1 vehicles, a lower vehicle mass does generate the potential to increase payload.	More closely linked to a key utility parameter – the ability of a vehicle to move volumes (though is not a measure of capacity available in m^3.)	More closely linked to a key utility parameter – the ability of a vehicle to move weight of goods. Anomaly exists where larger vans, e.g. long wheel base variants which have a larger load capacity, but are heavier when empty and with the 3,500 kg GVW limit of N1 LCV, have a lower payload capacity than their short wheel base relatives.
Fitting of utility parameter for all LCVs	Linear fit quite a good approximation. Already within regulations.	Linear fit poor. Better would be either a non-linear function, or a linear function up to a threshold, e.g. $8m^2$.	Linear fit poorer than for mass in running order. CO_2 emission values above payloads of ~1,900kg are misleading. However, this is probably not much of an issue because sales of such vehicles are very low (<1% of all LCVs). Better would be either a non-linear function, or a linear function up to a threshold, e.g. 1,000 kg. However, this would lead to significant methodological changes compared with current car and LCV CO_2 legislation, and therefore probably not preferable. These options could be investigated further.
Manufacturer by manufacturer analysis	Quite a wide spread of masses in running order for different manufacturers. Therefore gradient of the utility-based target function important because changes in the gradient affect manufacturers differently.	6 of the 7 high volume manufacturers have very similar average footprints. For these it is the target value that is key rather than the gradient of the utility-based target function. Single high volume manufacturers may be disproportionately impacted by the gradient dependent on that chosen.	As for mass in running order, quite a wide spread of payloads for different manufacturers. Therefore gradient of the utility-based target function is important because changes in the gradient affect manufacturers differently

11.3.6   Conclusions with respect to the choice of utility parameter

Of the three possible utility parameters, payload is the least attractive, not least because it is a declared value rather than a physical parameter of the vehicle that can be independently verified. Therefore the choice of the optimal parameter is between mass in running order and footprint. This study of light commercial vehicles indicates both are reasonable, but neither is clearly superior. The ultimate choice will probably be determined by the inclusion of additional criteria.

11.4   Matrix of technology measures, the likely importance of each technology to cars/vans pre- and post-2020, their impacts on CO_2 and their impacts on utility parameters

11.4.1   Summary of technologies considered and their likely importance

The purpose of this section is to analyse the extent to which new vehicle technologies may affect the utility parameter used for the CO_2 legislation. The list of technology measures and fuels that are anticipated to be important post 2020 for the reduction of CO_2 emissions, is presented in Table 44.

Table 44   The compatibility of technology options and fuels with the petrol and diesel ICE baseline vehicles

	Petrol	Diesel
Powertrain technologies		
Hybrid	Yes	Yes
Plug-in hybrid	Yes	Yes
Electric	Replaces	Replaces
Fuel cell	Replaces	Replaces
Non-powertrain technologies		
Light-weight materials	Yes	Yes
Improved aerodynamics	Yes	Yes
Fuels		
Biofuel	Yes	Yes
LPG	Yes	
CNG	Yes	

The table is constructed to indicate the compatibility of each technology, or fuel, with the primary fuel (petrol or diesel) to which the technology might be applied. A "Yes" implies use with the conventional fuel, i.e. there being diesel plug-in hybrids and biofuel replacement of fossil diesel fuel. "Replace" indicates the expectation that electric vehicles, or hydrogen fuel cell vehicles, could replace some (all) petrol and diesel light duty vehicles. The table makes no assumption regarding the extent to which the new technologies are anticipated to replace the current fossil fuelled ICE. Indeed this will vary for different technologies and for different vehicle segments. For example, the uptake of a technology for super-mini cars is expected to be quite different to its uptake for Class III diesel vans.

The average CO_2 emissions are taken from the decarbonisation scenario developed for the [EC 2011] white paper (and also discussed in Section 5.3, Fleet composition scenarios). This provides details of the overall fleet average, as a function of time, but **not the details of how this is achieved.**

Consequently, currently the model gives insufficient information to generate an evidence based matrix of technology measures, and the likely importance of each technology to the different groups of light duty vehicles both pre- and post-2020. Notwithstanding, the impact of each technology on CO_2 and their impacts on each of the utility parameters can be assessed, and is discussed in the next section.

11.4.2 Assessment of impacts of technologies on average CO_2 and on utility parameters

In this section the impacts of the different technologies on the three key potential utility parameters are examined together with reviewing the impact of the technologies on average CO_2 emissions. The key characteristics of weight, volume and some approximate dimensions are given in the table below. Also included in the table are some comments on the flexibility of the dimensions, and the potential location of the additional technology hardware. Appendix C contains some further details, and links to references from which the data in Table 45 has been drawn.

These characteristics of the different vehicle technologies lead to changes in the potential utility parameters:

- For mass in running order it is relatively straightforward, with a change in mass caused by the addition of technology leading directly to an equivalent change in mass in running order.
- For footprint the situation is not so simple. For most or all technologies, incl. e.g. the use of light-weight materials, it is unlikely that the addition of the CO_2 reduction technology will lead to a change in footprint. For improved aerodynamics this is less certain.
- For options involving switching to LPG or CNG manufacturers making such vehicles virtually always use the same chassis and basic body shell as for the petrol or diesel equivalents. Therefore, although the additional fuel tanks do occupy volume within the vehicles, this is usually achieved by reducing luggage capacity but with no change to the vehicles' footprint. Examples of this include the Honda Civic GX passenger car and the VW Caddy Eco van.
- For full electric vehicles matters are a little more complex because some electric vehicles are designed having no ICE counterpart. The approach taken is to consider a range of the electric vehicles, and the passenger car (or LCV) segment they belong to, and compare these with a number of ICE alternatives. Some FEVs are electric versions of an ICE model, e.g Mitsubishi i-Miev, smart FourTwo Electric Drive and BMW Mini-E are electric equivalents of the Mitsubishi I, the Smart FourTwo and BMW Mini. For these vehicles whilst their mass in running order varies, their footprints are the same as their ICE counterparts. Also the Toyota plug-in Prius has the identical footprint to the standard Prius T3.

For some models there is no direct equivalent. Appendix C contains comparisons of:

- Peugeot Ion and Citroen C_Zero are compared with other Category A vehicles (minis). However these vehicles are basically iMievs and so the comparison above also applies;
- Toyota Invicata EV and Renault Zoe and other Category B vehicles (super-minis);
- Vauxhall/Opel Ampera, Nissan Leaf and Ford Focus EV and other Category C vehicles (lower medium).

The analysis indicates that average pan area[48] of the electric vehicles is not significantly different to the ICE vehicles of that category. Specifically, the pan area of the 3 Category C EVs is 7.9 m^2 whereas the pan area of the 5 Category C equivalents is also 7.9 m^2. However, the Renault Fluence ZE does have a larger pan area (8.36 m^2).

Similar evidence is amassing for fuel cell vehicles, although there are fewer models available. The Honda Clarity has a footprint of 4.44 m^2, very similar to the Honda Accord (4.42 m^2), which is larger than for the Honda Civic (4.02 m^2), a smaller model. The Vauxhall/Opel Hydrogen 4 is built using the same chassis as the Chevrolet Equinox. The Mercedes B series hydrogen fuel cell vehicle uses standard B-series body shells, and consequently the footprint and footprint * height for the fuel cell version and its ICE parent are identical.

In summary, the large majority of technology measures, or fuel options, lead to **increases in vehicles' mass in running order**. The exceptions being light-weighting, which as the name suggests, leads to a reduction in mass in running order, and the use of biofuels, which causes very little change in mass in running order.

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[48] as wheel base and track width were not known for all these vehicles, the larger "pan area" (length x width) is used as a proxy for footprint.

Table 45   Characteristics of vehicle technologies

Vehicle technology	Weight of small, medium and large vehicles		Comments
Baseline petrol ICE, 2020 vehicles	875, 1030, 1140 kg		Inferred from Ricardo data for BEVs and evidence based additional weight of BEVs to current petrol ICEVs
Baseline diesel ICE, 2020 vehicles	900, 1065, 1180 kg		

Vehicle technology	Incremental weight of technology	Incremental volume of technology	Comments
Powertrain options			
Petrol hybrid vehicles	+237 - +324 kg	Around 50 – 70 litres	Weight data from Ricardo data, relative to BEV (FEV), volume based on average density of additional components
Diesel hybrid vehicles	+237 - +324 kg	Around 50 – 70 litres	
BEV (FEV) relative to petrol ICE	+180 - +360 kg	Around 35 – 70 litres	Weight data from Ricardo data, relative to BEV (FEV), volume based on average density of additional components
BEV (FEV) relative to diesel ICE	+155 - +320 kg	Around 35 – 70 litres	
PHEV – Petrol (2020)	+264 - +349 kg	Around 50 – 70 litres	Weight data from Ricardo data, relative to BEV (FEV), volume based on average density of additional components
PHEV – Diesel (2020)	+264 - +349 kg	Around 50 – 70 litres	
EREV	+290 - +353 kg	Around 55 – 70 litres	Assumptions as above
FCEV	+200 - +360 kg	Around 135 – 170 litres	From comparison of FC vehicles and their ICE counterparts. Volume change based on average density of additional components. Note need for fuel storage as for CNG or LPG
Non-powertrain options			
Light-weight materials	-30 to – 185 kg	-4 to -25 litres	All over bodywork
Improved aerodynamics	Negligible change	Rounding may reduce internal volume	Changes particularly at corners of vehicle. May lead to longer vehicles with reduced frontal area.

Vehicle technology	Incremental weight of technology	Incremental volume of technology	Comments
Options using alternative fuels			
Biofuels	Negligible change	Negligible change – used standard fuel tanks	Negligible change – used standard fuel tanks
LPG	Around + 80 kg	Around + 110 litres	Key item is LPG fuel tank, rounded LP cylinder e.g. 0.36 m diameter and 1.0 m long. Location variable, but safety limitations
CNG	Around + 120 kg	Around + 110 litres	Key item is CNG fuel tank, rounded HP cylinder e.g. as for LPG, but 100 litre cylinder is only equivalent to 17 litres petrol, but safety limitations

In contrast, the large majority of technology measures, or fuel options, lead to **no change in vehicles' footprint**. The most probable exceptions are those where the fuel used needs to be stored at a high pressure, and this leads to the requirement for pressure vessels (for example, switching to CNG, using hydrogen fuel cells, or, to a lesser extent, switching to LPG). These are labelled "probable exceptions" because to date there is little evidence that vehicles using these fuels have larger footprints, or are

higher. Also improved aerodynamics may impact on footprint as in the longer term this could involve longer / narrower vehicles.

11.4.3   Potential impact on cost effectiveness of technologies for different utility parameters

In principle different utility parameters can lead to different average costs for meeting a given target. This is mainly due to different resulting targets per manufacturer leading to different distributions of the required reduction efforts over the different manufacturers. This effect, however, turns out to be small as the costs for meeting the targets have been found to be similar for mass and footprint.

A more direct impact on cost effectiveness occurs when an applied technology directly changes the value of the utility parameter. This could be a positive or negative impact, and its magnitude will depend on the slope of the utility-based target function. The potential impact scales with the slope, being zero for a 0% slope, i.e. when the CO_2 emissions target is constant, and utility parameter independent.

A technology supporting impact arises when the addition of the technology leads to a change in utility parameter that further enhances its cost effectiveness. Consequently, this includes any technology which leads to an increase in vehicle weight **and** a reduction in CO_2 emissions. The largest difference occurs with electric vehicles with zero tailpipe emissions but an increase in vehicle weight of 180 to 360 kg for passenger cars relative to their petrol ICE equivalents. For the utility relationship given in EC No 443/2009, these weight increases lead to an **increase** in target CO_2 emissions of 8.2 – 16.4 g/km.

A technology disincentivising impact arises when the addition of the technology leads to a change in utility parameter that reduces its cost effectiveness. The most important of these is light weighting, where reductions of 30 – 185 kg lead to a **reduction** in target CO_2 emissions of 1.4 – 8.5 g/km. The impact on cost-effectiveness is illustrated by how the cost curve for CO_2 reduction in 2020 changes when the effect of mass on the target is accounted for in the net CO_2 reduction associated with light-weighting. This is depicted in Figure 65, which is taken from a separate note on this issue, delivered to the Commission as part of the Framework Contract on Vehicle Emissions. Even with this discounted effectiveness, however, weight reduction would become an increasingly important option for targets beyond the 95 g/km level for 2020.
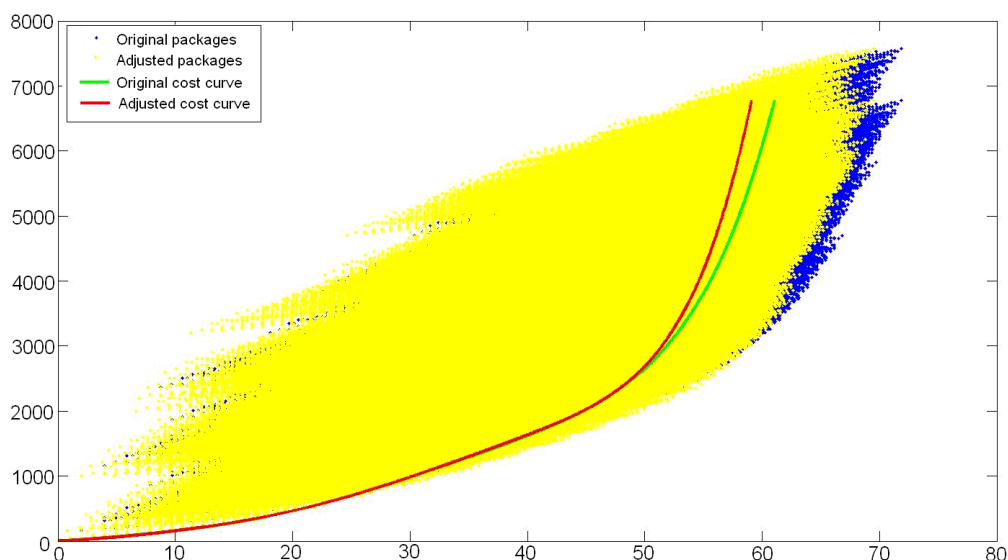

Figure 65   The original cost curve (green) for the **medium petrol segment**, based on the original technology packages defined in [TNO 2011] and alternative cost curve (green) based on technology packages corrected for the target shift resulting from applying mass-reducing technologies

The adjustment of the average utility parameter for the whole fleet, i.e. M_0 for mass in running order, partially mitigates against this. However, if 20% of the fleet became electric vehicles then each EV's

increase in CO_2 target is reduced by a fifth. Consequently, while the adjustment of the average utility parameter **mitigates against a net increase** in CO_2 emissions, it does not totally mitigate for each vehicle, or for each manufacturing group.

From the findings in the previous section it was found that the impact of new technologies on different utility parameters can be summarised as:

- mass in running order – generally an increase by typically 200 – 350 kg for the higher CO_2 emissions reduction technologies, although a decrease of -30 to -185 kg for light weighting;
- footprint – generally little change.

Consequently, the potential impact of the choice of utility parameter on the attractiveness of different technologies can be summarised as:

- mass in running order – generally technology supporting, leading to an **increase** in the CO_2 emission target from the addition of technology;
- footprint – generally little impact on target CO_2 emissions.

The adjustment of the average utility parameter for the whole fleet in the target function, i.e. M_0 for mass in running order, partially mitigates against this, as explained in the next section, and leads to early mover dilemmas when technologies are not applied equally by al manufacturers.

11.4.4   First mover dilemmas related to mass as utility parameter

Regulation (EC) No 443/2009 and the amendments proposed in COM/2012/393 set CO_2 emission targets as follows:

2015: $CO_2 = 130 + a \times (M - M_0)$ with $a = 0.0457$ and $M_0 = 1372$ kg

2020: $CO_2 = 95 + a \times (M - M_0)$ with $a = 0.0333$ and M_0 to be determined

Mass as utility parameter effectively reduces the impact of weight reduction, as discussed above. If a manufacturer reduces the weight of its cars he also reduces his CO_2 emission target under the European CO_2 legislation. How that works out, also in relation to the possibility for the Commission to adjust the value of M_0 in the above formulas, is explained in more detail in this section.

The CO_2 legislation allows the Commission to adjust the value of M_0 in the formulas describing the target line, if significant trends in average vehicle mass are observed. This provision is especially designed to counteract the impacts of "autonomous mass increase", which would otherwise undermine the effectiveness of the legislation. The provision, however, equally applies to situations in which a decrease in vehicle weight is observed through the Monitoring Mechanism. When such a trend results form a downward segment shift in the vehicle sales, the adjustment is likely to work out in a fair way on the individual manufacturer targets as such segment shifts generally occur throughout the market. Things, however, become slightly more complicated when reductions in average weight are the results of one or more OEMs applying significant levels of weight reduction technologies.

If one or a few OEMs apply weight reduction their targets are adjusted downwards. This reduces the effectiveness of weight reduction for these OEMs, as the reduction in distance to target is only a fraction of the reduced average CO_2 emission. If subsequently the M_0 in the target line is adjusted all OEMs get a higher target and the reduced targets for the OEMs applying weight reduction are only partially compensated. So first movers also have a disadvantage after adjustment of M_0, while they help other OEMs to get a higher target. This is illustrated in Figure 66.

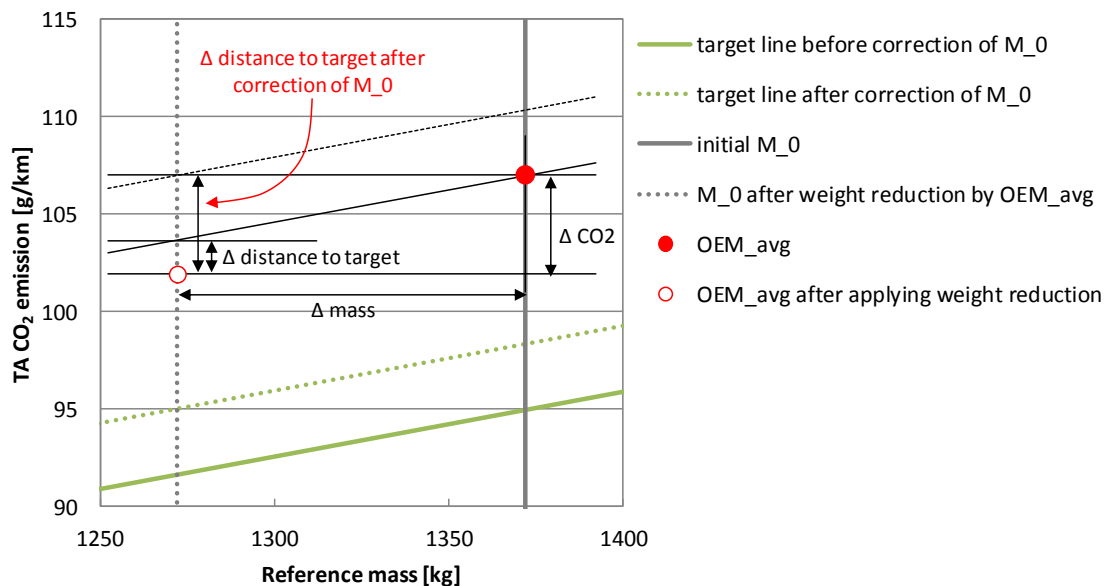**Impact of weight reduction on manufacturers' targets**
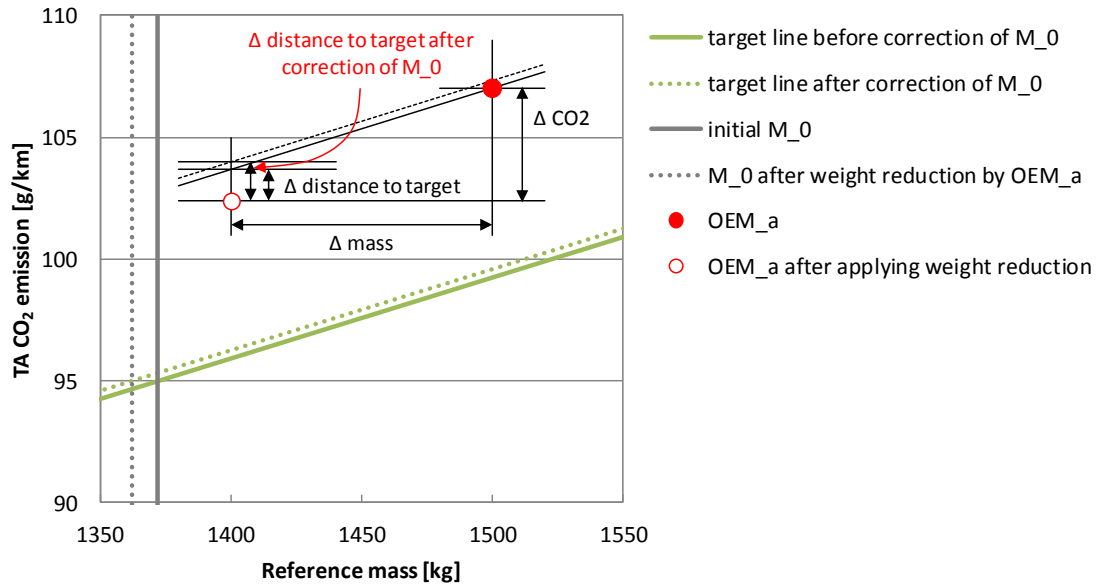
Assumptions: OEM_a applies weight reduction of on average 100 kg for its entire sales. Impact on CO_2 is estimated using $\Delta CO_2/CO_2 = 0.65 \Delta m/m$. Change in M_0 is for the situation in which OEM_a is the only OEM to apply weight reduction.

Figure 66   Impact of weight reduction on manufacturers' targets when a single OEMs applies weight reduction

No problem occurs if all OEMs apply weight reduction to the same extent, if indeed the Commission decides to adjust M_0 in response to that. In that case, after correction of M_0, the change in distance to target resulting from weight reduction is equal to the reduction in average CO_2 emissions of each manufacturer. This is illustrated in the Figure 67.

Impact of weight reduction on manufacturers' targets

Assumptions: All OEMs apply weight reduction of on average 100 kg for their entire sales. Impact on CO_2 is estimated using $\Delta CO_2/CO_2 = 0.65 \Delta m/m$. Change in M_0 is therefore 100 kg.

Figure 67   Impact of weight reduction on manufacturers' targets when all OEMs apply weight reduction to the same extent

The opposite of this effect occurs when OEMs apply CO_2 reducing technologies that increase the weight of vehicles. Battery electric vehicles are an extreme example of that. Due to the mass of the batteries, the average mass increases if an OEM sells a significant share of BEVs or HEVs/PHEVs. This leads to an increased target for this OEM, while the fact that electricity consumed by BEVs and PHEVs counts as 0 g/km already creates a leverage reducing the reduction efforts to be made by the OEM on conventional vehicles. If a few OEMs sell BEVs/HEVs/PHEVs, M_0 may be adjusted upwards leading to reduced targets for all manufacturers, while only partially compensating the higher target for the OEMs selling BEVs/HEVs/PHEVs. These therefore keep their advantage, while they cause their competitors to get a lower target. This is illustrated in Figure 68. Obviously, if all manufacturers sell a similar share of EVs and M_0 is adjusted, then all manufacturers go back to their original target. The effect of EVs on mass is then fully compensated for each manufacturer.

Impact of selling EVs on manufacturers' targets
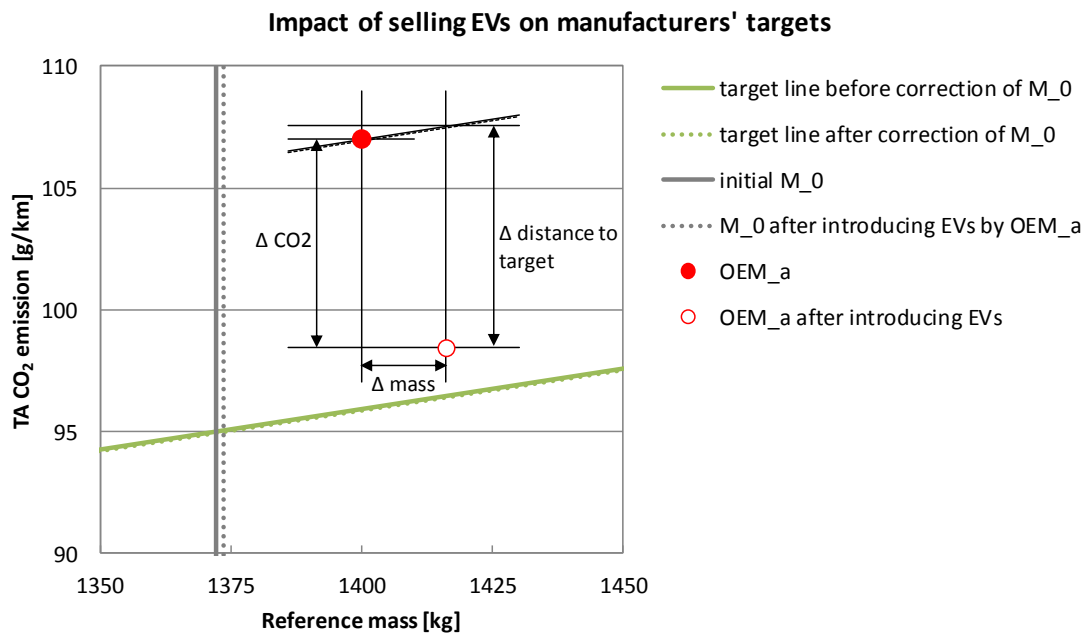
Assumptions: OEM_a has 10% market share in EU and sells 8%EVs, which are on average 200 kg heavier than ICEVs. Change in M_0 is for the situation in which OEM_a is the only OEM to sell EVs.

Figure 68   Impact of selling EVs on manufacturers' targets when a single OEMs sells EVs

11.4.5   *Anticipating the technologies most likely to become important post-2020*

In order to meet the 95 g/km average passenger car target and the 147 g/km average light commercial vehicle target by 2020, and to deliver further reductions beyond this date, changes in light-duty vehicle powertrain technologies and fuels and weight reduction are likely to continue to be required.

The selection of the technologies most likely to be used will depend on the regulatory approach taken, and the metric that is used in the future.

It is presumed that similar progress is made towards reducing the carbon footprint of Member States in areas other than transport, and specifically that there is a large decarbonisation of the electricity supply industry. This is important because if the metric changed from being simply tailpipe (i.e. TTW) CO_2 emissions to a metric that included a WTW factor for zero emission vehicles, the attractiveness of electric vehicles would decrease, and this may lead to a reduction in their uptake.

Nevertheless, in order to reduce CO_2 emissions from passenger cars to the levels aimed for in the 2011 White Paper, battery electric vehicles and/or fuel cell electric vehicles must become dominant in new sales beyond 2030. In parallel with the above zero tailpipe emission technologies, the adoption of other CO_2 emission technologies are expected for ICE powertrain vehicles.

11.5   Conclusions

The SR#1 study concluded that for passenger cars there were three reasonable candidates for a regulatory utility parameter:

* Mass in running order
* Footprint (wheelbase x average track width
* Footprint x height (as a proxy for internal volume).

For LCVs the SR#3 study concluded that of the three possible utility parameters, payload is the least attractive, and the choice of the optimal parameter is between mass in running order and footprint. The study indicated both are reasonable, but neither is clearly superior. The ultimate choice will probably be determined by the inclusion of additional criteria, for example the potentially optimal parameter for passenger cars.

The survey of the impacts of new technologies on the possible utility parameters concluded:

* The vast majority of CO_2 emissions reduction technologies lead to **increase in mass in running order**, the exceptions being light-weighting and improved aerodynamics;
* The combined effects of measures is to lead to a net **increase in mass in running order** because the mass increase due to EVs / HEVs / PHEVs is larger than the max reduction due to light-weighting (the BEV or PHEV + strong light weighting leads to a net mass increase of around 180 kg);
* Also, mass in running order as the utility parameter disincentives the use of light weighting because it reduces the cost effectiveness of applying weight reduction;
* The vast majority of CO_2 emissions reduction technologies lead to **no change in footprint;**
* Whilst there is very little evidence, it is most likely that height too will be unaffected by the vast majority of CO_2 emissions reduction technologies. This, when combined with the above conclusion that footprint too will broadly remain constant, leads to the conclusion that internal vehicle volume, or footprint x height, is also anticipated to remain constant.

Consider a future scenario where a sizeable fraction of light duty vehicles are full electric vehicles and a few per cent are hydrogen powered fuel cells, and the majority of vehicles are ICE combined with one, or more probably several, CO_2 emissions reduction technologies. In such a scenario the footprint vs. CO_2 emissions plot will become somewhat polarised, with a group of zero tailpipe emission vehicles having a range of foot prints, and the remainder spanning a **similar footprint range** to the current profile, but with lower CO_2 emissions.

In this scenario, there will be a similar polarisation in the mass in running order vs tailpipe CO_2 emissions graph, because of the zero tailpipe emission vehicles. The remaining vehicles are predicted to span **a higher mass in running order range** to the current profile because of the weight of the CO_2 reduction technologies.

Based on the utility relationships for mass in running order given in Regulations 443/2009 and 510/2011, and equivalent equations linking footprint to CO_2 emissions, the target CO_2 emissions will have changed as follows:

* They will have increased for mass in running order since the net average mass in running order will most likely have increased;
* They will be virtually unchanged for footprint.

If all vehicles were, for example, BEVs or PHEVs with strong light weighting, leading to a net increase in mass in running order of 180 kg, then M_0 increase by 180 kg leading to CO_2 targets for each manufacturer to increase by 8.3 g CO_2/km. For this scenario the technologies would not affect average footprint, leaving the CO_2 target unaltered.

However, if the average vehicle mass in running order M_0 were adjusted so that despite increases in the average vehicle in mass in running order the average CO_2 emissions value does not increase, then this drawback of using mass in running order as the utility parameter would be mitigated for the whole fleet. But this would not necessarily be the same for all manufacturers, depending on whether only a few or all manufacturers apply technologies that affect mass.

The above analysis concludes that the addition of CO_2 reduction technologies is unlikely to lead to increases in footprint. However, there may be other pressures that lead to an "autonomous footprint increase". In this case if FP_0 were also adjusted so as to not allow the average vehicle footprint to increase, this would be a strong disincentive against this trend.

Overall it is expected that the choice of utility parameter, whether mass in running order or footprint could influence the choice of vehicle technologies that might be used. Mass in running order, is an incentive for the adoption of electric vehicles, because they are heavier and have a higher CO_2 emissions target than their ICE counterparts, and is a disincentive for strong light-weighting. In part, this could be mitigated with adjustments to M_0, but care needs to be taken regarding how equable this is for different manufacturers, particularly those not producing electric vehicles. Having footprint as the utility parameter, on the evidence currently available, generally circumvents these distortions, and appears to be more technology neutral.

In view of the above the following reasoning could be developed: The use of an adjustable M_0 in the target function is intended to correct for autonomous mass increase resulting from market trends or OEMs adding luxury features to vehicles. It was not introduced in view of mass effects of new technologies. Selecting a utility parameter U that is not affected by new technologies makes that U_0 only has to be changed to compensate for autonomous market effects. This reduces the chance that it will have to be changed and as such increases planning certainty for OEMs regarding their target. Moreover, it avoids undesired "distributional" impacts on OEMs with different technology strategies. This could be a powerful argument in favour of moving away from mass in the longer term.

12 Border between van and car legislation

12.1 Introduction

The regulations concerning CO_2 emissions from passenger cars and light commercial vehicles (vans) are two separate pieces of legislation. They are based on the same overall approach in the sense that they regulate EU fleet average CO_2 emissions and that manufacturer-specific targets are based on a linear target function that uses reference mass as utility parameter. The two pieces of legislation differ in the sense that they have different targets levels, different implementation dates for the short term targets, and different utility-based target functions (CO_2 target as function of vehicle mass in running). They do have a common implementation date (2020) for the longer term target, although the target values are different.

It could be attractive to simplify the legislation post 2020 by merging the regulatory approaches for cars and vans. However, such a merging should:

- not lead to a net increase in GHG emissions, and
- be equitable for the different car and van manufacturers.

This chapter considers options for increased integration of the regulations for cars and vans as an element of alternative approaches to regulating CO_2 emissions from light duty road vehicles for the period after 2020. To that end the analysis contains the following steps:

- review of the current different legislative regulations
- review of the average emissions and their dependence on utility parameters from the most recent analysed European sales databases;
- identification of the underlying reasons for / origins of the different sloped utility functions, and consequences of those for the possibility to merge the regulations;
- assessment of the potential to merge the regulatory approaches in a manner that does not lead to a net increase in CO_2 emissions, whilst simplifying the legislation, by examining four different approaches to this.

Table 46   Summary of CO_2 regulations for light duty vehicles

Parameter	Passenger cars EC No 443/2009	Light commercial vehicles EU No 510/2011
Short term target	130 g/km	175 g/km
Target year	2015	2017
Utility-based target function: Specific emissions CO_2 =	$130 + 0.0457 (M - M_0)$ with $M_0 = 1,372$ kg	$175 + 0.093 (M - M_0)$ with $M_0 = 1,706$ kg
Gradient of utility-based target function	60%, i.e. 60% of the slope of the 100% target line based on a constant % reduction relative to the sales weighted best fit through 2006 data	100%, i.e. equal to slope of the target line based on a constant % reduction relative to the sales weighted best fit through 2007 data
Longer term targets	95 g/km	147 g/km
Year 100% compliance required by	2020	2020
Proposed utility-based target function[49]: Specific emissions CO_2 =	$95 + 0.0333 (M - M_0)$ with M_0 to be defined pursuant to Article 13(2)	$147 + 0.096 (M - M_0)$ with M_0 to be defined pursuant to Article 13(2)

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[49] European Commission proposals for the modalities for implementing the 2020 targets have been laid down in COM(2012) 393 final for passenger cars and COM(2012) 394 final for light commercial vehicles.

12.2 Review of the current light duty vehicles CO$_2$ regulations

Regulation EC No 443/2009 details the CO$_2$ emissions limits for passenger cars, while regulation EU No 510/2011 gives analogous details for light commercial vehicles. The average CO$_2$ emissions, date for 100% compliance, and the mass in running order vs. CO$_2$ emissions target relationship are summarised in Table 46. As can be seen, the two different regulations are distinctly different in many respects.

12.3 Review of the characteristic of the latest sales databases

The type approval CO$_2$ emissions values of passenger cars and light commercial vehicles, as a function of the value of the utility parameter mass in running order are given in Figure 69. The sales distributions for the two vehicle categories as function of mass are given in Figure 70. From the latter it is especially clear that for passenger cars the sales of vehicles with high mass (e.g. > 1,700 kg) are limited, while LCVs almost half of the sales has a mass above 1,700 kg.
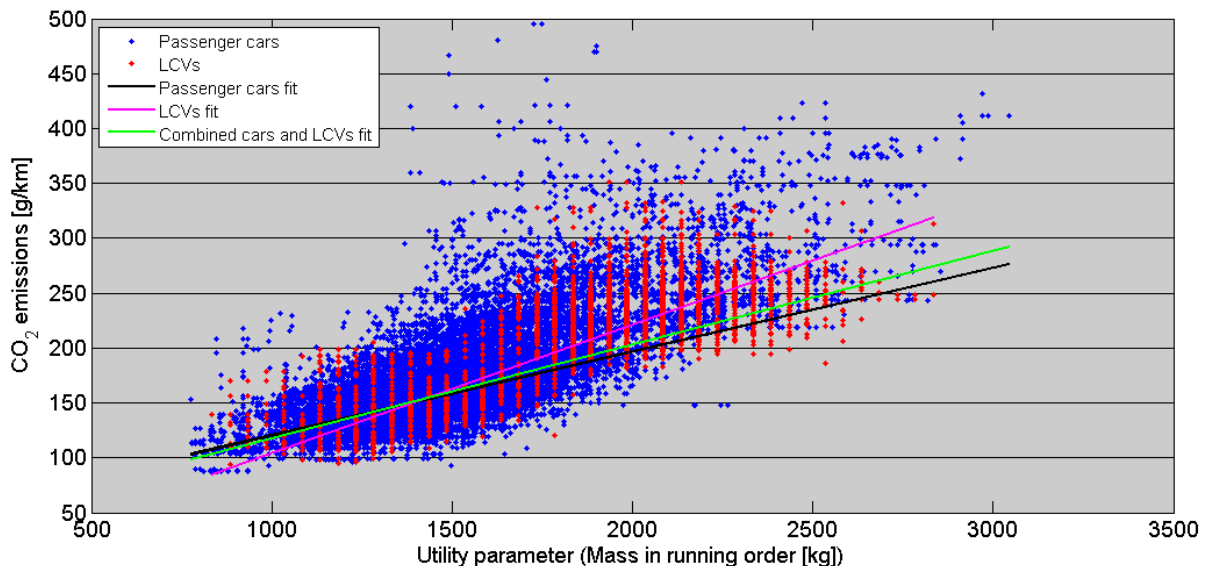

Figure 69   CO$_2$ and mass values of passenger car sales in 2009 and light commercial vehicle sales in 2010, and the sales weighted least squares fits through both datasets

It is seen that the datasets of passenger cars and light commercial vehicles have significant overlap. However, the sales weighted least squares fit through each dataset are markedly different. It is these least-squares fits that form the basis for determining the relationships between the CO$_2$ emission target and the utility parameter mass in running order that are used to define the 2020 targets.

The equations for the two sales weighted least squares fits are:

For cars: CO$_2$ emissions = 0.0763 M + 43.92, and average mass in running order = 1,346 kg

For vans   CO$_2$ emissions = 0.1173 M – 13.15, and average mass in running order = 1,649 kg.
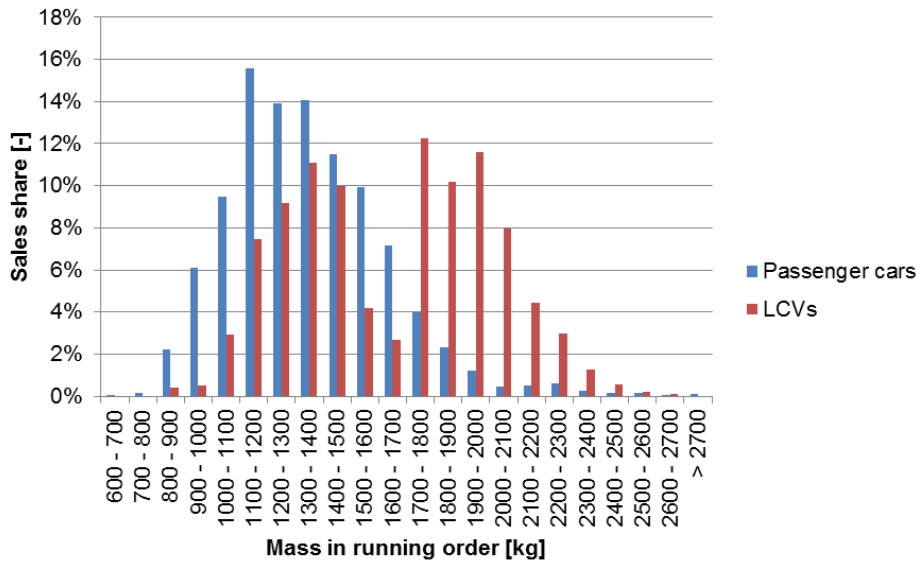
Figure 70   Sales distribution of passenger cars and LCVs over the utility parameter range: mass in running order

From chapter 11 on the choice of utility parameter, it is evident that choice for the optimum utility parameter is between mass in running order and footprint (wheel base x average track width). Consequently, although the analogous footprint / CO_2 emissions relationship has no current legislative relevance, this too is reviewed with a view to informing options for the future legislative framework. The type approval CO_2 emissions values of passenger cars and light commercial vehicles, as a function of the vehicles' footprints are given in Figure 71.
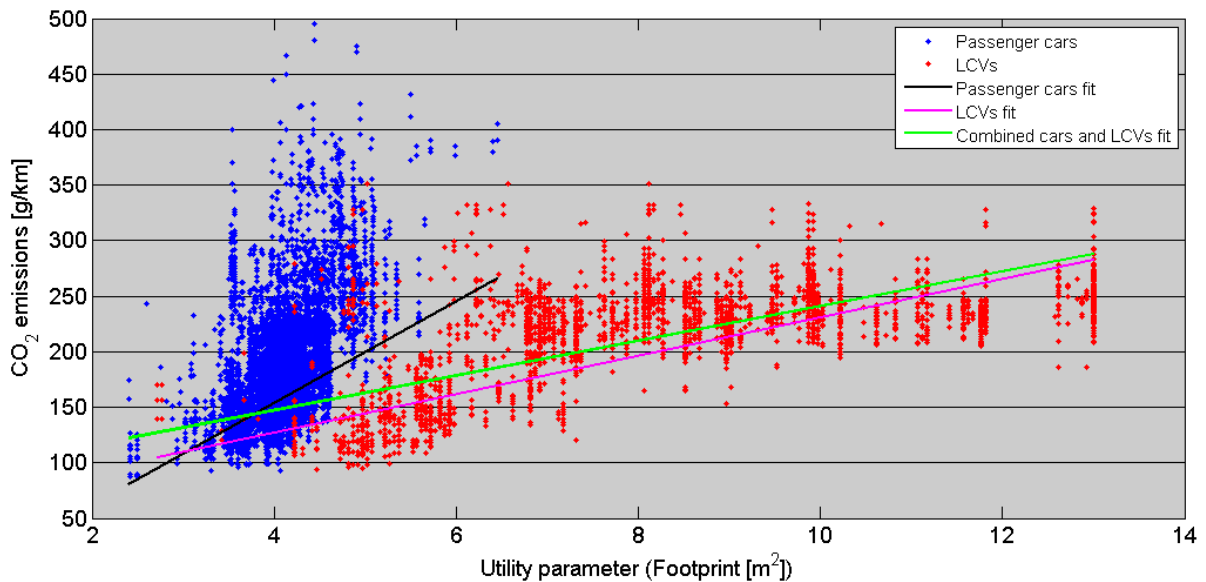

Figure 71 CO_2 and footprint of passenger car sales in 2009 and light commercial vehicle sales in 2010 and the sales weighted least squares fits through both datasets

In contrast to Figure 69 it is seen that the datasets for passenger cars and vans have little overlap. The sales weighted least-squares fit through each dataset are:

For cars: CO_2 emissions = 45.852 FP - 29.97, and average footprint = 3.85 m^2

For vans CO_2 emissions = 17.325 FP + 57.68, and average footprint = 7.08 m^2.

The graphs in Figure 69 and Figure 71 have a mark for each row of data in the database, irrespective of how many sales are involved. Consequently, in addition to the "overlap" of the footprints of different models the distribution of sales among the different footprints is also important. These are shown in Figure 70 (mass in running order) and Figure 72 (footprint).
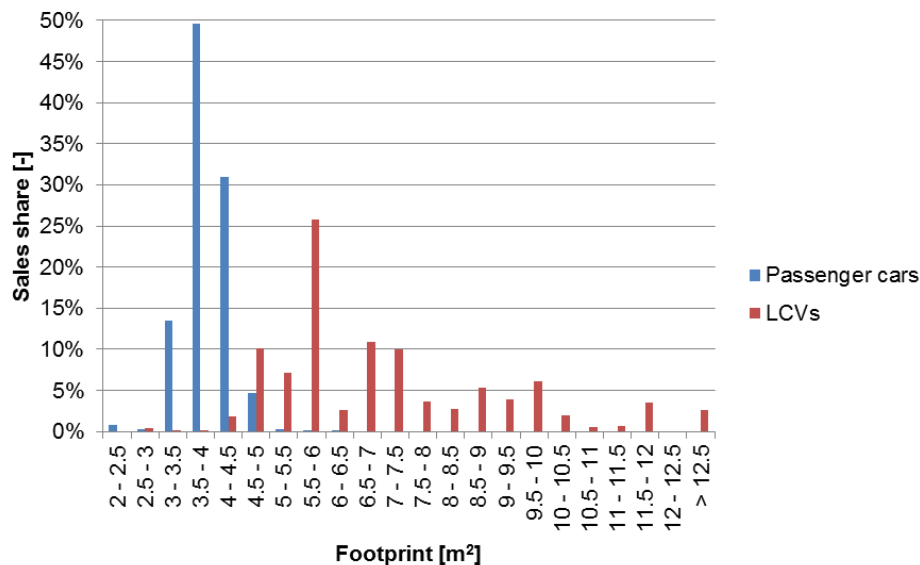

Figure 72   Sales distribution of passenger cars and LCVs over the utility parameter range: footprint

12.4   Origins of the differences between the cars and vans regulations

For mass in running order vs. CO_2 emissions over a larger part of the mass range, i.e. above around 1,400 kg, vans have a higher CO_2 emissions. Origins of the differences can be categorised as:

- being due to differences in the vehicles, and
- being due to differences in the testing procedures.

For the smaller vans some can be described as car derived vans, e.g. Ford Fiesta, Vauxhall/Opel Astra(van) and Corsa(van), Renault Clio, Peugeot Bipper (and Citroen Nimo) and Peugeot Teepee. For other vans there are van derived cars, for example the VW Caddy and Renault Kangoo, Whilst for some small vans there are no car equivalents, for example the Ford Transit Connect.

Analysis of new vehicle CO_2 data indicates:

- vans have CO_2 emissions similar to (though often a few g/km higher than) their car equivalents
- however, in the breadth of models available the vans are generally the diesel fuelled versions,
- there are fewer higher performance vans available.

Consequently, where there are car derived vans (or van derived cars) the sales weighted average emissions from vans **is less than** the equivalent figure for its car brothers and sisters, though the emissions are comparable to that from its twin. Consequently, in this segment of the CO_2 emissions/mass graph vans tend to have lower CO_2 emissions than cars.

At the other end of the weight range are the Class III N1 vans, whose reference mass is > 1,760 kg. If vehicles are tested using the default dynamometer load settings given in UNECE Regulations 83 and 101, then for vehicles other than passenger cars, weighing more than 1,700 kg the road load coefficients are multiplied by 1.3[50]. Furthermore large passenger cars tend to be rather aerodynamic, while esp. Class II and II vans are box-shaped and have larger frontal areas. Both these factors

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[50] See Clause 6.2.1.2 of Annex 4a: Type I test

contribute to the conclusion that the CO_2 emissions for an N1 Class III light commercial vehicles are generally higher than for a passenger car of the same mass.

The combined effect of the lightest commercial vehicles having a smaller average CO_2 emissions than the equivalent car, and of the Class III commercial vehicles having a higher average CO_2 emissions than the equivalent car, is for the 100% gradient of the sales weighted best fit (as function of mass in running order) for vans **to be steeper** than the sales weighted best fit for cars. Another reason for this difference in slope lies in the sales distribution, which shows that for cars the sales of vehicles > 1600 kg is very small so that the fit is dominated by smaller vehicles. For vans half of the sales are > 1600 kg, and these vehicles thus have a bigger influence on the position of the fitted line at high mass.

In addition to the above systematic differences it may be that there are contributing factors to the difference in average CO_2 emissions as a function of weight that affect the relative gradients of the sales weighted best fits for light commercial vehicles and cars.

12.5 Potential ways of merging regulatory approaches

Until now CO_2 legislation has been developed and implemented for passenger cars and light commercial vehicles separately. A reason for that is that the two vehicle categories represent different markets, with to a large extent unrelated vehicle models. Given the different characteristics and applications of passenger cars and vans, the two categories may have different CO_2 emission reduction potentials, both from a technical and from an economic perspective.

On the other hand there is also overlap between the categories. The class I and II segments of the van market contain a large share of passenger car derived vans. And even for dedicated van platforms, often engines and other powertrain components are shared with passenger car models.

The latter consideration has motivated the question of whether it would be feasible and beneficial to bring passenger cars and vans under a common regulatory target. Based on available evidence, this section explores the feasibility and possible consequences of a combined target for passenger cars and vans.

In the SR#1 report [TNO 2011], Chapter 12 assessed the impacts of a combined target for passenger cars and vans. This identified and assessed three approaches through which the targets for passenger cars and vans could be combined. One approach had already been explored in the 2008 study by AEA, CE Delft, TNO and Öko-Institut [AEA 2008]. In the current study four approaches are considered as indicated in Table 47.

Table 47   Options for merging regulatory approaches for cars and vans

Approach 1	Having a different approach for Class I & II vans and Class III vans, and a combined target for passenger cars and the smaller vans.	This is a new approach
Approach 2	Allowing pooling of the targets for passenger cars and vans	This was Approach 1 in the SR#1 final report, and in the 2008 study.
Approach 3	A combined target for passenger cars and vans	This was Approach 2 in the SR#1 final report
Approach 4	Bringing car derived vans under the passenger target	This was Approach 3 in the SR#1 final report

Much of the discussion, presented below, on Approaches 2, 3 and 4 is based on the SR#1 report, reviewed in the context of the work undertaken in SR#3 [TNO 2012] and work performed in other tasks of this Service Request.

12.6 Approach 1: Having a different approach for Class I & II vans and Class III vans, and a combined target for passenger cars and the smaller vans

12.6.1 Introduction

Past assessments of potential ways of merging the regulatory approaches have:

- either treated cars as one group and all vans as another group (the basis of Approach 3), or
- separated out car derived vans (the basis of Approach 4).

This approach involves dividing the vans into just two groups, differentiated by their reference mass such that vans with reference mass ≤ 1760 kg, i.e. Class I and II vehicles form one group and vans with reference mass > 1760 kg, i.e. Class III vehicles form the other group.

The option of a combined target for passenger cars and Class I and II is assessed as an example. Alternatively it would also be an option to combine passenger cars with Class I vans only.

Prior to the advantages and drawbacks of this approach being assessed, more fundamentally a re-analysis of the van database is required. Previous analyses, i.e. that undertaken in SR#3, either considered all vans (together or disaggregated by manufacturer) or vans in terms of the six vehicle categories, petrol and diesel, Classes I, II and III. In this section the re-analysis of the van database is based on these two weight categories, and undertaken for two utility parameters, mass in running order and footprint.

12.6.2 Re-analysis of the van database

Overall van fleet

Table 48 contains the shares of N1 sales of different vehicle types, fuels and classes, as reported in Table 1 of the Task 3 report for SR#3, but with the added columns for the combining of all class I and II LCVs, and for Class III LCVs.

Table 48   Shares of total LCV N1 sales of different vehicle types / classes / fuel from the JATO 2010 database

Fuel	Class I	Class II	Class III	Unknown	total	Class I & II	Class III
Compressed natural gas	1.25%	0.52%	0.09%	0.02%	1.87%	1.77%	0.09%
Diesel	17.56%	32.82%	44.78%	0.80%	95.96%	50.38%	44.78%
E85	0.00%	0.00%		0.00%	0.01%	0.01%	
LPG	0.33%	0.06%	0.03%	0.02%	0.44%	0.39%	0.03%
Petrol (premium unleaded)	1.20%	0.32%	0.09%	0.05%	1.66%	1.52%	0.09%
Electric	0.01%	0.04%	0.00%	0.02%	0.06%	0.05%	0.00%
TOTALs	20.35%	33.75%	44.99%	0.91%	100.00%	54.10%	44.99%

From this table it is seen that for the 2010 LCV sales database approximately 55% of vehicles were the smaller classes whilst approximately 45% were Class III vehicles. The breakdown of the total European LCV sales according to the manufacturing groups, the obligated entities for CO_2 emissions compliance, disaggregated according to the Class I & II and Class III categorisation is given in Table 49. This table has been derived from Table 8 of the Task 3 report for SR#3 which has this data disaggregated into the six van categories (mass class and engine type) plus electric vehicles.

Table 49   Shares of Class I & II and Class III van per manufacturer, and the share the manufacturer's sales in the total EU sales, derived from the JATO 2010 database for 5 large EU countries

Manufacturer	Class I & II	Class III	Share in total EU LCV sales
Daimler	5.3%	94.7%	8.4%
Fiat	67.5%	32.5%	11.2%
Ford	45.6%	54.4%	11.3%
GM	61.6%	38.4%	5.1%
Hyundai	6.2%	93.8%	0.2%
Isuzu	1.4%	98.6%	0.6%
Iveco	1.9%	98.1%	3.2%
Land Rover	0.0%	100.0%	0.7%
Mazda	0.0%	100.0%	0.1%
Mitsubishi	1.6%	98.4%	1.2%
Nissan	46.7%	53.3%	2.5%
PSA	77.3%	22.7%	24.7%
Piaggio	100.0%	0.0%	0.4%
Renault	70.5%	29.5%	19.6%
Ssangyong	0.0%	100.0%	0.1%
Toyota	10.4%	89.6%	1.3%
Volkswagen	40.8%	59.2%	9.5%
Other small LCV volume manufacturers	22.1%	77.9%	0.1%
TOTAL	54.8%	45.2%	100.0%

Mass In running order

Table 50 contains the average mass in running order, and CO_2 emissions for the whole LCV van fleet, and when it is disaggregated into the two weight categories.

Table 50   Average mass in running order, CO_2 emissions and numbers of LCV N1 sales for different vehicle groups from the JATO 2010 database

	Average	Class I & II	Class III
Mass in running order (kg)	1649	1366	1994
CO_2 emissions (gCO_2/km)	180	145	223
Sales		55%	45%

Figure 73 shows the LCV dataset, as shown in Figure 2 of the Task 3 report for SR#3, but with separate sales weighted least squares fits for the Class I & II and the Class III groups of data. The sales weighted least squares fit equations are given in Table 51.

Table 51   Sales weighted least squares fit parameters from analysis of 2010 LCV sales, calculated for each segment

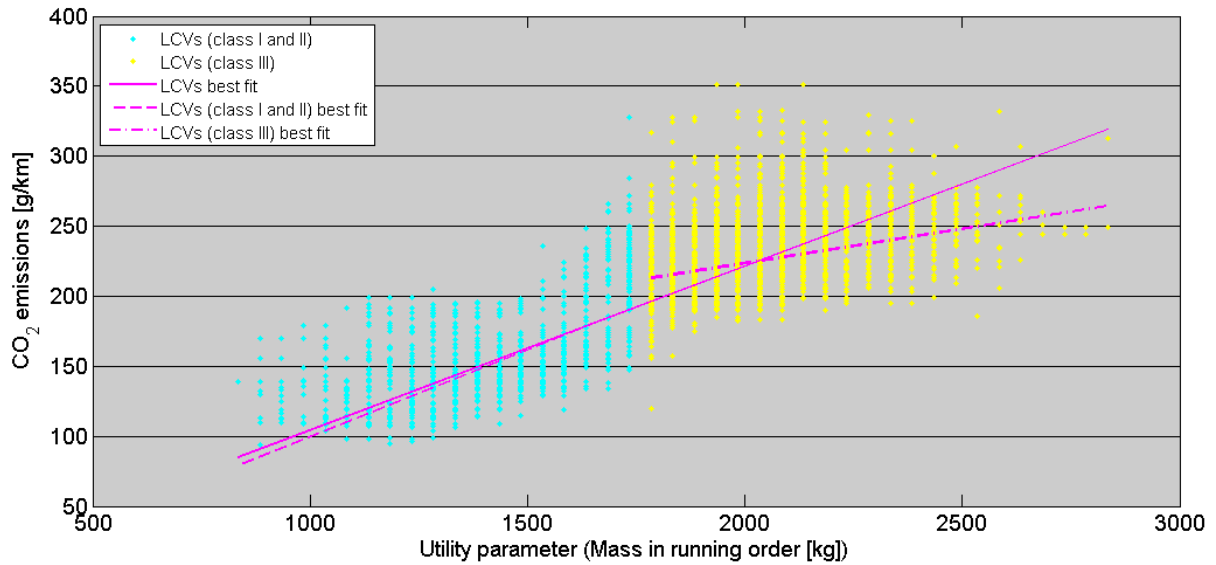| Vehicle segment	Gradient	Intercept	Segment's average CO_2 emissions
All LCVs	0.117	-13.1	180
Class I & Class II	0.124	-24.2	145
Class III	0.0492	125	223

Figure 73   CO$_2$ and mass in running order values of LCV sales in 2010, and the sales weighted least squares fit through all the data, and through the smaller and larger vehicle groups separately

Figure 73 shows that the sales weighted fit through all data is very close to the fit through the Class I & II vans alone, even though the sales of the two categories of LCVs are of the same order of magnitude. A target line for all LCVs, based on a constant percentage reduction compared to the fit, would thus lead to rather even burden sharing over the range of Class I & II vans, but would affect the lighter class II vans differently than the heavier ones.

In Figure 74 the datasets for passenger cars and Class I & II LCVs are combined. It is clear from this graph that the fit through the Class I & II LCVs is significantly steeper than the fit through the passenger cars. A combined target for passenger cars and Class I & II LCVs would be based on a sales-weighted fit through the combined dataset. The coefficients of the fits through the different datasets are given in Table 52.
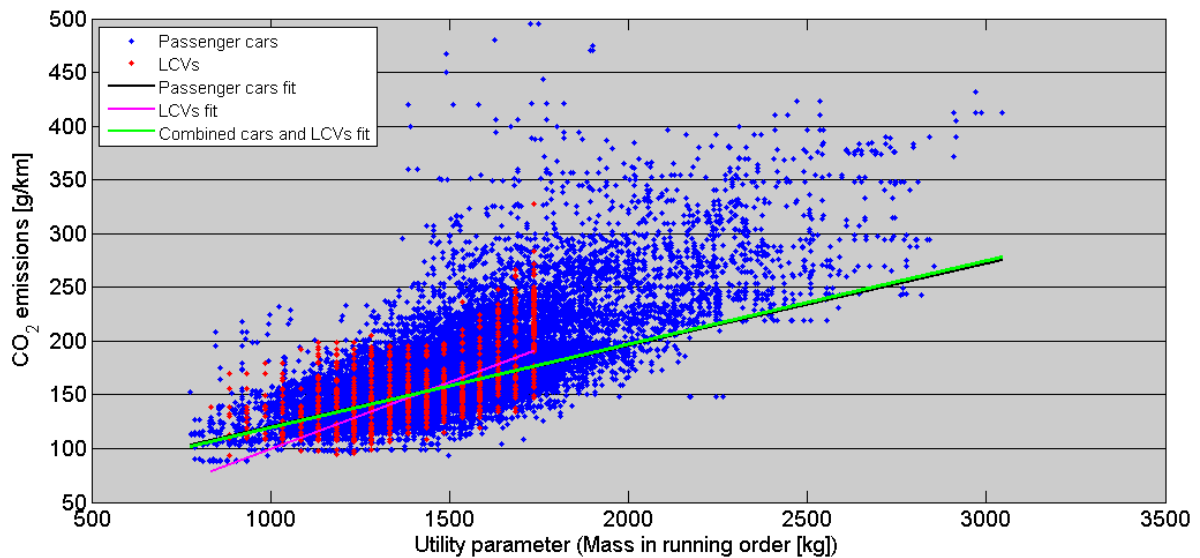

Figure 74   CO$_2$ and mass of passenger car sales in 2009 and small light commercial vehicle (class I and II) sales in 2010 and the sales weighted least squares fits through both datasets

The graph shows that it is in principle possible to define a combined target for passenger cars and Class I & II vans. However, due to the large difference in sales volumes between passenger cars and Class I & II vans, the data for the latter group hardly influence the fit through the combined dataset. This also means that, if a target function were to be derived for passenger cars and Class I & II vans together based on a constant reduction compared to the fit through the combined data, this target would be tougher for the Class II vans than for the lighter Class I vans. A flattened slope of the target line, as applied to the present target for passenger cars, would further enhance this unbalance. Depending on their division of sales over class I and class II vans, this could lead to uneven burden sharing among manufacturers of these LCVs. On the other hand, due to the possibility of internal averaging, manufacturers that sell both cars and vans have significant room to compensate a remaining distance to target for some of their vans by a fairly small additional CO_2 reduction in their passenger car sales.

Table 52   Sales weighted least squares fit parameters from analysis of 2009 car sales and 2010 Class I & II LCV sales,

Vehicle segment	Gradient	Intercept	Segment's average CO_2 emissions
Passenger cars	0.0763	43.9	147
LCVs Class I & Class II	0.124	-24.2	145
Combined	0.0776	41.9	146

Footprint

Table 53 contains the average footprint and CO_2 emissions for the whole LCV van fleet, and when it is disaggregated into the two weight categories. This is the analogous data to Table 50 but for footprint as the utility parameter rather than mass in running order.

Table 53   Average footprint, CO_2 emissions and numbers of LCV N1 sales for different vehicle groups from the JATO 2010 database

	Average	Class I & II	Class III
Vehicle footprint (m^2)	7.07	5.75	8.69
CO_2 emissions (gCO_2/km)	180	145	223
Sales		55%	45%

Figure 75 shows the LCV dataset, as shown in Figure 5 of the Task 3 report for SR#3, but with separate sales weighted least squares fits for the Class I & II and the Class III groups of data. The sales weighted least squares fit equations are given in Table 54.

With footprint as utility parameter the difference between the Class I & II vans and the Class III vehicles is even more prominent. CO_2 emissions of Class III vans hardly depend on footprint, while for Class I & II vehicles there is a clear correlation. Also in this case the fit through all LCVs aligns more closely with the fit through the Class I & II vehicles, even though the sales of both vehicle groups are of the same order of magnitude. But the difference in slope between the fit through all vehicles and the fit through the Class I & II vehicles is larger than in the case of mass as utility parameter (see Figure 73).
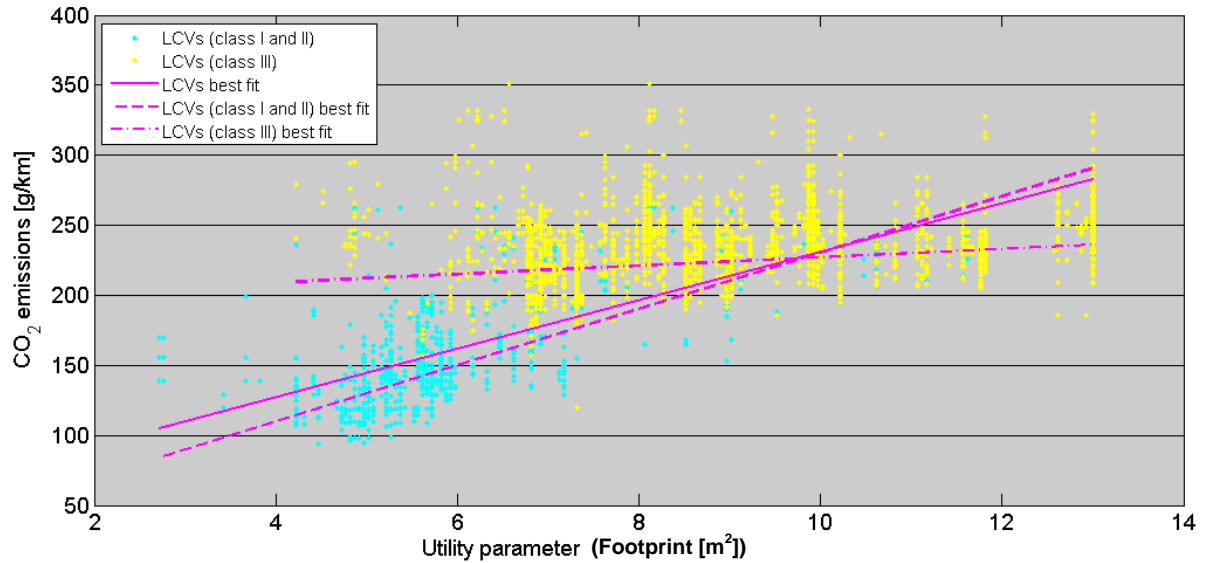
Figure 75 CO_2 and footprint of LCV sales in 2010, and the sales weighted least squares fit through all the data, and through the smaller and larger vehicle groups

Table 54   Sales weighted least squares fit parameters from analysis of 2010 LCV sales, calculated for each segment

Vehicle segment	Gradient	Intercept	Segment's average CO_2 emissions
All LCVs	17.3	57.7	180
Class I & Class II	20.1	▪ 29.3	145
Class III	2.97	197	223

In Figure 76 the datasets for passenger cars and Class I & II LCVs are combined. It is clear from this graph that in this case the fit through the passenger cars is significantly steeper than the fit through the Class I & II LCVs. Also the spread in footprint values is much smaller for cars than for the Class I & II LCVs. A combined target for passenger cars and Class I & II LCVs would be based on a sales-weighted fit through the combined dataset. The coefficients of the fits through the different datasets are given in Table 55.

Even though the passenger car sales are an order of magnitude higher than the Class I & II LCV sales, the fit through the combined dataset is heavily influenced by the vans. This is due to the strong leverage on the fit that is created spread in LCV footprint to values that are more than a factor of 2 times the highest footprint values for cars.

Figure 76 shows that for footprint as utility parameter it may not be realistically possible to define a workable combined target for passenger cars and Class I & II vans. If a target function were to be derived for passenger cars and Class I & II vans together based on a constant reduction compared to the fit through the combined data, this target would be extremely difficult and possibly impossible to achieve for passenger cars with a footprint above 4 m^2. For the class I & II vans the required reductions would be rather limited. Even though manufacturers, that sell both cars and vans, have the possibility of internal averaging, they will most likely not be able to compensate a lack of reduction potential in the larger passenger cars by additional reductions in their vans. Due to the difference in sales volumes relatively large reductions in vans are needed to compensate for a small part of the underachievement by cars.
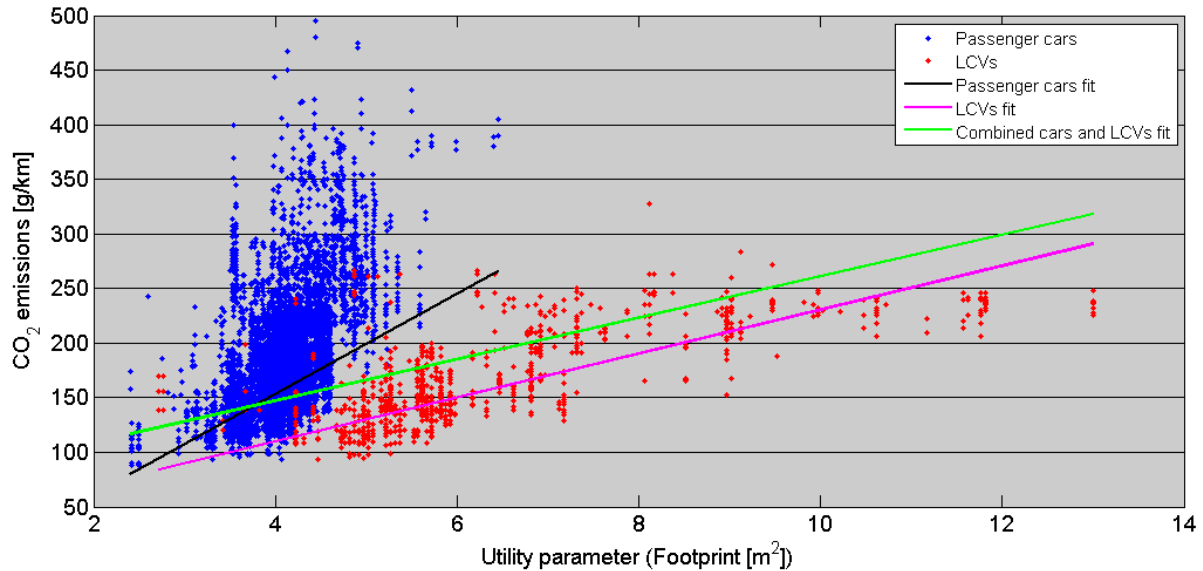
Figure 76 CO_2 and footprint of passenger car sales in 2009 and light commercial vehicle (class I and II) sales in 2010 and the sales weighted least squares fits through both datasets

Table 55   Sales weighted least squares fit parameters from analysis of passenger cars, LCVs (class I and II) and of a combination of these vehicles.

Vehicle segment	Gradient	Intercept	Segment's average CO_2 emissions
Passenger cars	45.9	-30.0	147
LCVs Class I & Class II	20.1	29.3	145
Combined	19.0	71.2	146

12.6.3   A combined target for passenger cars and the smaller vans

A combined target (target level and target function) for passenger cars and vans can be defined in the following steps:

1) Based on a combined database of passenger car and van sales, determine the average emissions of passenger cars and vans together in the reference year, and determine the sales weighted fit through the combined sales plotted as function of the utility parameter;
2) Determine the combined target by sales-weighted averaging of the separate targets for passenger cars and vans;
3) Calculate the reduction percentage required to go from the average emissions of the combined sales of passenger cars and vans in the reference year to the combined target;
4) Apply this reduction percentage to the sales weighted fit through the combined sales plotted as function of the utility parameter to determine the combined target function (with so-called 100% slope, see e.g. [TNO 2011]).
5) Target functions with alternative slopes can be derived by pivoting the target line around the point defined by x = average mass and y = target.

For determining a combined target for passenger cars and all vans in 2020 in step 2) the individual targets as defined in the regulations can be used (see section 12.8). For the case of a combined target for passenger cars and the Class I & II vans, a target for the vans is not defined. As a starting point two options are considered here, in which the small vans target is defined by either:

• applying the same reduction percentages to the small vans as is required for all vans to meet the legislative target of 147 g/km in 2020, or
• applying the same reduction percentages to the small vans as is required for passenger cars to meet the legislative target of 95 g/km in 2020.

Reference mass as utility parameter

From Table 50 it is seen that the sales weighted average for all vans, calculated from the 2010 database, was 181.4 g CO_2/km. To reach the 147 target will require a reduction of 19.0%. Table 50 also indicates that the sales weighted average for only the Class I and II vans, calculated from the 2010 database, was 147.0 g CO_2/km. If it is assumed that these too will need to be reduced by 19.0%, this would lead to a 2020 "target" of 119.1 g/km for this category. The sales weighted target for the combined sales of passenger cars and the smaller vans would then be 96.2 g/km.

The determination of the combined target for passenger cars and Class I & II vans is shown in Figure 77. It indicates the overall sales averages and the sales-weighted fits derived for passenger cars, small vans and the two vehicle categories combined, as well as a 100% slope limit function for cars[51] and a fictitious 100% slope limit function for small vans. The latter is derived by applying the overall reduction percentage for vans as defined by the legislation to the fit through the smaller vans. The solid green line is the combined target function determined using the steps described above.
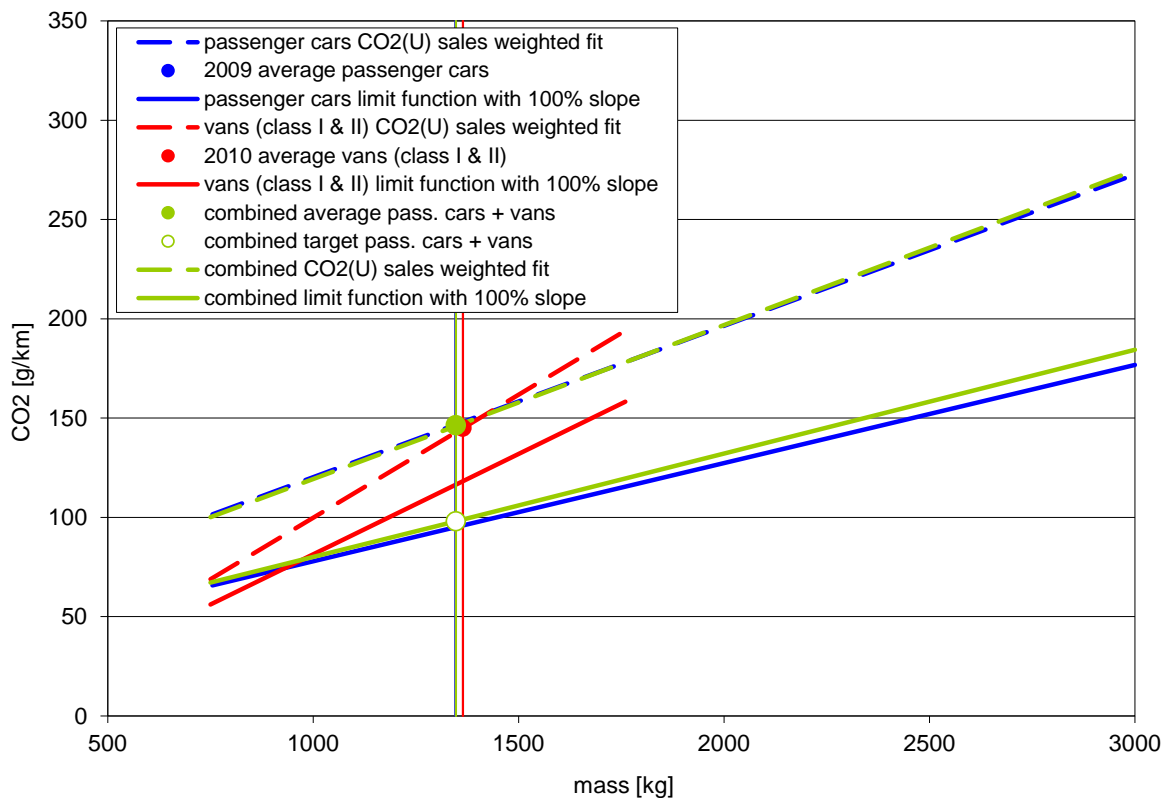

Figure 77   Sales weighted fits through CO_2 and mass for the passenger car sales in 2009 and the Class I & II light commercial vehicle sales in 2010 separately and combined, and the mass-based limit functions with 100% slope based on these fits

As a result of the order of magnitude difference in sales between cars and the small vans, the combined target line is very close to the target line for passenger cars alone. This means that combining the targets for cars and small vans would reduce the reduction efforts required for passenger cars by a small amount. On the other hand the reductions required for most of the smaller vans would be significantly higher than the average based on the legislation for all vans. Given that vans are mostly diesel vehicles, which have a lower reduction potential than petrol vehicles, the additional reduction might be difficult to achieve. Depending on their division of sales over class I and class II vans, this could also lead to uneven burden sharing among manufacturers of these LCVs. This effect would even be more pronounced if the flatter slope from the passenger car regulation would

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[51] Note that the slope of the limit function as defined in R443/2009in is flatter.

have been used to determine a combined target. Only for the lightest vans the target required reduction would be less.

If for defining a combined target the smaller vans average would be required to be reduced by the same reduction percentage relative to the reference year as is required for the passenger cars, the target line for the smaller vans would be shifted downwards compared to the example of Figure 77. In that case the combined target line would even be closer to the 100% sloped target line for passenger cars. As the green line in Figure 77 is already very close to the passenger car target function, this different assumption for the vans target would not affect the conclusions drawn above.

It is clear from the above that a combined limit function for passenger cars and small vans would lead to challenging targets for manufacturers that sell only or mostly light commercial vehicles. For manufacturers that sell more passenger cars than vans the stricter target values for vans would be compensated by somewhat less stringent target values for larger amount of passenger cars. For manufacturers that do not sell vans, setting a combined target for passenger cars and vans would generally mean a relaxation of their reduction target.

Footprint as utility parameter

Figure 78 is similar to Figure 77, and shows how a combined target for cars and small vans could be derived if footprint were the utility parameter. Due to the strong leverage caused by the wide spread of footprint values for the Class I & II vans, the combined target line is in this case dominated by the vans and is very close to the fictitious 100% slope target line defined for the small vans using the approach described above (applying the same relative reduction as required on average by the legislation for all vans).
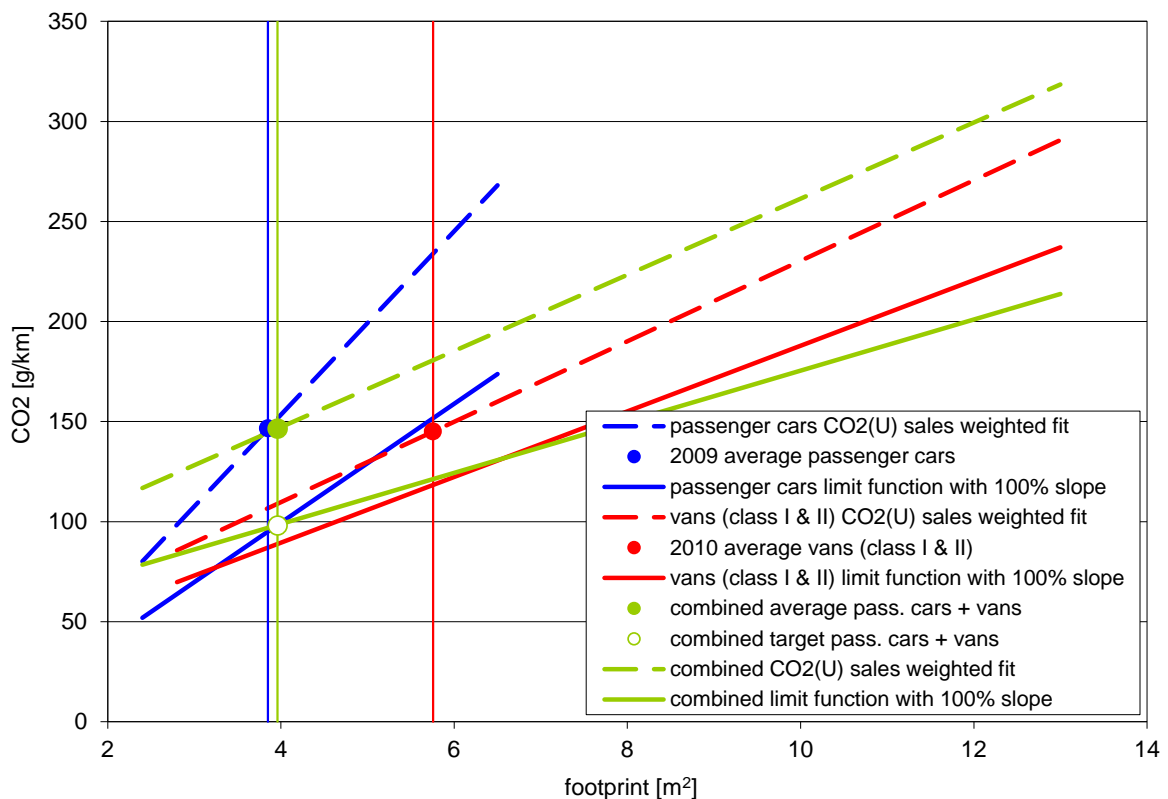

Figure 78   Sales weighted fits through CO_2 and footprint for the passenger car sales in 2009 and light commercial vehicle sales in 2010 separately and combined, and the footprint-based limit functions with 100% slope based on these fits

For footprint as utility parameter, a combined target for passenger cars and small vans would lead to higher (lower) reduction requirements for passenger cars with above-average (below-average) footprint. CO_2 emissions of small passenger cars would hardly need be reduced. Due to the non-linear nature of the cost curves for CO_2 reduction, this would lead to higher costs for meeting the target. For the vans the combined target has little effect on the distance to target.

It is noted that whilst the boundary between the smaller (Class I & II) and larger (Class III) vans is clear for mass in running order as the utility parameter, it is not clear cut for footprint. A figure of $7m^2$ appears appropriate from the footprint vs. CO_2 emissions plot for the six van segments, see Figure 7 of the Task 3 report for SR#3 [TNO 2013]. For the example shown here the division is based on mass, as this is the basis of the class definition, but in case of a footprint-based CO_2 legislation it could be more logical to divide smaller and larger vans on the basis of their footprint.

12.6.4   Summary and conclusions regarding Approach 1

From the above it can be concluded that a combined target for passenger cars and Class I & II vans would appear possible for mass as utility parameter, but would be less desirable if the target line would be based on footprint as utility parameter. In the latter case a combined target would most likely lead to higher costs for meeting the target.

In case of mass as utility parameter a combined target for cars and small vans could motivate manufacturers to utilize a larger part of the reduction potential available for the smaller vans. The costs for that could be limited if a sufficient amount of technology spill-over could be utilized.

Singling out the smaller vans and joining these with passenger cars greatly reduces the size of the remaining sales that would still fall under the vans target. This strongly reduces the room for internal averaging by manufacturers. It would also make it more difficult to set low emission targets for light commercial vehicles as the remaining vans will be vehicles with more limited reduction potential and limited possibilities to benefit from technology cross-over.

12.7   Approach 2: Allowing pooling of the targets for passenger cars and vans

This approach was discussed in detail in Section 12.2 of the final report on Service Request 1 [TNO 2011]. This discussion forms the basis of the assessment below.

Pooling of the targets for passenger cars and vans would mean that manufacturers can compensate underachievement in one category (expressed in average g/km above target times total sales in that category) by an equivalent overachievement in the other category (expressed in average g/km below target times total sales in that category).

The manufacturers affected would only be those making both passenger cars and light commercial vehicles. The shares of passenger cars and of the smaller (Class I and II) and larger (Class III groups) vans in the sales of the largest manufacturers are illustrated in Figure 79. From these data it is seen that pooling of cars and vans would have no direct impact on BMW, Suzuki, Honda, Geely (incl. Volvo) and the small volume sports car manufacturers. For Isuzu, which only sells LCVs, it also has no direct impact. Indirectly for all these manufacturers their competitive position could be affected if other manufacturers would have the opportunity to pool targets for passenger cars and vans.

Further, this approach could be used for pooling the targets of all vans with those of the manufacturers' cars (this is the scenario discussed in the 2008 study and in the SR#1 report), or for only pooling the targets of the Class I and II vans with those of the manufacturers' cars. For this latter case Mercedes and Mitsubishi would also cease to be affected directly because their vans are virtually only of the heavier group.
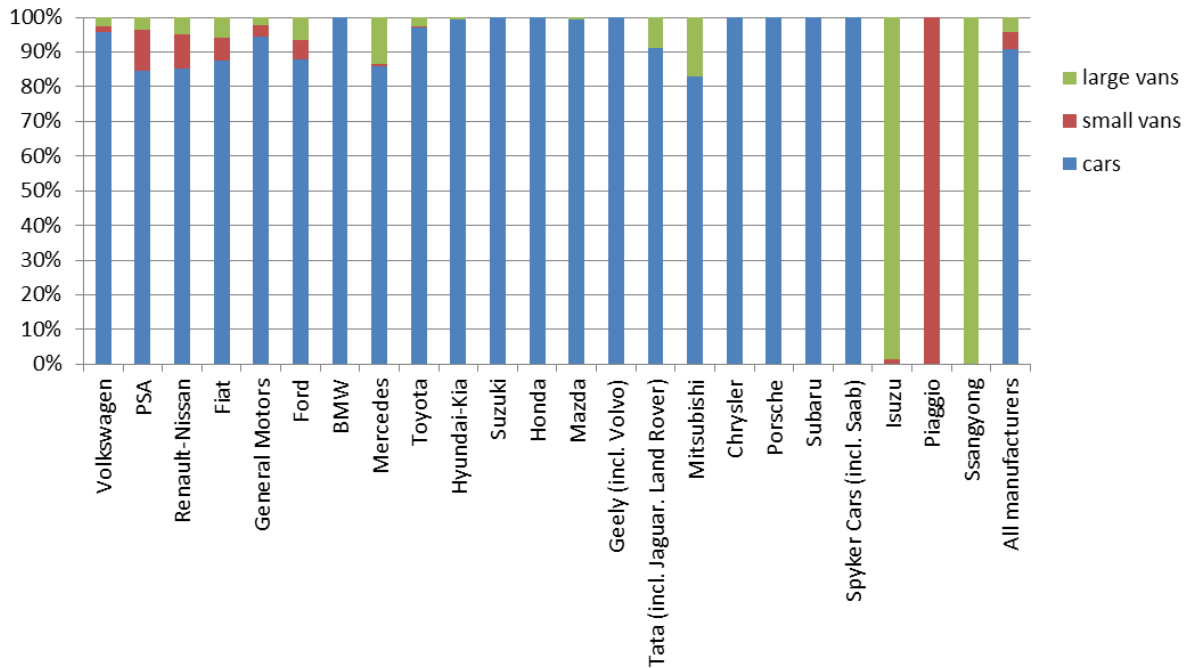
Figure 79   Shares of of passenger cars and small (class I & II) and large vans (class III) in the sales of different manufacturing groups (indicative numbers based Polk 2009 resp. JATO 2010 for 5 EU countries)

The distance to target in passenger cars (M1) and vans (N1) can be compared with different weights:

1) sales:

$$sales_{M1} \times \Delta CO_{2\,M1} + sales_{N1} \times \Delta CO_{2\,N1} = 0$$

2) total mileage (= sales × avg. annual mileage × avg. lifetime):

$$sales_{M1} \times mileage_{M1} \times lifetime_{M1} \times \Delta CO_{2\,M1} + sales_{N1} \times mileage_{N1} \times lifetime_{N1} \times \Delta CO_{2\,N1} = 0$$

For the analysis in the 2008 study only option 1) was used, as possible differences in mileage for different vehicle categories are also not taken into account in the internal averaging per manufacturer as well as in the pooling between manufacturers that is allowed under the separate regulatory targets for passenger cars and vans. The second option does, however, highlight that shifting g/km reductions from one category to the other may have consequences for the net fleet-wide GHG emission reduction that is achieved. This is due to the very different average mileages of passenger cars and vans. Indicative figures for the annual mileage, as used in the 2006 study by TNO, IEEP and LAT [TNO 2006], are 16,000 km p.a. for passenger cars and 23,500 km p.a. for vans.

The analysis on pooling passenger cars and vans for the 2015 targets showed that for many manufacturers the marginal costs for meeting the vans target in 2015 are higher than for passenger cars, so that they would reduce less on vans and more on passenger cars.

Marginal cost for meeting passenger cars and vans targets in 2020 have been assessed and compared in [TNO 2012a]. For the established 2020 targets of 95 g/km for cars and 147 g/km for vans the marginal costs as indicated in Figure 80 are significantly different, with those for vans being the lowest. Under a pooled target, however, the lowest cost option for manufacturers to meet the combined target is to reduce emissions in cars and van to levels where the marginal costs are the same. Given the large difference in sales volumes the pooling of targets for passenger cars and vans only increases the target for passenger cars marginally. Figure 80 illustrates that the marginal costs for reaching 95 g/km in passenger cars correspond to a reduction to around 113 g/km in LCVs. For individual manufacturers the situation may be different depending on their specific target. But overall it can be concluded that allowing pooling of the cars and vans targets would lead to average CO_2

emissions for vans in 2020 that are significantly below the currently established 2020 target of 147 g/km, while the average for passenger cars would only be slightly increased above 95 g/km.
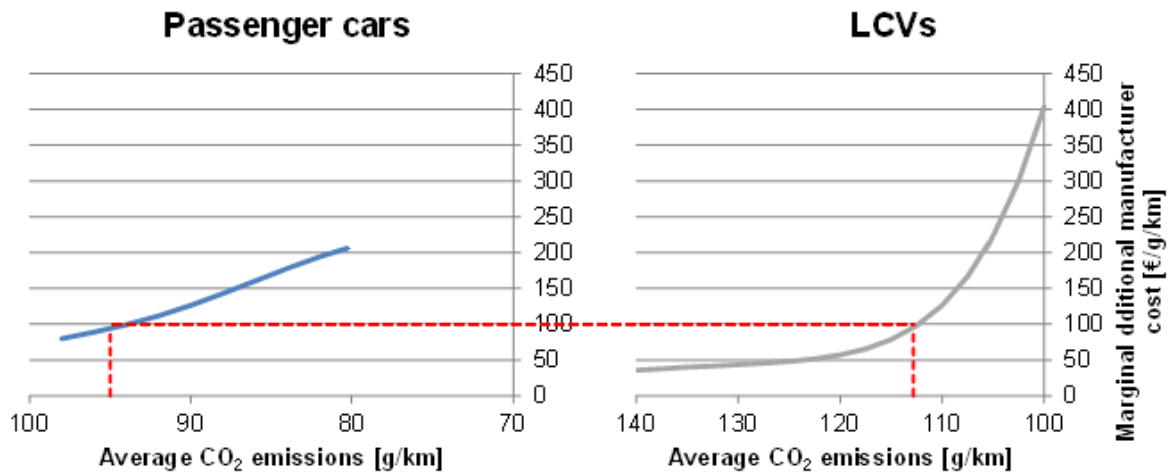

Figure 80   Marginal costs for CO_2 emission reduction in passenger cars and vans, based on [TNO 2012a]

Conclusions

- In principle pooling of targets for passenger cars and vans is also a feasible option for the 2020 targets. The general pro's and con's identified in the study assessing the 2015 vans target remain valid.
- Pooling of passenger car and van targets may reduce the costs for meeting the combination of targets for both vehicle categories for most manufacturers (as it increases the room for internal averaging) and may allow more flexibility in achieving the target for light commercial targets.
- Due to the fact that for most manufacturers the sales of light commercial vehicles are much smaller than the passenger car sales[52] the over/underachievement in g/km CO_2 reduction for passenger cars that is necessary to compensate an under/overachievement in light commercial vehicles is much smaller than the g/km under/overachievement in light commercial vehicles;
- As marginal costs for meeting the 147 g/km target for LCVs are lower than for meeting the 95 g/km target for passenger cars, the likely result of pooling the passenger car and van targets in 2020 is that CO_2 emissions of LCVs will be reduced to levels significantly below 147 g/km, while the average for passenger cars may end up somewhat above 95 g/km.
- Pooling of passenger car and van targets is not possible for companies that only sell passenger cars or vans. Allowing pooling may thus negatively affect the competitiveness of such companies compared to manufacturers that produce cars and vans.

12.8   Approach 3: A combined target for passenger cars and vans

This approach was discussed in detail in Section 12.3 of the final report on Service Request 1. This discussion forms the basis of the assessment below. It is similar to Approach 1, but it involves considering the prospects of having a combined target for all vans i.e. for all light duty vehicles.

Using the existing targets of 95 g/km for passenger cars and 147 g/km for vans as a starting point, and taking account of the factor of 9 to 10 difference in sales volumes for these two categories, the sales-weighted target for the combined sales of passenger cars and vans would be 100 g/km.

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[52] Annual passenger car sales in the EU 27 are about a factor of 9 to 10 larger than sales of light commercial vehicles. See: http://www.acea.be/collection/statistics

Figure 69 and Figure 71 display the type approval CO_2 emission values of passenger cars and vans as a function of the value of the utility parameter for mass and footprint. In addition Figure 77 and Figure 78 indicate the overall sales averages for both vehicle categories, the combined average and the utility-based limit functions with 100% slope derived on the basis of the sales-weighted fits and the 2020 targets of 95 and 147 g/km respectively.

Considerations for mass as utility parameter

For mass Figure 69 shows that the datasets for passenger cars and vans have significant overlap. Nevertheless the sales-weighted least squares fits through both datasets, which form the basis for determining utility-based limit functions, are significantly different. Over a large part of the spectrum vans show on average higher CO_2 emissions (up to 50 g/km for larger vehicles). Due to the fact that the sales volume of passenger cars is a factor of 9 to 10 larger than that of light commercial vehicles, the sales weighted fit through the combined database is found to be fairly close to the fit for the passenger car dataset. For the same reason the combined overall sales-weighted target of around 100 g/km (see Figure 77) is also closer to the 95 g/km target for passenger cars than to the 147 g/km target for vans. Determining a linear mass-based limit function on the basis of such a combined fit would thus lead to target values which, especially for large vans, would be significantly lower – and hence more ambitious – than what would be the case with a separate target for vans.
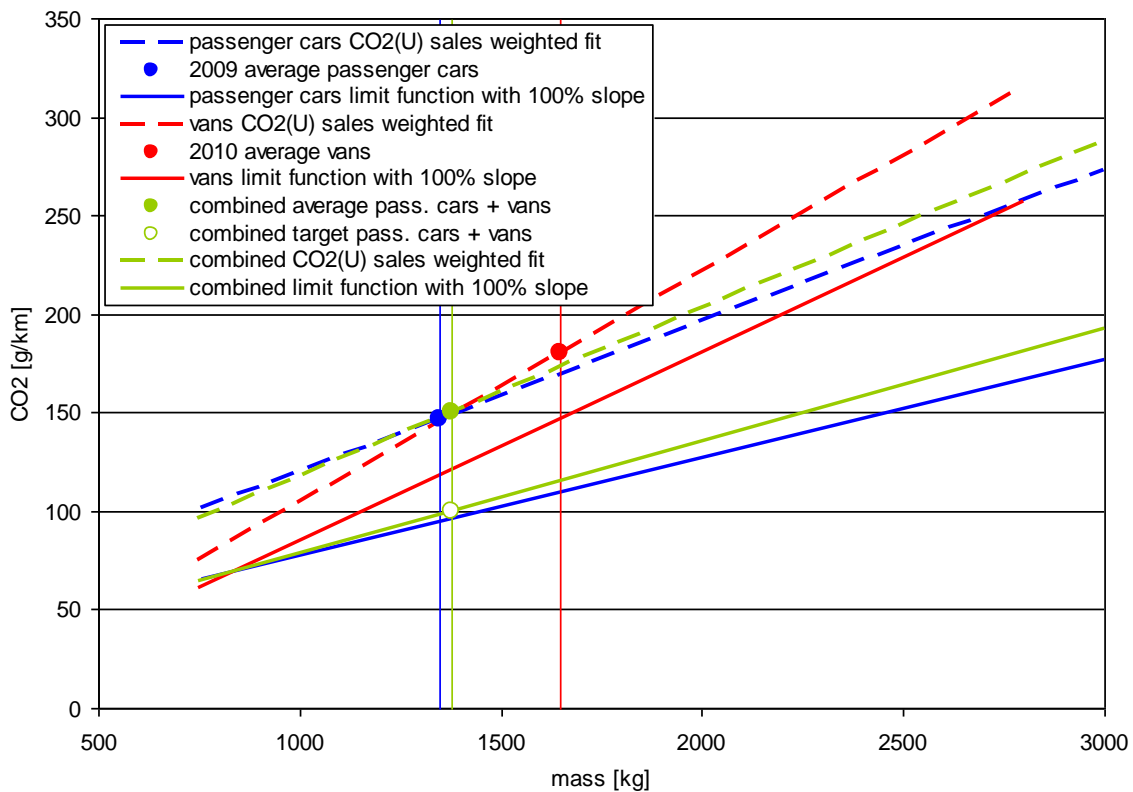

Figure 81   Sales weighted fits through CO_2 and mass for the passenger car sales in 2009 and light commercial vehicle sales in 2010 separately and combined, and the mass-based limit functions with 100% slope based on these fits. The width of the lines indicates the spread in utility values for both vehicle categories [TNO 2011].

The above is further exemplified in Figure 81, taken from [TNO 2011]. Especially for higher mass values the limit function for passenger cars is several tens of g/km below that for vans. Defining a combined target results in a limit function with 100% slope which is close to the blue line. Other slopes can be realised by pivoting the green line around the indicated combined average target. Knowing that the vans market is dominated by diesel vehicles which have a lower reduction potential than petrol vehicles, as well as a lower reduction potential compared to passenger cars, it is clear that such a combined limit function would lead to unattainable targets for manufacturers that sell only or mostly light commercial vehicles. For manufacturers that sell more passenger cars than vans the stricter

target values for vans would be compensated by less stringent target values for passenger cars. For manufacturers that do not sell vans setting a combined target for passenger cars and vans would generally mean a relaxation of their reduction target.

Considerations for footprint as utility parameter

Figure 71 shows that for footprint the datasets for passenger cars and vans have hardly any overlap. Vans generally have higher footprint values and the spread in these values is also much larger. For the same footprint value vans generally have much lower CO_2 emissions than passenger cars (the line for vans is below the line for passenger cars). It is also clear that the sales-weighted fits have very different slopes.

In contrast to what is observed for mass as utility parameter, for footprint the sales weighted fit through the combined dataset for passenger cars and vans is found to be close to the fit for vans alone. The 10 times higher sales still give a large weight to the passenger car data, but the large spread in utility values for vans creates a strong leverage resulting in a combined fit that is much flatter than the fit through the passenger car data alone. A linear limit function with 100% slope, based on the sales weighted fit through the combined dataset for footprint as utility parameter (see Figure 82, taken from [TNO 2011]), is thus also completely different from the 100% slope limit function for passenger cars.
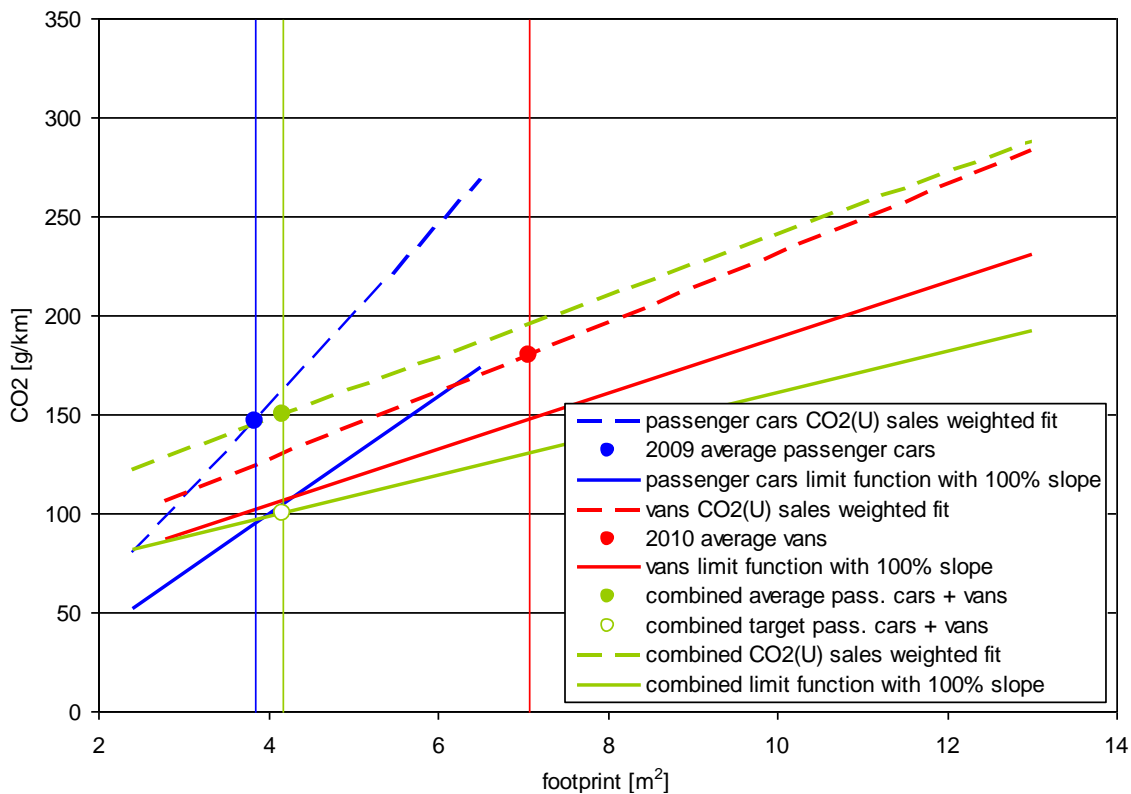

Figure 82   Sales weighted fits through CO_2 and footprint for the passenger car sales in 2009 and light commercial vehicle sales in 2010 separately and combined, and the mass-based limit functions with 100% slope based on these fits. The width of the lines indicates the spread in utility values for both vehicle categories [TNO 2011].

The combined 100% slope limit function sets targets for vans that are much lower than is the case for the 100% limit functions for the separate 147 g/km vans target for 2020. At the same time it sets targets for large passenger cars that are so low that they are unattainable, while for small passenger cars the target is relaxed to levels that are already realised in 2009. In order for the limit function to demand meaningful and attainable reductions from both passenger cars and vans the slope would need to be increased to above 100% by pivoting around the combined target in Figure 82. However. slope values that bring the limit function closer to the original 100% slope limit function for passenger cars result in setting targets for medium-sized and large vans that are at or even above the levels

already realised in 2010. A reasonable compromise does not seem possible with a linear limit function defined in this way.

One way in which this conundrum could possibly be resolved to some extent would be to define a non-linear limit function with a high slope at low footprint values and a lower slope at higher footprint values. But even then the large difference in sales between passenger cars and vans, as well as the very different CO_2 values for passenger cars and vans for footprint values between 4 and 6 m^2, would make it extremely difficult to find a compromise that could still represent meaningful targets for medium size vehicles in both categories. As the origin of the conundrum is to a large extent related to the test procedure for vans (as discussed in [TNO 2012]), another options would be to improve the test procedure. In the current procedure the inertia level in the TA test does not increase beyond 2270 kg for vehicles weighing above 2210 kg. Moreover the dynamic coefficients do not change for vehicles weighing above 2610 kg. As a result the relation between size/mass and CO_2 emissions levels off between 2210 kg and 2610 kg. Above 2610 kg the CO_2 emissions are only defined by the efficiency of the engine. Consequently, the CO_2 emissions level off even more. This is further enhanced by the fact that for relatively large vehicles (with high air drag and rolling resistance) the chassis dyno settings are usually based on "cook book values" which tend to result in lower type approval CO_2 emission values compared to the use of dyno load test settings derived from coast down testing.

Conclusion

- Based on the overall targets defined in the current regulations for 2020 a combined target for passenger cars and vans would result in a new car sales-weighted average of 100 g/km. Due to a factor of 10 difference in sales volumes, the average utility value as well as the combined target would be much closer to the values for passenger cars than for vans.
- Technically speaking the methodology, developed for defining targets and utility-based limit functions for the two vehicle categories separately, can be applied also to a combined database for both categories.
- In the case of mass as utility parameter, however, a combined linear limit function is likely to lead to targets that are unattainable for vans.
- In the case of footprint as utility parameter, a combined linear limit function that still requires some meaningful reduction effort from vans is likely to lead to targets that cannot be attained by passenger cars with above average footprint values.
- In the case of mass as utility parameter a combined target would lead to less stringent targets for manufacturers that do not sell vans. For manufacturers that do not sell passenger cars the combined targets would be much stricter and likely to be unattainable.
- In the case of footprint as utility parameter a combined target would lead to more stringent, and probably difficult to attain targets for manufacturers that do not sell vans. For manufacturers that do not sell passenger cars the combined targets are stricter than those based on a separate vans target for the case of a 100% sloped limit function, but are likely to be much less demanding for the higher slope values that are needed to make the target attainable for large passenger cars.

12.9 Approach 4: Bringing car derived vans under the passenger target

This approach was discussed in detail in Section 12.4 of the final report on Service Request 1 [TNO 2011]. The reason for including this option is because the van market contains a significant number of passenger car derived vans, or vans with engines that are shared with passenger car models. At the same time the passenger car market contains vehicles that are van-derived. Examples of the latter, such as the Citroen Berlingo, are almost equally popular in both markets. For vehicle models that are based on the same type of technologies it could be argued that they have similar CO_2 reduction potentials and could thus be brought under a single regulatory target.

The option of bringing car-derived vans under the passenger car target, however, has two important drawbacks:

- It requires a legally waterproof definition of what is a passenger car derived van. It will be difficult to objectively establish the status of a vehicle model without information from the manufacturer. Letting the manufacturer decide in which category a vehicle falls, is likely to give rise to arbitrariness and may provide perverse incentives.

- Singling out this group and joining it with passenger cars greatly reduces the size of the remaining sales that would still fall under the vans target. This strongly reduces the room for internal averaging by manufacturers. It would also make it more difficult to set low emission targets for light commercial vehicles as the remaining vans will be vehicles with more limited reduction potential and limited possibilities to benefit from technology cross-over.

An alternative to this approach is provided by the above discussed Approach 1, where instead of car derived vans all Class I and II vans are included. The procedure for defining the combined target is not fixed for Approach 1. One option is a combined target, instead of applying the passenger car target also to the vans included in the combined regulation. In that case the combined target is dominated by the passenger cars because of the large difference in sales volume of cars to vans.

12.10 Summary and conclusions

In this chapter four approaches are evaluated that effectively combine the targets for passenger cars and vans:

- Approach 1: Having a different approach for Class I & II vans and Class III vans, and a combined target for passenger cars and the smaller vans;
- Approach 2: Allowing manufacturers to pool their targets for passenger cars and vans, whereby over- or underachievement in one market can be compensated by under- or overachievement in the other market;
- Approach 3: Setting a single target for the combined sales of passenger cars and vans in combination with a single utility-based limit function that is applied to both passenger cars and vans;
- Approach 4: Bringing vehicles / vehicle platforms that are designed to be both cars and vans at the same time under the passenger car legislation.

Approach 1) is considered feasible for mass as utility parameter. However, due to the large difference in sales volumes between passenger cars and Class I & II vans, combined target function will be dominated by the passenger car data. A target function derived for passenger cars and Class I & II vans together based on a constant reduction compared to the fit through the combined data, leads to targets for the Class II vans that are tougher than for the lighter Class I vans. A flattened slope of the target line, as applied to the present target for passenger cars, would further enhance this unbalance. Depending on their division of sales over class I and class II vans, this could lead to uneven burden sharing among manufacturers of these LCVs. When footprint would be used the target function describing the combined target would lead to distances to target for large passenger cars that cannot be overcome with the available reduction potential, while for small passenger cars hardly any or no reductions would be required.

Approach 2) is technically feasible for the 2020 targets and does not appear to have major drawbacks in principle. The viability, however, needs to be determined by detailed impacts that go beyond generic arguments. An important condition for avoiding undesired consequences is that the marginal costs for meeting the separate targets for passenger cars and vans are about the same. This condition is not satisfied for the existing cars and vans targets for 2020. The marginal costs for vans are much lower than for cars. Allowing pooling of the cars and vans targets would thus lead to average CO_2 emissions for vans in 2020 that are significantly below the currently established 2020 target of 147 g/km, while the average for passenger cars would only be slightly increased above 95 g/km. Pooling on the basis of sales and mileage weighted CO_2 emissions, instead of sales weighted emissions, is preferred to avoid that shifting reductions from vans to passenger cars leads to a lower net GHG emission reduction at the overall fleet level.

The impacts of approach 3) strongly depend on the choice of utility parameter. Setting a combined utility-based limit function is likely to lead to unattainable targets for either vans (mass) or passenger cars (footprint). The risk of undesirable distributional impacts (disproportionate impacts on a limited number of manufacturers) is considerable, especially given the fact that for reaching the 2020 target manufacturers will have to use a substantial part of the available reduction potential and are thus more likely to "hit the ceiling" of the cost curves.

The main problem with approach 4) is the legal definition of which vans would qualify for inclusion in the (possibly adapted) passenger car target. Also, this option reduces the room for internal averaging which manufacturers have available to meet the specific targets that are set for the remaining light commercial vehicles that do not fall under the passenger car target.

Important factors that hinder the establishment of a combined target without undesired impacts are that:

- the EU27 passenger car sales are 9 to 10 times larger than the sales of light commercial vehicles;
- the new van sales consist almost entirely of diesel vehicles. which have a more limited reduction potential and offer that reduction at a higher cost than petrol vehicles;
- not all manufacturers sell both passenger cars and vans. and even among those that do the proportions are very different.

All in all approaches 1) and 2) appear the most feasible, provided that mass is used as utility parameter. However, overall the evaluation of existing evidence with respect to the different approaches does not seem to create a convincing motivation to strive for a combined target for passenger cars and vans.

13 Impacts of changes in operating cost on overall use and total GHG emissions

13.1 Introduction

Vehicle CO_2 regulation may have impacts on the cost structures of new passenger cars. In general, the purchase price of the cars may go up (due to the application of fuel-efficient technologies) and the cost of using the car may go down (due to lower energy costs and, in case of electric vehicles, lower energy taxes). These kinds of changes in the cost structures of cars may be expected both from shifts to more energy efficient conventional (petrol/diesel) technology as from shift from fossil fuel cars to electric or hydrogen cars. In this chapter, we explore the potential impact (knock-on consequence) of this kind of shift in the cost structure of vehicles, especially on the overall transport demand (i.e. vehicle kilometres driven) and thus GHG emissions. Additionally, we assess whether the choice of metrics might influence the likelihood of such an knock-on effect.

In the remainder of this chapter we first briefly discuss the impact of vehicle CO_2 regulation on the future costs structure of passenger cars. Next, the impact of changes in the cost structures of passenger cars on the total transport demand is discussed, with a focus on the role of the chosen metric on the likelihood and size of these effects. Finally, we present the main conclusions of this chapter.

13.2 Future cost of vehicle purchase and use

Future cost of vehicles and their operation still has significant uncertainty, and mainly depends on

- cost, annual mileage and lifetime of the vehicles;
- in case of electric cars: cost and lifetime of batteries;
- cost of the energy used, in terms of €/kWh, €/kg, €/l (or, in more general term: €/MJ);
- energy use of the vehicles (MJ/km);
- taxation of vehicles (purchase, ownership and use) and energy.

For the short and medium term several studies are available which have investigated the impact of fuel efficiency standards on both purchase and variable costs of passenger cars. For example [IEEP 2007] estimates that application of efficiency improving technology in response to the current CO_2 legislation for passenger cars (130 g/km in 2015) leads to an average retail price increase per car of around € 1100 (about 5% of the average retail price in 2006). The average net present value of the lifetime fuel cost savings[53] are estimated at € 2240 (fuel price[54] of 1 €/litre) to € 3460 (fuel price of 1.5 €/litre). The impact on vehicle retail price is thus outweighed by the lifetime fuel cost savings, resulting in a net decrease in total cost of ownership. With a fuel price of 1.5 €/litre the payback time for the additional investment is around 3.5 years. This is about equal to the time horizon over which consumers value cost savings ("consumer myopia").

The impacts of the 95 km target for 2020 on the cost structure of passenger cars have been assessed in [TNO 2011]. Due to the non-linearity of the 2020 cost curves for CO_2 reduction in passenger cars through application of fuel-efficient technologies, the impact on purchase prices are expected to be larger compared to the 2015 situation: Relative to maintaining 130 g/km between 2015 and 2020 the retail price increase due to the 95 g/km target are estimated around € 1160[55]. At a fuel price of 1.5 €/litre, the net present value of lifetime fuel savings are estimated at € 4040, so also for the 2020 target the lifetime fuel cost savings outweigh the additional vehicle costs. The payback time is around 6 years, which is longer than for the 130 g/km target and longer than the time horizon over which consumers value cost savings. However, as was indicated in [Smokers et al. 2012] recent evidence on the actual (market) costs of fuel-efficient technologies suggests that the additional costs of meeting the 95 g/km target are overestimated by [TNO 2011]. [Smokers et al. 2012] estimate that the additional

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[53] EU average for petrol and diesel
[54] EU average for petrol and diesel
[55] Based on scenario a) cost curves, for consistency with European Commission's Impact Assessment

costs to meet the 95 g/km target may be 40% to 65% lower than estimated by [TNO 2011], resulting in payback times of 4 to as low as 2.5 years.

With respect to potential future CO_2 legislation for passenger cars beyond 2020, it may be expected that reductions in the CO_2 emissions far beyond 95 g/km are likely to lead to significant increases in the costs of fossil fuel related reduction technologies [Smokers et al. 2012]. The fuel cost savings are difficult to predict, since they depend largely on the future fuel prices. According to Smokers et al. (2012) stricter CO_2 targets beyond 2020 will result in net increases in the total cost of ownership if current fossil fuel prices apply; however, the impact on total cost of ownership becomes uncertain in case fuel prices increase significantly in the future.

Targets below the values agreed for 2020 (95 g/km) 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 this have a significant impact on the composition of the fleet in terms of applied propulsion technologies and energy carriers used. Although the additional manufacturer costs of these vehicles are still very uncertain, it may be expected that for the short to medium term these costs are significant, mainly because the costs of batteries and fuel cells are high [Schroten et al. 2012]. On the other hand, these cars are expected to have lower energy costs, partly due to higher energy efficiency (i.e. less energy is needed per kilometre), and partly because the energy they use may be cheaper (per MJ), especially because excise duties on the conventional transport fuels are much higher than on electricity and hydrogen. In addition, maintenance cost are expected to be lower as well, as the engine/fuel cell and drive train are simpler (e.g. with less moving parts) than that of the ICE.

However, there are a number of issues and potential developments that could change the expected changes in cost structures in case of a large scale market penetration of electric/hydrogen cars:

- Especially in the short to medium term, **battery depreciation cost** might be significant, and directly related to vehicle use, i.e. to the number of charging cycles. Even though battery and car manufacturers put a lot of effort into developing batteries (and battery management systems) that will last a vehicle lifetime, the performance of current EV batteries deteriorates over time. Battery capacity will reduce over time, which will impact driving range of the cars. Battery cost typically need to be depreciated with the number of charging cycles, which is, of course, related to the use of the car. Therefore, users will probably consider these costs as variable costs instead of fixed costs, changing the (perceived) cost structure of the car.
- **Changes to the business model** of car ownership may also reduce purchase cost, and increase usage cost. Car manufacturers but also other private enterprises and cities are exploring different business models to market the electric car, mainly because of the reasons mentioned in the previous bullets: battery costs are relatively high and battery life and therefore depreciation cost are still relatively limited and in any case uncertain. Batteries could be leased instead of bought, as is currently the approach taken by Renault[56]. This might result in either fixed cost per time period (e.g. a monthly tariff) or in a tariff per kWh or per charging cycle – and perhaps in a combination of these tariffs. The variable cost would in fact be a cost per kilometre, these costs should then be added to the energy cost per kilometre mentioned above. Additionally, there are also some developments to move from the current individual car ownership towards mobility services. In that case, people might not own a car, but they can use one when needed (e.g. car sharing schemes). These exist for conventional cars in many countries, but there are also some specific electric car sharing initiatives in place[57]. This development could have significant impact on the cost structure of passenger cars.
- Governments may **adapt taxation schemes** to ensure stable tax revenues. It is too early to say if, how, and when this will be done, but a number of options can be envisaged that will impact the cost of using electric cars[58]:
  - Tax on electricity for cars could be increased – although this requires separate metering which is currently not in place.

[56] This also fits the system where batteries are swapped at battery swap stations rather than charged. Battery ownership might become a barrier to the future growth of these systems.
[57] See, for example, http://www.guardian.co.uk/environment/2011/dec/07/electric-car-rental-paris-autolib
[58] It should be noticed that increasing the cost of electric driving by adapting the taxation schemes may hamper the market uptake of these technologies – in the current situation, car buyers will only consider buying these vehicles if the relatively high purchase cost can be recovered over time (at least to some extent) by the relatively low operational cost. Increasing taxes for EVs should thus take into account the potential impacts on TCO and sales. Alternatively, they could be accompanied by compensating measures (i.e. tax increases) of conventional cars and fuels – assuming that EV market uptake is more about competitiveness of EVs' TCO with that of conventional cars, rather than about absolute cost.

o Various tax systems are currently differentiated to either the technology used or the vehicle emissions. Low emission vehicles such as electric cars often receive discounts or are free of charge, in order to promote the use of electric cars. Examples are urban congestion charging, road charging and tolls, parking tariffs, etc. If the differentiation is reduced, the cost of using these cars may increase.

o A shift from fuel/energy taxes to road usage taxes could be implemented, to ensure significant tax revenues from all kinds of vehicles.

To conclude, the impact of CO_2 legislation for passenger cars on the cost structure of these vehicles is rather uncertain, particularly for the period beyond 2020. However, it is appropriate to assume that in all cases the purchase costs of future vehicles will rise, while at the same time the variable costs will decrease (assuming no significant changes in the taxation schemes of the Member States). These changes in cost structures are expected to be larger if a large shift to non-fossil fuel vehicles is realised. In case of electric/hydrogen cars a significant change in the business models for these vehicles (e.g. large shift to car sharing initiatives) may reduce this shift from usage cost to ownership cost.

13.2.1   Overview of knock-on consequences

The changes in purchase and usage costs of passenger cars that result from vehicle CO_2 regulation may impact total transport demand in various ways. [Smokers et al. 2012] distinguishes five potential knock-on consequences due to the changes in cost structures of passenger cars:

- *More/less people buying new cars;* the increase of purchase costs may incentivize consumers to buy less cars. However, the reduced usage costs may result in lower total cost of ownership, which may stimulate the purchase of a car. It should be noticed, that private car buyers tend to undervalue savings in the longer term, a phenomenon which is known as 'consumer myopia'. Car buyers tend to have a 3 to 4 year time horizon for valuing fuel cost savings. Therefore the lifetime fuel cost savings need to be significantly higher than the price increase to motivate consumers to buy a fuel efficient model. In other words: In order for private consumers to be willing to pay more for a more fuel efficient car the payback time needs to be short and proven.
- *People buying larger/smaller cars;* as for the first effect, the changed cost structure of passenger cars provides contrary incentives with respect to the choice of the size of the car. The increased purchase costs may stimulate people to buy smaller cars, while the lower usage costs may incentivize the purchase of larger cars. Again, the ratio between the (relative) changes in both cost elements determines the actual impact on consumer decisions.
- *Shifts in sales between petrol and diesel;* If the price differential between petrol and diesel vehicles or the difference in fuel consumption change due to CO_2 legislation this may shift sales from one fuel to the other. Assuming full and even cost pass-through, the [IEEP 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. Based on these effects a shift to petrol cars may be expected.
- *People driving more/less per car;* in general, the lower usage costs results in lower marginal costs of using the car and hence people will drive more per car.
- *Net increase/decrease in demand for car transport*; this is the combined effect of the four effects mentioned before plus the impact on the composition and usage of the fleet of existing vehicles.

The impact on lower fuel/energy costs on the number of kilometres driven per car are investigated in several studies. [TNO 2011] quantified this impact based on a thorough review of the literature on fuel price elasticities. They estimated a rebound effect due to lower fuel costs of about 18% to 44% of the first order impact of the fuel efficiency improvement. This is quite well in line with [UKERC 2007] which presents a long term rebound effect of 10% to 30%. [Hymel 2010] estimates, based on an econometric analysis of time series data across a long period from various US states, a rebound effect ranging from 5% (short term) to 24% (long term). Finally, [Nässén 2009] estimates the rebound effect to be in the range of 5% to 15%. Based on these results it may be expected that the long term rebound effect of lower fuel/energy costs will probably be in the range of 10% to 40% of the first order impact of the fuel efficiency improvement.

Evidence on the knock-on consequences with respect to the size/composition of the vehicle fleet is rather scarce. This impact is only investigated by [TNO 2011]. Based on a review of some TREMOVE modelling runs in support of the development of the current CO_2 legislation for passenger cars it was

estimated that the positive knock-on consequence with respect to vehicle purchase behaviour (less vehicles sold results in less kilometres and hence less CO_2 emissions) exceeds the negative knock-on consequence of increased vehicle usage due to lower fuel/energy costs, resulting in a net positive knock-on impact. These net positive impacts may increase in the future, in case the additional vehicle costs per unit of CO_2 reduction achieved may increase and hence the associated knock-on consequences on purchase behaviour, as predicted by TREMOVE, may increase. However, it should be noticed that these impacts on purchase behaviour are not confirmed by other, empirical studies and hence they are very uncertain.

Based on this limited evidence on the knock-on consequences of vehicle CO_2 regulation, [Smokers et al. 2012] qualitatively assessed the overall knock-on consequences of both the 130 g/km target and the 95 g/km target. With respect to the 130 g/km target, they expect a small negative knock-on effect (rebound) on overall GHG emissions. Since this target only results in a rather small increase in average purchase prices of vehicles the positive CO_2 impact of lower car ownership is expected to be exceeded by the negative CO_2 effect of higher mileages due to lower fuel/energy costs. With respect to the 95 g/km target a small net positive knock-on effect is expected, mainly the consequence of the larger purchase price effects. As mentioned in section 13.2 it may be expected that future CO_2 legislation for passenger cars may increase the fixed/variable costs ratio of passenger cars, resulting in larger net positive knock-on consequences. However, it should be noticed that these conclusions are very premature and should be considered carefully.

13.2.2   Impact of metrics on knock-on consequences

The choice of metric for the CO_2 regulation may affect the likelihood and size of the knock-on consequences. A summary of a qualitative assessment of the impact of the type of metric on the likelihood and size of the knock-on effects is given in Table 56.

The tailpipe CO_2 emission and energy consumption based metrics (option a and b) are expected to result in smaller negative knock-on effects compared to option a1. These metrics will result in a smaller shifts to non-fossil fuelled cars and hence the average usage costs of passenger cars will decrease less. As a consequence the increase in car use will be lower compared to the current metric (option a1). The smaller shift to non-fossil fuelled cars may, on the other hand, result in smaller increases in average purchase prices and hence smaller reduction in car ownership and car usage. Since it is expected that the positive knock-on effects of a shift to electric/hydrogen cars are larger than the negative knock-on effects, the net knock-on effect is expected to be less positive (or more negative) compared to the case the current metric (as in the existing Regulation) is applied. These effects are strengthened in case the various metrics take embedded emissions into account (option f).

If transport is included in the EU ETS, it may be expected that transport becomes a net buyer of allowances. As a consequence less fuel-efficient technologies are applied on new passenger cars and hence usage costs will decrease less compared to the reference situation, while purchase costs will increase less. As a result both the negative and positive knock-on effects will be smaller. As mentioned before, due to the non-linearity of the CO_2 cost curves for fuel efficient technologies for passenger cars it is expected that – on the longer term – purchase costs may increase relatively more due to the implementation of fuel-efficient technologies than that usage costs decrease. Therefore, it may be expected that the net knock-on effect for this option will be less positive (or more negative) compared to the case the current metric (as in the existing Regulation) is applied.

The metrics including mileage weighting or a (cap & trade) trading system for manufacturers do not have any negative knock-on effect due to increased car usage. Car manufacturers are required to compensate any additional CO_2 emissions due to increased car use by increasing the average fuel efficiency of their cars. However, these metrics may have different impacts on car ownership. In case of cap & trade trading schemes, any reduction in car sales may provide manufacturers the opportunity to lower the fuel efficiency improvements of their cars and as a result no net impact on GHG emissions is expected. In case of mileage weighting it may be expected that the increased costs due to the additional investments in fuel-efficiency measures to overcome the additional CO_2 emissions due to increased car usage may result in lower car ownership and hence less CO_2 emissions. However, in case of the manufacturer based trading schemes based on lifetime CO_2 emissions the latter effect is at least partly compensated for by the efficiency improvements realised by the fact that manufacturers are allowed to trade with each other. The overall impact on car ownership is therefore unknown for this option.

Table 56   Qualitative assessment of knock-on effects of various types of metrics (compared to option a1: Tailpipe CO_2 emissions as in existing Regulation.

Type of metric	Increased car usage (negative knock-on effect)	Decreased car ownership (positive knock-on effect)	Net knock-on effect
Alternative CO_2 emission based metrics (option a2 – a4) Energy consumption based metrics (option b)	Due to smaller shift to non-fossil fuel cars, reduction in average usage costs are smaller and hence increased car usage is lower.	Due to smaller shift to non-fossil fuel cars, increase in average purchase costs is lower and hence decrease in car ownership is lower.	Net knock-on effect probably be less positive/more negative (as the effect of the car ownership is expected to outweigh the effect of car usage)
Inclusion in EU ETS (option c)	Since transport will probably be a net buyer of allowances, cars will on average become less fuel-efficient. As a consequence usage costs will decrease less and hence car usage will increase less.	Since transport will probably be a net buyer of allowances, less fuel-efficiency technologies for cars will be applied. As a consequence purchase prices will increase less and hence car ownership will decrease less.	Net knock-on effect will be less positive/more negative (since due to the non-linearity of CO_2 cost curves effect on purchase prices will decrease more than effect on usage costs).
Manufacturer based trading system based on lifetime GHG emissions (option d)	Manufactures are required to compensate any increase in car usage by implementing additional fuel-efficient technologies. Depending on the way this is implemented no net effect on GHG emissions could be expected (which implies less GHG emissions compared to option a1)	The potential investments in additional fuel-efficient technologies may increase purchase costs, but trading between manufacturers may lower purchase costs. Overall impact is unknown.	Net knock-on effect is unknown.
Cap & Trade system for vehicle manufacturers (option e)	See 'Manufacturer based trading system based on lifetime GHG emissions'	Lower sales of new cars may provide manufacturers the opportunity to lower the fuel efficiency improvements of their cars. No net effect on GHG emissions (which implies more GHG emissions compared to option a1).	No net knock-on effect is expected. Assuming a positive net knock-on effect for option a1, this implies a negative knock-on effect compared to option a1.
Inclusion of embedded emissions in WTW approaches (option f)	Due to even smaller shift to non-fossil fuel cars, reduction in average usage costs are even smaller and hence increased car usage is even lower (compared to relevant options a and b)	Due to even smaller shift to non-fossil fuel cars, increase in average purchase costs is even lower and hence decrease in car ownership is even lower (compared to relevant options a and b).	Net knock-on effect probably be less positive/more negative (see option a and b).
Inclusion of size dependent mileage weighing (option g)	See 'Manufacturer based trading system based on lifetime GHG emissions'	The potential investments in additional fuel-efficient technologies may increase purchase costs and hence strengthen car ownership decrease.	Net knock-on effect will be more positive/less negative.

13.3   Conclusions

The introduction of new (fuel-efficient) technologies could change the cost and cost structure of passenger cars. It seems likely that usage cost will then reduce and car purchase cost increase. The impact of these changes in the cost structure of passenger cars on transport demand and overall GHG emissions are rather uncertain. On the one hand, decreased usage cost may increase the usage per vehicle. But the increased purchase cost, on the other hand, may lengthen vehicle lifetimes or reduce car ownership which reduces total transport demand. Particularly the evidence on the latter impact is scarce, as a consequence of which it is difficult to determine the net impact on transport demand and overall GHG emissions. A first expert guess provided by [Smokers et al. 2012] indicates that on the longer term (2020 and beyond) the impact of decreased car ownership on total transport demand is larger than the increased usage per vehicle, resulting in a net decrease of car usage and overall GHG emissions. This would imply that these indirect (knock-on) effects would strengthen the direct GHG effects of vehicle CO_2 regulation.

As is shown in this chapter, the choice of metric may affect the likelihood and size of the impact on transport demand. Most alternative metrics result in smaller (or maybe even negative) reductions in total transport demand and hence less positive knock-on effects in terms of GHG emissions. An exception is the mileage weighting which may result in a more GHG emission reduction.

Although the likelihood and size of the impacts of vehicle regulation on transport demand are still rather uncertain, it is important to consider them from the start of developments, as these may largely affect the effectiveness of this policy option. In that case potential supporting policy instruments could be considered, like for example economic instruments.

14 Literature

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15   Glossary

BEV	Battery electric vehicle
CONCAWE	R&D organisation of leading oil companies into environmental issues
COPERT 4	Software tool used to calculate air pollutant and GHG emissions from road transport. coordinated by European Environment Agency
EC	European Commission
ECE	Economic Commission for Europe
EREV	Extended range electric vehicle
EUCAR	European Council for Automotive R&D
EUDC	Extra-urban driving cycle
EV	Electric vehicle
FCEV	Fuel cell electric vehicle
GHG	Greenhouse gas
GWP	Global warming potential
HCCI	Homogeneous charge compression ignition
ICE	Internal combustion engine
ICEV	Internal Combustion Engine Vehicle
IPCC	Intergovernmental panel on climate change
JRC	Joint Research Centre (of European Commission)
LCA	Life cycle analysis
LLGHG	Long lived greenhouse gas
MAC	Mobile air conditioning
NEDC	New European driving cycle
NMVOC	Non-methane volatile organic compounds
PHEV	Plug in hybrid electric vehicle
TTW	Tank to wheel
WTT	Well to tank
WTW	Well to wheel (note: WTW = WTT + TTW)
ZEV	Zero tailpipe (TTW) emission vehicles

A   Upstream emissions for different energy carriers

A.1 Review of options for and definition of methods for assessing upstream emissions for different energy carriers

The main purpose for comparing alternatives to the tank-to-wheel (TTW) CO_2-based metric of the current CO_2 regulation for passenger cars and vans is to assure that future regulation of GHG emissions of the European vehicle fleet achieves the desired impacts in an efficient and cost-effective manner. Various alternative approaches are under consideration and some require the development of ways in which the well-to-tank (WTT) or upstream GHG emission impacts of various vehicle technologies and energy carriers can be factored into the regulation.

The assessment in this Annex includes the following fuels and energy types:

- petrol and diesel,
- CNG and LNG
- various types of biofuels
- electricity
- hydrogen

This Annex explores methodological issues and derives WTT emission factors for use in the assessments carried out in chapter 5 using a fleet model.

A.1.1   Large variations in actual emission factors

Transport fuels and other energy carriers may have very different WTW characteristics. For example, in case of electricity and hydrogen, TTW emissions (i.e. vehicle emissions) will be zero, but emissions may occur in the upstream part of the energy chains. Biofuels are typically accounted under Kyoto linked regimes as zero emissions, although their TTW emissions are comparable to the fuel they replace. Upstream emissions are attributed to the agricultural sector under IPCC guidelines. Petrol and diesel typically have only about 15% of WTW emissions in the upstream, WTT, part of the fuel chain, with the remainder occurring during combustion of the fuel, in the TTW part.

Also, it should be realised that with all these fuels and other energy carriers, there can be a significant variation in WTW emissions even within a category. For biofuels, these may depend on, for example, the type of biomass used as feedstock, or the type of energy used for biofuel production processes. In case of electricity and hydrogen, it will depend on the type of energy used to produce these: WTW emissions can then range from practically zero in case of wind-, solar- and hydro-electricity, to values higher than that of petrol and diesel in cases where lignite is used for electricity production. In addition, part of the upstream emissions will be within the EU, part will be outside, and some may be covered by the EU Emission Trading System (ETS), whereas the majority of WTW emissions will be outside the scope of the ETS.

Life cycle analyses of many of these routes have shown that the actual WTW emissions may depend on many different parameters, including time of day and location (in case of electricity production, for example), and, in case of biofuels, the specific characteristics of the biofuels production plant. For the purpose of EU regulation, it is often too complex, and thus practically impossible, to determine emission factors in all detail. Average values are then typically used, with differentiation where possible and necessary. In the RED and FQD, for example, different default emission factors are given for a number of categories of biomass-to-biofuels routes, but not for each (type of) biofuel production plant. Biofuel producers may, however, calculate and use their own specific values if they can prove that their biofuels have lower GHG emissions than the default value.

The challenge is to use average (default) values where possible, to reduce the administrative burden and simplify policy implementation, whilst ensuring sufficient differentiation between fuels and other energy carriers with different emission factors in order to optimise the efficiency and effectiveness of the policy.

Both for the assessment of possible options for metrics for post-2020 CO_2 legislation, and for the implementation of a suitable option it is necessary that WTT GHG emissions can be determined in a sufficiently reliable, robust and acceptable manner.

A.1.2   The options

There are quite a number of choices to be made when defining a methodology to determine the upstream GHG emission intensity of the various energy carriers. Some of these will apply to all energy types, others are mostly relevant for some of them.

Standard life cycle analysis methodology should be used as a starting point, where all emissions along the life cycle of the fuel or energy carrier are considered, using a number of well-defined methodological assumptions. This approach is also taken in the Renewable Energy Directive and the Fuel Quality Directive, where upstream GHG emission factors are provided for all of these fuels and other energy carriers[59].

The main methodological choices to be made are the following:

- The fuel and energy categories that are differentiated;
- The methodology used for allocation of by-products and blends;
- How to account for indirect emissions, mainly due to indirect land use change (ILUC)?
- GHG intensity for average or marginal fuel production and energy generation? In the case of marginal, short or long term marginal emissions could be distinguished;
- One average factor for the EU, or differentiation between Member States?
- In case of electricity: whether to use consumption or generation data, and how to treat co-generation of heat?
- Emission factors of which year?
- Scope of emissions.

Fuel and energy categories

For example, the RED and FQD differentiate between quite a number of biofuels, fossil fuels and hydrogen, and, in case of electricity, use different GHG intensity factors for different Member States. However, this level of detail may not be necessary in the vehicle emission regulation.

When a vehicle is sold in the EU, in most cases the fuel type is known, i.e. it will drive on petrol, diesel or CNG/LNG, electricity or hydrogen. The petrol and diesel may contain biofuels in low blends (currently defined as up to 7vol% in diesel and up to 10vol% in petrol). In some cases, e.g. plug-in hybrid electric or hydrogen vehicles, extended range electric or hydrogen vehicles and dual fuel vehicles, various types of fuel can be used. This is also true for most of the vehicles that are suited for high biofuels blends, e.g. B100 or E85, these can often also run on fossil fuel only or lower biofuel blends.

With this in mind, it seems reasonable to define GHG intensity factors for the various 'basic' types of fuels and energy, and then use type approval measurements, perhaps combined with other methods, to estimate the fuel mix that can be expected to be used in real life. The main categories of fuel and energy that should have separate GHG intensity factors are then:

- Petrol
- Diesel
- Biofuel for petrol engines
- Biofuel for diesel engines
- Natural gas
- Biomethane[60]
- Electricity
- Hydrogen

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[59] Note that the methodology and default values for fossil fuels, electricity and hydrogen are not yet decided on. However, the Commission has issued a draft proposal for the FQD that includes these in October 2011.
[60] Possibly differentiating between (bio-)CNG and (bio-)LNG

Methodology used for allocation of by-products and blends

In the biofuels regulations of the RED and FQD, emissions are allocated to by-products based on energy content. When fuels are blended a mass balance approach should be used.

Especially regarding allocation, there are other methodologies that are generally considered to be more representative of the actual emissions. Substitution is, for example, a more accurate technique at least from a theoretical viewpoint, but it requires very detailed analyses for each fuel (which have to be repeated regularly, as circumstances change), and is thus considered not feasible to provide robust default values for longer-term policies.

Somewhat similar discussions take place regarding electricity production. In cases where electricity is produced together with heat (co-generation), a methodology has to be defined with which the GHG emissions of these processes are distributed over the heat- and electricity that is being produced. For reasons of consistency and simplicity, it seems best that a CO_2 regulation would use the same approach as typically taken in either EU statistics (Eurostat) or in other, related policies. In this study we have made the following choices:

- Fossil fuels: allocation in line with the methodology used to determine the GHG intensity of these fuels in the FQD methodology (JEC WTW study).
- Biofuels: allocation as defined in the RED and FQD methodologies to calculate GHG intensities (JEC WTW study)
- Electricity: methodology used in line with Eurostat methodology.
- Hydrogen: in line with approach taken in the FQD methodology (JEC WTW study)

Indirect emissions

Especially emissions due to indirect land use change (ILUC) can be very significant for (some, not all) biofuels. However, these are not yet included in the RED and FQD methodologies. Within the EU, there is quite a strong debate on-going on the best methodology to use for these two directives regarding these indirect emissions. However, the way forwards has not yet been decided.

It is proposed to keep the methodology to calculate the WTW GHG intensity of biofuels for the vehicle emission regulation in line with the one used for the RED and FQD regulations. This means that in the current situation, where indirect effects are not included in these regulations, they would not be included in the CO_2 regulation either. In that case, these effects should still be included in calculations on the WTW impacts of the regulation, as modelling work has provided estimates of indirect effects (see, for example, IFPRI, 2011). As it seems quite likely that the current GHG emission calculation methodology will have be adapted in the future, it is assumed here that from 2020 onwards, indirect emissions are included.

Average or marginal production

Various studies have shown that GHG intensity of average fuel or electricity production can be quite different than that of marginal production. This can best be illustrated with an extreme example: if an electric vehicle is charged at night, in many EU countries this electricity will be produced by increasing coal or nuclear power production – these are often the power plants that provide the base load at night time, when there is low demand. Renewable electricity may also contribute to power production at that time, but not all renewable energy sources can be increased because of additional demand (e.g. wind and solar energy are typically supply driven), and PV will not produce at night. The actual, marginal GHG intensity of that electricity can thus be quite different from the GHG intensity of the average power production in a Member State or of the EU, which will be a mix of a whole range of electric power production types.

This effect is most profound for electricity and hydrogen production, but may also be significant for fossil fuels. For example, WTW GHG intensity of natural gas produced in the EU is typically much lower than that of NG imported from Russia (which could be the marginal NG source at times). This effect is less pronounced for petrol and diesel, even though there are differences.

In this respect, it has also been argued that the marginal emissions of electricity production are actually zero (or close to zero) because of the EU Emission Trading System (ETS) – any additional

emissions are 'automatically' compensated by CO_2 reductions elsewhere in the system (or with additional CDM measures). These emission reductions are, however, mainly 'automatic' from a policy point of view, they are likely to lead to additional cost and efforts within the ETS, In addition, it is quite likely that the future ETS system (beyond 2020) may take into account the electricity demand from transport, leading to an increase of the number of emission allowances accordingly.

Another issue worth noting is that marginal emissions in the short term may be different from the longer term marginal emissions. An increasing electricity demand will not lead to additional production capacity in the short term [CE Delft, 2011], but it may require investments in the longer term. The resulting long term marginal emissions may then differ from those in the short term.

Therefore, even though using GHG intensity of marginal electricity production may provide a more realistic and accurate result, it would require setting up very detailed monitoring and reporting of both vehicle charging and power production over time, and it might even require a detailed assessment of short versus long term impacts. This does not seem to be a feasible (and cost effective) option. Therefore, in this study the average GHG intensity of a fuel or energy is used to define upstream emissions of vehicles.

EU average or individual Member State data

Upstream GHG intensity may vary, depending on the Member State where the vehicle is filled up or charged. Again, this will be most pronounced in case of electricity and hydrogen, but also occurs with other fuels. In some related transport policies, notably in the RED and the FQD, some differentiation is applied. In the RED, Member States may choose to either use their own average share of renewable electricity production to calculate the contribution of renewable electricity to the transport target in 2020, or the EU average. However, the default values for GHG intensity of biofuels are assumed to be the same throughout the EU. In the October 2011 draft proposal for the FQD[61], the GHG intensity for electricity is differentiated by Member State, but this is not the case for fossil fuels (incl. natural gas) and hydrogen from fossil origin.

This approach is probably the result of balancing administrative cost on the one hand (higher with more differentiation), and added value on the other hand (i.e. there should be clear benefits from a more complex methodology): the GHG intensity of fossil fuels (at least of petrol and diesel) does not vary much between countries[62], whereas it does vary significantly in case of electricity[63].

In the context of the CO_2 regulation for cars and LDVs, Member State differentiation of electricity GHG intensity might also have a positive effect, whereas for the other fuels, EU-average values should be sufficient. The life time GHG emissions of an electric vehicle that drives in a country with high GHG emissions (e.g. Poland or Estonia) are much higher than if the same vehicle would drive the same number of kilometres in Denmark or Austria, because of the very different electricity production mix. Differentiating between countries could then provide an incentive to focus EV sales in Member States with low GHG intensity electricity production.

Emission factors of electricity consumption or generation

The electricity mix (and thus GHG emissions) of a Member State, and indeed of the EU27 as well, depends on whether imported and exported electricity are included, or whether only national production is taken into account. The latter is the basis for many statistics, and is also easier to determine than the first, which could be expected to provide the most realistic, accurate picture of electricity consumption in a country.

However, as GHG intensity of electricity generation is used in the FQD (according to the draft proposal of October 2011), and these data are typically used in emission reports, statistics etc., we suggest to also take that approach in this study.

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[61] Note: this is a draft proposal, so this might change in the coming months.
[62] Although variations might be significant in case of natural gas.
[63] And probably also for hydrogen, but the current share of hydrogen in transport is negligible, so a differentiation would not have significant impact.

Choice of the year to be used

Some of the GHG intensities will vary over time, for example because of an increasing share of renewable energy, or because of other CO_2 mitigation measures, for example taken to meet the FQD target. The question therefore arises whether emission factors should be used that are valid at the time of the vehicle sales (or of the most recent official statistics, typically of 2 years before), or whether an estimate should be used of the 'average' emission factor during the lifetime of the vehicle. That would then have to be based on a prognosis of the emission factor development over time, using an agreed model and methodology.

Scope of emissions

Are GHG emissions outside of the EU also included in the GHG emission factors, or is the scope limited to the EU, following IPCC reporting methodology? Both the RED and FQD directives have taken a global, well-to-wheel approach, as this increases the effectiveness of these policies (i.e. they will reduce more GHG-emissions than if they would only include emissions within the EU). On the other hand, the ETS is limited to emissions within the EU, as it is limited to end-of-pipe emissions.

From both an efficiency and level-playing field point of view, it would be best to take a WTW approach, rather than limit the scope to the EU. If an EU scope were taken, an energy route that causes emissions outside the EU would have clear advantages compared to energy with emissions within the EU – even if they have the same contribution to global GHG emissions.

Furthermore, the IPCC methodology is used as a monitoring and target-setting measure, not to provide specific incentives such as the CO_2 regulation. If accounting for IPCC purposes would take a WTW approach, many emissions would count double: for example, GHGs that are emitted in the production processes of products that are exported would then be counted both in the countries were they occur and in the country where the final product was used. In the applications studied in this report, double counting is not an issue, though, as discussed further in section A.2.

A.2 Generation of indicative upstream emission factors for different scenarios (2020-2050)

In this section, upstream emission factors are generated for use in the assessment model developed in Annex B and used in chapter 5. Values are developed for WTT figures from a global perspective as well as figures according to IPCC accounting rules for the EU. The expected development over time of these upstream emission factors will be described for the 2020-2050 timeframe, the scope of this study.

Assumptions will need to be made regarding the most likely future developments of upstream emissions of all types of energy carriers. Modelling such a development is relevant for:

- conventional fuels: WTT emissions could increase as a result of using oil from increasingly less conventional sources, however, CO_2 mitigation options exist also in that part of the fuel chain.
- electricity and hydrogen: average and marginal WTT emissions are likely to go down as a result of declining caps under the EU-ETS and increased uptake of renewable electricity production;
- biofuels: WTT emissions may reduce if more stringent GHG emission criteria are implemented in the future (incl. inclusion of ILUC effects).

The question how the Fuel Quality Directive, Renewable Energy Directive and the ETS will develop after 2020 will be relevant here, as these may affect the emission factors of the various fuels. Assumptions will also be needed about how WTT emissions will change over time. These should be compatible with the EU 2050 Roadmap as far as possible.

A.2.1 GHG intensity of conventional fuels

As mentioned above, WTT emissions of petrol and diesel are likely to increase as a result of using oil from increasingly less conventional sources, which require more energy than conventional oil production and thus have higher emissions – depending on the energy used. On the other hand, however, it can also be expected that more CO_2 mitigation options will be implemented in the future, due to the FQD (currently only relevant for the period until 2020, but perhaps further tightened

afterwards) and perhaps other (incl. global) climate policies. Venting and flaring can be reduced, energy efficiency could be improved, low-carbon energy sources could be deployed, etc.

The actual development of emissions thus depend strongly on the future policies in place: the FQD after 2020, policies in the oil producing countries and global climate policies.

Regarding natural gas, the same argumentation applies, although in this case, the main reason for a potential future increase of emissions would be an increase of the share of NG imports and transport distances (both via pipelines and with LNG tankers).

We thus propose to assess two different scenarios, one which assumes effective CO_2 reduction policies in the fossil fuel chains, and one which assumes that a future shift to high-carbon fossil fuels will gradually increase emissions:

- Scenario 1: Starting with current WTT emission factors, a 0.5% reduction per year is assumed[64].
- Scenario 2: Starting with current WTT emission factors, a 0.5% increase per year is assumed.

The baseline emission factor is based on the results in Annex II of [JEC 2011], for 2020.

Table 57   Potential scenarios for fossil fuel WTT GHG intensities (gCO_2/MJ)

	Scenario 1				Scenario 2			
	Petrol	Diesel	Natural gas	LPG	Petrol	Diesel	Natural gas	LPG
2020	14.2	15.9	8.7	8	14.2	15.9	8.7	8
2030	13.5	15.1	8.3	7.6	14.9	16.7	9.1	8.4
2040	12.8	14.4	7.9	7.2	15.7	17.6	9.6	8.8
2050	12.2	13.7	7.5	6.9	16.5	18.5	10.1	9.3

A.2.2   GHG intensity of biofuels

Biofuels need to achieve a minimum GHG emission reduction, compared to fossil fuels, to be able to count towards the RED and FQD target. The calculation methodology does not yet, however, include emissions due to indirect land use change (ILUC), and thus overestimates GHG emission savings very significantly for quite a large share of the current biofuels (especially for biodiesel, see [IFPRI 2011]. Efforts are on-going to include ILUC impacts, but it remains questionable whether the system can be made watertight for all biofuels, i.e. whether the GHG emission factor that is reported is indeed a realistic value[65]. We therefore propose to assess two different variants:

- Scenario 1: assumes that biofuels meet the minimum GHG reduction targets set by the EU policies, also in real life[66]. It is assumed that the minimum GHG reduction level follows the RED minimum levels until 2020, and then lowers to 70% from 2020 onwards and to 80% from 2030 onwards.
- Scenario 2: assumes that ILUC emissions cannot be effectively included in the policies (although some form of ILUC policy is implemented) or that they are included but the minimum levels are kept at higher levels than in scenario 1. The result is that GHG emission factors are effectively equal to fossil fuels in 2010, achieve an average reduction of 20% in 2020, and 40% from 2030 onwards, and 60% from 2040 onwards .

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[64] For comparison: the current FQD requires a 6% emission reduction between 2010 and 2020, which amounts to -0,62% reduction per year. Assuming that part of this target will be met by shifts to alternative, low carbon fuels such as CNG and electricity, and assuming that this rate of emission reduction will continue after 2020, an annual reduction of 0.5% would seem a reasonable estimate.
[65] For example, the current ILUC debate focusses on biofuels from food crops. However, ILUC and other indirect effects also occur for biofuels from waste and residues, as many waste and residue streams are already in use in other sectors, or could be used in more efficient applications.
[66] The current minimum level is 35% (although installations from before 2008 do not have to comply until 1.5.2013), but this increases to 50% from 2017 onwards. Biofuel production plants that start production after 1.1.2017 must achieve a minimum of 60%.

To convert these GHG reduction levels to GHG emission factors, the 2010 fossil fuel emission factors are used as a reference, as provided in the recent draft FQD proposal: 87.5 gCO_2/MJ for petrol, and 89.1 g CO_2/MJ for diesel.

Looking at current biofuels, there is a difference in average GHG intensity of ethanol and biodiesel, especially when ILUC effects are included (ethanol typically has lower GHG intensity than biodiesels from vegetable oils). It is not clear, however, how this will develop in the future. In these scenarios, we have therefore taken equal values for biofuels, irrespective if they replace petrol or diesel.

Table 58   Potential scenarios for biofuels WTT GHG intensities (gCO_2/MJ)

Year	Scenario 1		Scenario 2	
	Biofuels for petrol vehicles	Biofuels for diesel vehicles	Biofuels for petrol vehicles	Biofuels for diesel vehicles
2010	70	71.3	87.5	89.1
2020	26.3	26.7	70	71.3
2030	17.5	17.8	52.5	53.5
2040	17.5	17.8	35	35.6
2050	17.5	17.8	35	35.6

A.2.3   GHG intensity of electricity

To calculate the well-to-wheel GHG emissions of electric vehicles, the GHG emission per unit of electricity used is an important parameter. As discussed in the previous section, quite a number of choices will have to be made before the value of this parameter can be given. Key questions are, for example:

- Use a marginal value of the parameter (answering the question what type of electricity production corresponds to the extra electricity demand of the electric vehicle at the specific time of charging the vehicle), or a statistical value (e.g. a year average)?
- Counting 'fossil' electricity generation only, or counting the total electricity generation (fossil plus renewable)?
- Which geographical area (Member State, EU average)?
- Take import and export of electricity into account or only the generation within the area?
- Take 'self-consumption' of power plants and grid losses into account or not? To do so results in a value at the point of the user, otherwise the result will be a parameter at the point of generation.
- Take only the direct GHG emissions of the electricity generation into account, or a life cycle value in which also upstream GHG emissions are accounted for?

For the EU, the PRIMES-model is the current standard for energy forecasts. Within the PRIMES-model, each EU Member State is separately modelled. Note that, since the structure and energy mix of the power sector is different in each Member State, values for the carbon intensity of electricity generation are different for each Member State[67]. With the PRIMES-model, a baseline is calculated for the trends in the EU to 2030 [EC 2010], but PRIMES modelling is also used for longer term modelling, in the context of the EU Roadmap to 2050.

In the PRIMES-model, the following definitions are used in the calculations of the carbon intensity of electricity production:

- Year average
- Total electricity generation
- EU27 as geographical area, and not taking export and import into account

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[67] For example, the 2010 data on the carbon intensity of electricity generation ranges from 0,80 to 0,03 tCO2/MWh for Malta and Sweden, respectively

- Carbon intensity at the point of generation (i.e. disregarding 'self-consumption' and grid losses in the value of the parameter)
- Upstream GHG emissions not taken into account.

As we look at the timeframe until 2050 in this study, emission factors can best be based on the EU scenarios developed for the EU Roadmap for transport 2050 [EC 2011]. As depicted in the roadmap, power generation in the EU will be almost completely decarbonized by 2050. Note that the PRIMES carbon intensity numbers are for 'Electricity *and Steam* production'.

The PRIMES emission data are in line with Eurostat statistics for 2009 (most recent data), and thus seem to use the same definitions. A different set of values seems to be used in the FQD draft proposal (of October 2011), however. This gives substantial higher GHG intensities than the PRIMES-TREMOVE scenarios.

In this study, we use the PRIMES-TREMOVE v.1 results of different scenarios to assess the sensitivity of the different options to variations in GHG intensity of electricity:

- Scenario 1: Decarbonisation scenario as used for the Roadmap 2050 (PRIMES-TREMOVE v.1, Decarbonisation scenario)
- Scenario 2. Reference scenario developed for the Roadmap 2050 (PRIMES-TREMOVE v.1, Reference scenario)

Table 59   Carbon intensities for electricity generation in the EU27.

Year	Scenario 1: Carbon intensity (ton CO_2/MWh)[68] Decarbonisation scenario	Scenario 2: Carbon intensity (ton CO_2/MWh) Reference scenario
1990	0.4624	0.4624
2000	0.3729	0.3729
2010	0.3113	0.313
2020	0.2053	0.2256
2030	0.1005	0.1756
2040	0.0314	0.0992
2050	0.0036	0.0734

Source: DG CLIMA, Background data to EU Roadmap for transport 2050 [EC 2011]

A.2.4   GHG intensity of hydrogen

Hydrogen is still in the R&D stage, with several pilot and demonstration projects on-going in the EU. Expectations vary, but most experts will agree that it will take quite some time before it could achieve significant market shares in transport. Furthermore, since costs are still relatively high, significant investments are required to roll out a large scale hydrogen distribution network in the EU and other alternatives such as battery electric vehicles are also being developed, it cannot yet be said with certainty whether hydrogen will achieve a breakthrough in the transport sector at all.

Hydrogen was included in this study as a potential future energy carrier, however, since it has a number of potential advantages over the other alternatives such as electric transport and biofuels, which may make it a fuel of choice in at least some niche markets or transport modes in the time frame beyond 2020/2030. Some of its main advantages are that it can be produced from a wide range of energy sources (either directly, or via electricity), it can store energy quite efficiently and it can be used in efficient fuel cells to drive the cars. The main disadvantages are the relatively high cost, mainly because of the need to roll out a new infrastructure for its distributions, and the fact the pathway for using renewable energy in transport provided by hydrogen is significantly less efficient than the pathway provided by electricity as energy carrier.

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[68]   1 ton CO2/MWh = 0,278 kg CO2/MJ (MJ electricity or MJe, not primary energy)

When estimating the WTW GHG intensity of hydrogen, the key questions are

- What energy source is used to produce the hydrogen?
- With what efficiency is the hydrogen produced and then converted into power to drive the vehicles?

In the current situation, most of the world's hydrogen is produced from reforming of natural gas (about 90%). Most of this hydrogen is used in refineries [ECN 2011]. A large range of potential production routes exist, however, such as coal gasification, biomass processing (e.g. gasification of wood) and hydrogen production from electrolysis (i.e. from electricity). The technology to produce the hydrogen though gasification of woody biomass is not yet fully developed, but the other options are.

The WTW GHG intensity of hydrogen production from reforming of natural gas has been calculated in [JEC 2011] for a number of specific routes in 2020. The WTW GHG intensity was found to vary quite significantly, depending on, for example, the scale of hydrogen production (e.g. on-site reforming or central reforming), the origin and transport distance of the natural gas, the technology used for distribution to filling stations (e.g. via pipeline, compression or liquefaction) and whether CCS is used or not. The 'best case' was found to be about 38 g CO_2eq/MJ (with CCS), the 'worst case' had a GHG intensity of more than 140 g CO_2eq/MJ. The GHG emissions of hydrogen production from coal gasification were found to be even higher (about 235 g/MJ), although CCS could reduce these significantly, to about 53 g/MJ.

Hydrogen production via electricity was found to result in a large range of GHG intensities, strongly dependent on the energy source for electricity generation. If fossil fuels are used to produce the electricity, GHG emissions are typically relatively high (up to 400-500 g/MJ in case of coal electricity, about half of this if natural gas is used). Using renewable energy sources such as woody biomass or wind will result in a much more attractive GHG intensity, around 10-30 g/MJ.

Hydrogen production through gasification of wood waste and residues has much lower GHG intensity, about 7.5 to 15 g CO_2eq/MJ, depending on the scale of the gasification process and the distribution means mainly.

Note that these GHG emission factors were calculated for the 2020 situation. In the longer term, WTW emissions can be expected to reduce quite significantly. For example, more of the energy used in the processes and transport will be renewable or otherwise low-carbon, the efficiency of processes is likely to increase over time as GHG policies will become more stringent and R&D may result in more efficient solutions.

Comparing these results and general trends with future decarbonisation requirements, only a limited number of these hydrogen routes could be attractive energy routes for future transport:

- hydrogen production through gasification of wood waste and residues
- hydrogen produced from electricity from renewable energy sources
- hydrogen from gasification of fossil fuels with CCS (where natural gas would cause less GHG emissions that coal)

In the current situation, however, these are relatively costly routes, and hydrogen through steam reforming of natural gas (without CCS) is the economically attractive option in most cases.

Assuming that the GHG intensity of transport fuels will be gradually reduced over time, for example because of further tightening of the FQD GHG emission reduction target, lower WTW GHG emissions will become increasingly financially attractive. It then seems reasonable to assume that during the coming decades, hydrogen production for transport fuels will gradually shift from the current natural gas reforming practice to either production from renewable energy sources (biomass, wind, solar), or that fossil fuels remain the main energy source but CCS is applied. A mix of these two options would, of course, also be possible, depending on the development of cost and GHG intensity of these routes. Note that the FQD is a crucial policy in this respect, as it will have to ensure that the hydrogen production routes chosen will indeed move towards the low-carbon options.

These conclusions are in line with the results from the 2010 study by McKinsey [McKinsey 2010], where a similar but more in-depth assessment of economically attractive future hydrogen production

routes was carried out. That study concludes that the WTW GHG intensity of the hydrogen will be relatively stable until 2020, as hydrogen production methods will remain mostly the same as in the current situation. After 2020, GHG intensity will reduce, as the production will decarbonize over time. The rate of this reduction will depend on the rate of the changes in the energy mix, and on the energy sources and production routes that will be competitive first.

Based on these trends, two scenarios were developed for the GHG intensity of hydrogen use in transport: a decarbonisation scenario that is in line with that of electricity generation (see the previous paragraph), and a less optimistic scenario that is in line with the reference roadmap scenario for electricity generation. In both cases, emissions of hydrogen are assumed to be higher than that of electricity, because of the (additional) energy needed for H_2 production. This energy use is quite high: Appendix 2 of [JRC 2011] estimates that if in 2020 hydrogen is produced from the average EU electricity mix, almost twice as much energy is used to produce 1 MJ of hydrogen, compared to the energy needed to produce 1 MJ of electricity. However, as the decarbonisation of electricity progresses over time, the impact of this additional electricity use on CO_2 emissions reduced.

Table 60   Carbon intensities for hydrogen use in transport in the EU27, in g CO_2eq/MJ.

Year	Scenario 1: Carbon intensity (g CO_2eq/MJ) Decarbonisation scenario	Scenario 2: Carbon intensity (g CO_2eq/MJ) Reference scenario
2010	111	111
2020	89	100
2030	36	60
2040	13	35
2050	2	24

In view of the uncertain future developments described above, the uncertainty of these figures is relatively large, especially in the period between 2020 and 2040. During that time frame, natural gas reforming is likely to remain an economically attractive route, and decarbonisation of the hydrogen production pathways will depend on (yet uncertain) EU policies and/or own initiatives of the industry.

A comparison of the various scenarios for the evolution of GHG intensities of electricity and hydrogen is given in Figure 83.
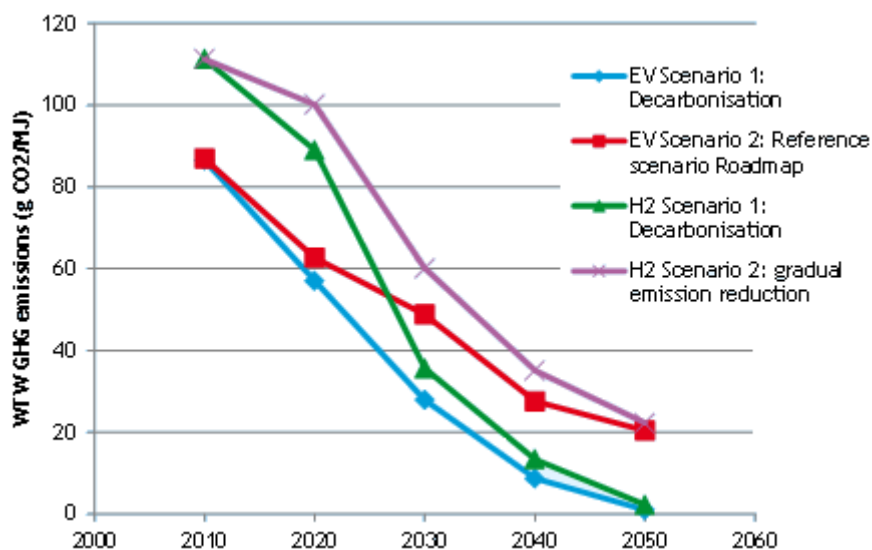

Figure 83   Comparison of WTW CO_2 emissions of electricity and hydrogen

A.3 WTW energy use

Some of the regulatory options to be investigated in this study are based on well-to-wheel energy use, as an alternative to well-to-wheel CO_2 emissions. To this end, well-to-tank energy use factors need to be developed for the various fuels and energy carriers, similar to what was done for CO_2 in the previous paragraph. Tank-to-wheel energy use factors are developed separately in section B.3.

In the current situation, WTT energy use is typically relatively low for fossil fuels and electricity, but it can be quite high in case of biofuels and hydrogen. WTT App. 2 of [JRC 2011]) provides a good basis for these data, but focusses on the 2020 situation. The longer term developments of WTT energy use have not yet been explored in much detail. The potential future developments and the resulting estimates for the various fuels and energy carriers will be derived in the following. For simplicity, it was decided that for each fuel or energy carrier, only one scenario would be sufficient, in line with the decarbonisation scenarios of the previous paragraph.

A.3.1 Conventional fuels

The development of WTW energy use of fossil fuels can be expected to remain quite stable or perhaps reduce somewhat at first, as energy efficiency measures are implemented at refineries because of the ETS, increasing cost of energy due to autonomous price increases or taxation, or other government policies both within and outside of the EU, in countries oil production or refining takes place. However, in the longer term, it is to be expected that energy use will increase as the share of crude oil from unconventional, more energy intensive oil production technologies will increase (see [EC 2007]). Crude oil from tar sands and oil shales, for example, requires much more energy to produce and process than conventional oil, and CTL (coal-to-liquid) and GTL (gas-to-liquid) processes require energy to convert the coal or gas to a liquid transport fuel.

Notably, some of the CO_2 mitigation options that oil companies may implement in order to comply with GHG intensity regulations such as the FQD may increase WTT energy use[69]. For example, if GHG intensity is reduced by reducing flaring and venting, energy use might increase: the gas that used to be flared will then be captured and processed into LNG or GTL which is then transported to end users. Energy use will also increase if GHG emissions are reduced through use of carbon capture and storage (CCS). On the other hand, if the GHG regulation will prevent a shift to unconventional oil, the impact on energy use will be positive. A future increase of renewable energy use in the well-to-tank part of the fossil fuel chain will have little impact on WTW energy use, apart from a price effect that may result.

Summarising, the WTW energy use of conventional diesel and petrol can be expected to reduce less fast than the GHG intensity, and is even likely to increase in the longer term. This increase depends quite strongly on the future shares of unconventional oil – the higher their shares in the EU fuels, the higher the WTW energy intensity of conventional fuels. Furthermore, some of the GHG mitigation options that are likely to be implemented will also increase energy use.

When looking at natural gas (CNG), energy use is also likely to increase in the future, mainly because average transport distances will increase as EU production declines. This will increase energy use, as is shown in WTT App. 2 of [JEC 2011]: the current EU mix requires about 0,12 MJ of energy per MJ gas (CNG) delivered to the vehicles whereas CNG that is transported by 7000 km of pipeline requires 0.30 MJ/MJ_{final}. If the gas is transported by LNG tanker, for example from the Middle East, emissions are similar to that of pipeline transport.

LPG is typically produced from condensates from remote gas production. Energy use is not likely to change much in that chain.

Most literature focusses on the impact of the above changes on GHG emissions, rather than on energy use. As a more detailed analysis is outside the scope of this study, rough estimates of WTT energy use have been derived, based on the expected developments described above. The JEC data were

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[69] The way in which fossil fuels are included in the FQD has not yet been defined. In the following, it is assumed that this will be along the lines as described in the FQD proposal of the European Commission (d.d. October 2011)

used as a starting point for petrol, diesel, CNG and LPG. Results are given in the table below. Key assumptions are:

- petrol and diesel energy use increase, with 10% every 10 years;
- natural gas shifts from the current EU-mix towards increasing imports over long-distances (via pipeline or LNG tankers);
- LPG WTT energy use remains constant over time.

Table 61   WTT energy intensity of conventional fuels, in $MJ_{expended}/MJ_{final}$

Year	Petrol	Diesel	Natural gas	LPG
2020	0.17	0.20	0.12	0.12
2030	0.19	0.22	0.16	0.12
2040	0.21	0.24	0.19	0.12
2050	0.23	0.27	0.23	0.12

A.3.2   Biofuels

A number of developments can be identified that may impact the WTW energy use of biofuels in the coming decades: the feedstock used for biofuel production may change, new production technologies may come on the market and replace the current ones, and GHG mitigation measures will be implemented in response to sustainability criteria and climate policies.

One development that is to be expected in response to a future tightening of GHG emission targets and ILUC implementation is an increased use of feedstocks with low GHG impact such as waste and residues or commodities that are cultivated with relatively limited land and fertiliser use. Especially the latter are likely to also require less energy to produce than current biofuels from agricultural commodities. However. as shown in [JEC 2011], biofuels from waste, residues and wood typically require more energy than biofuels from commodities, as the waste streams need energy-intensive pre-processing. Other key GHG mitigation options that can be expected to be applied are an increasing use of renewable energy in the biomass-to-biofuel chain and use of CCS. Renewable energy is not likely to significantly impact on energy use. CCS will, however, increase overall WTT energy use. This effect may be relatively limited in case of ethanol, where the CO_2 is produced in pure form and there is no need for (potentially energy intensive) separation technologies.

When comparing this potential future shift in biomass-to-biofuel routes with the WTT energy use factors in [JEC 2011], it can be concluded that the energy intensity will remain quite constant over the coming decades. It may increase or decrease to some extent, mainly depending on the mix of feedstocks used and by product utilisation. In view of the uncertainties, it was decided to assume that these values will remain constant at the levels shown in the table below.

Table 62   WTT energy intensity of biofuels, in $MJ_{expended}/MJ_{final}$

Year	Bio-petrol	Bio-diesel
2010	1.5	1.1
2020	1.5	1.1
2030	1.5	1.1
2040	1.5	1.1
2050	1.5	1.1

A.3.3   Electricity

The WTT energy use of electricity production is relatively high in the current situation. as on average about 1.8 MJ of primary (additional) energy is needed to produce 1 MJ of electricity [JEC 2011]. The energy efficiency of coal or gas power plants is somewhat better than that average, while nuclear energy scores less than average. The WTT energy intensity of electricity production from woody biomass is comparable to that of coal powered plants if the biomass is co-combusted with coal, but

increases if a gasification route is used. WTT energy input for wind and solar power is limited to losses in the grid, and almost negligible.

Therefore, if the electricity sector is decarbonized by shifting towards a mix of renewable energy sources, WTT energy intensity of electricity will reduce significantly in the future. However, if decarbonisation is for a large part achieved through CCS, where coal and gas remain the main energy source, this reduction will be much less, and even (partly) counterbalanced by the energy demand of the CCS.

In the EC Energy Roadmap 2050 a number of different decarbonisation scenarios are provided for the electricity sector, with very different mixes of energy sources, and different contributions of CCS. Upstream energy intensities were not specifically calculated, but in view of the above different mixes are likely to result in different WTT energy intensities. However, a number of consistencies were found throughout the decarbonisation scenarios. For example, power generation in 2050 was found to be based on renewables for around 60%-65% in all scenarios, except for the high renewable energy (RES) case, in which this share is much higher. Wind alone accounts for about one third of power generation in most decarbonisation scenarios. In the high RES case, the wind share reaches even close to 50% in 2050.

Looking at the energy mixes in the various scenarios, the following 'best guess' mix for 2050 has been derived: about 35% wind power and 30% of other renewables (mainly hydro, solar and biomass), 20% fossil power (for a large part with CCS) and 15% nuclear. The resulting estimates for WTT energy intensity of electricity are shown in Table 63[70].

Table 63   WTT energy intensity of electricity production, in $MJ_{expended}/MJ_{final}$

Year	WTT energy intensity of electricity production
2010	1.87
2020	1.61
2030	1.35
2040	1.09
2050	0.83

A.3.4   Hydrogen

As explained in section A.2.4, hydrogen can be produced from a whole range of energy carriers. In line with the approach taken above for electricity, it is assumed here that the hydrogen production will decarbonize in the future. The main options to achieve this are hydrogen production through gasification of wood waste and residues, from electricity from renewable energy sources and from gasification of fossil fuels with CCS.

Table 64   WTT energy intensity of hydrogen, in $MJ_{expended}/MJ_{final}$

Year	WTT energy intensity of hydrogen
2010	0.84
2020	0.88
2030	0.92
2040	0.95
2050	0.99

We thus assume that in 2010 hydrogen production is 100% based on natural gas reforming, while in 2050 each of the three low-carbon routes contribute one third to the hydrogen production. The WTT energy intensity of hydrogen is then expected to increase, as shown in Table 64. The energy intensity was assumed to increased linearly between 2010 and 2050. Comparing these factors with that of

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[70] For simplicity, a linear reduction of energy intensity is assumed between the current situation and 2050.

electricity in the previous paragraph, it can be seen that hydrogen has a better energy efficiency in the short term, but this will change over time as less energy efficient routes are assumed to be used for hydrogen production in order to reduce GHG emissions. The energy intensity will only reduce over time if renewable electricity is used as a main energy source for hydrogen. Nevertheless, even in that case energy losses will be inevitable as the electricity will have to be converted to hydrogen: [JEC 2011] estimates energy intensity of wind-to-hydrogen to be about 0.8 MJ/MJ$_{final}$.

A.4 Conclusions

When determining the WTT GHG intensity of the various fuels and other energy carriers quite a number of methodological choices are to be made.

- The fuel and energy categories that are differentiated;
- The methodology used for allocation of by-products and blends;
- How to account for indirect emissions. for example due to indirect land use change (ILUC)?
- Whether to use GHG intensity for average or marginal fuel production and energy generation?
- Use one average factor for the EU, or differentiate between Member States?
- In case of electricity: whether to use consumption or generation data. and how to treat co-generation of heat?
- Emission factors of which year?
- Geographical scope: for example limited to the EU or take a global approach?

The options and their pros and cons have been discussed in this Annex, and suggestions for a preferred approach have been made for each issue separately. Where possible, it seems preferable to choose a methodology which is in line with related policies on transport fuels (e.g. the RED and FQD). In some case. a simplified approach is preferred over a more detailed but also more complex method. A detailed approach might then lead to more efficient policy, but would also increase the administrative burden and overall complexity of the policy.

To capture the uncertainties of future developments two scenarios were derived for each of the fuels/energy carriers. For each scenario well-to-tank emission factors were determined. Combustion emissions are only relevant to fossil fuels.

The WTT energy intensity was also determined for each of the fuels. This is expected to increase in all cases except electricity. The main reasons for this are the increase of the share of unconventional fossil fuel production and increased transport distances of natural gas. In addition many of the GHG reduction measures that are expected to be implemented cause energy use to increase.

B Structure of the simplified fleet model

A simplified fleet model has been developed, that allows assessment of the impact of different technology uptake scenarios and different metrics for CO_2 regulation on total and average TTW and WTW GHG emissions of new car sales as well as the total European passenger car fleet. The model has been used to generate the results presented in chapter 5.

B.1 Set-up of the cohort model

Definition of vehicle categories

In the fleet model vehicles are divided into three different size segments, i.e.:

- small
- medium and
- large

and nine different energy carrier / drivetrain types, i.e.:

- petrol/petrol hybrid
- diesel/diesel hybrid
- LPG
- CNG
- electric (BEV)
- biofuel,
- petrol plug-in hybrid,
- diesel plug-in hybrid,
- fuel cell (FCEV)

A cohort model is used to describe the EU 27 passenger car fleet composition for all years between 2020 and 2050 (intervals of 5 years) in terms of:

- number of vehicles per age category
- annual mileages of vehicles per age category

The fleet used in this study is based on PRIMES-TREMOVE data as much as possible. This way the basis corresponds to other studies executed for and by the European Commission. This allows comparison of various metrics on different fleet compositions that are considered realistic by the Commission.

However, as a subdivision of the vehicle fleet into ages is not available in the PRIMES-TREMOVE baseline, these data are taken from the TREMOVE baseline. TREMOVE, however, does not forecast beyond 2030. For every year beyond 2030 the vehicles older than 5 years are derived from the fleet composition five years earlier (taking their survival rate into account). Newly introduced vehicles for the years beyond 2030 are obtained by subtracting the number of vehicles already introduced in previous model years by the total number of vehicles in that year according to PRIMES-TREMOVE.

As stated before, various metrics will be assessed on different fleet compositions. These different fleet compositions or fleet scenarios include rather large shares of fuel types that exist only limitedly in the current fleet and in the PRIMES-TREMOVE baseline. This way the sensitivity of the various metrics for potential fuel shifts is assessed.

The total transport demand is dominant in the construction of the fleet scenarios. This means that the total transport demand from the PRIMES-TREMOVE baseline is preserved in all fleet scenarios. Moreover, the CO_2 reduction rate is taken from the 'decarbonisation scenario' developed for the [EC 2011]. Applying these constraints allows a fair comparison between the different fleet scenarios.

Shifting of vehicle kilometres between vehicle categories

When constructing a fleet scenario, vehicles can be removed from one vehicle category (e.g. small petrol vehicles) and added to another vehicles category (e.g. small electric vehicles). Shifting is

achieved by vehicles rather than by vehicle distances. As PRIMES-TREMOVE prescribes a certain annual mileage per vehicle type, the number of vehicles removed from one class is not necessarily equal to the number of vehicles added to another class to comply with the constraint of conservation of the total transport demand.

Survival rate of newly introduced vehicle types

Survival rates are introduced to determine the amount of cars left (of the newly introduced cars), after a period of five years for the years between 2030 and 2050. The survival rates are based on the TREMOVE data and are calculated by dividing the amount of cars age y in year x by the amount of the cars age $y - 5$ in year $x – 5$. This is done for every age:

- Survival rate age 5 = (#cars year 2020 age 5) / (#cars year 2015 age 0)
- Survival rate age 6 = (#cars year 2020 age 6) / (#cars year 2015 age 1)
- Survival rate age 7 = (#cars year 2020 age 7) / (#cars year 2015 age 2)
- Etc.

This method is used, because TREMOVE data is not available for every single future year. Therefore it is impossible to determine the survival rate for every age with respect to age zero. This exercise is performed on the basis of TREMOVE data for the segment medium diesel (1.4 – 2.0l) and the segment medium petrol (1.4 – 2.0l) and shown in Figure 84.

The differences in survival rates for petrol and diesel seem large for the cars with age 25 years and older (dashed lines in Figure 84). These survival rates however are the percentages of cars left with respect to five years earlier. These survival rates relate to a very small amount of the cars left (5% of the initial amount of newly sold cars), which is shown in the survival rates with respect to the age zero (solid lines in Figure 84).
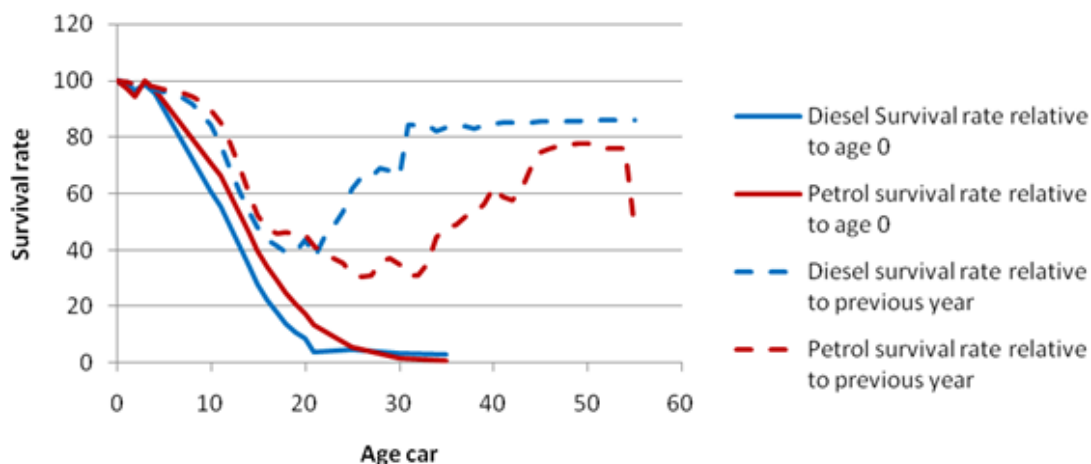

Figure 84   Survival rates of vehicles relative to age 0 and relative to the previous year.

The survival rates with respect to the age zero are comparable for diesel and petrol, also for cars of 25 years and older. These survival rates are calculated with five year intervals due to the earlier mentioned lack of data and also shown in Figure 84. For instance:

- Survival rate age 5 = (#cars year 2000 age 5) / (#cars year 1995 age 0)
- Survival rate age 10 = (#cars year 2005 age 10) / (#cars year 1995 age 0)
- Survival rate age 15 = (#cars year 2010 age 15) / (#cars year 1995 age 0)
- Etc.

Survival rates are needed for every vehicle age and every size class (small, medium and large) and every assessed fuel type (nine unique types). For simplification reasons, one survival rate trend is applied to all vehicle categories. Since the differences in the survival rates between medium diesel and medium petrol cars (with respect to age zero) are small, the five year survival rates of diesel and petrol are averaged and applied to all segments in the fleet model.

ICEV emissions and energy adjusted to make new vehicle average comply with target

In order not to favour certain technologies, CO_2 emissions are regulated at the level of the fleet wide average of new registrations within a certain year. As the shares of all vehicle categories are assumed per fleet scenario and the CO_2 emissions of the non-ICEVs are fixed assumptions, the sales weighted average CO_2 emissions and/or energy consumption of non-ICEVs is known. Since, according to the way energy consumption or CO_2 emissions are regulated, every fleet scenario has to meet the sales average type approval TTW or WTW CO_2 emissions or energy consumption in a certain year, the average TTW CO_2 emissions and energy consumption of the ICEVs can be determined from the target and the average performance of the other technologies. The way manufacturers will, on average, reduce CO_2 emissions in the ICEV vehicle categories (dividing reduction efforts over different size segments of petrol and diesel vehicles) to meet their targets can be determined using the optimisation model developed for Service Request 1 [TNO 2011][71].
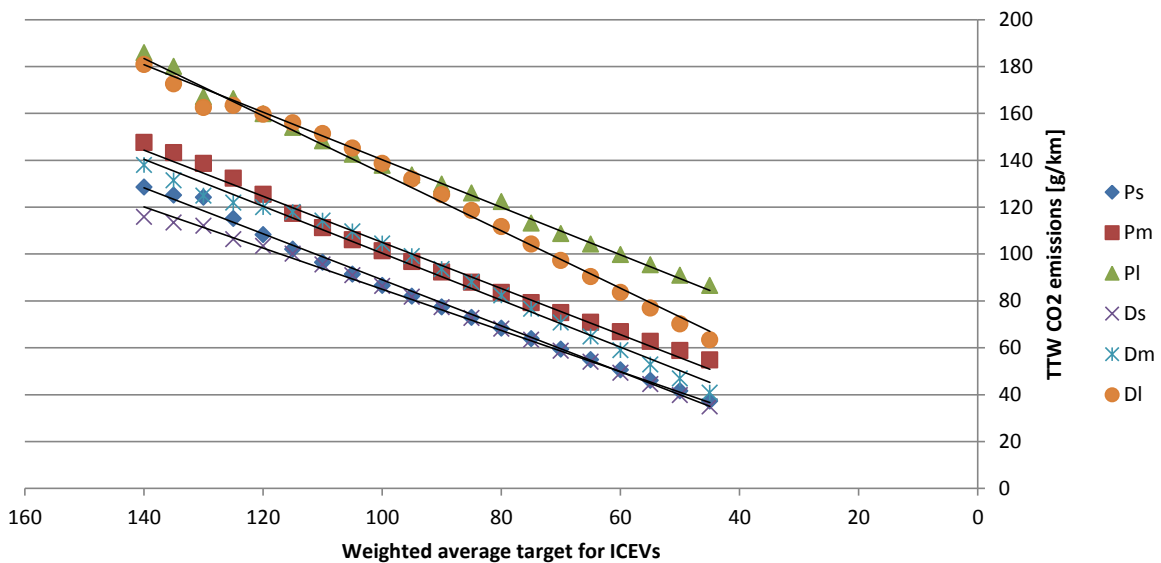

Figure 85   Average TA CO_2 emissions per segment in relation to the overall average TA CO_2 emissions of newly registered passenger cars

B.2 Description of assessed fleet scenarios

To assess how different metric affect the way in which total GHG emissions from road transport are affected by varying penetration rates of technologies for vehicle propulsion systems and the use of alternative energy carriers, four fleet scenarios are developed representing potential 'technology pathways' towards 2050. These different fleet scenarios are then used to assess the robustness of potential metrics, i.e. the extent to which the metric used for regulating the GHG emissions from the transport sector ensures efficient and effective CO_2 reductions independent of technological developments and the resulting trends towards certain powertrains.

Scenario 1: Baseline scenario (reproduction of the White Paper fleet composition)

In 2011 a White Paper on the transport sector was published by the EU [EC 2011]. In support of the policy vision developed in this paper the evolution of various transportation modes was forecasted, including the transport demand, vehicle stock and CO_2 emissions. As the decarbonisation rate assumed in the policy scenario developed in this White Paper meets the CO_2 reductions from the transport sector required to achieve the EU's overall CO_2 reduction objective of 80% by 2050, the forecasted developments used in the White Paper form a suitable baseline to construct different scenarios that coincide with EU objectives.

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[71] This model determines for every manufacturer the distribution of reduction efforts over the manufacturer's sales in different ICEV vehicle segments that meets the manufacturer specific target at the lowest costs.

However, as detailed information on this forecast is not publicly available, the fleet composition development and decarbonisation rate of the White Paper have been reproduced as accurately as possible using:

- the roadmap for moving to a competitive low-carbon economy in 2050, which was constructed by the European Commission using the PRIMES model[72] for:
  - vehicle mileages;
  - fuel and energy use of BEVs, FCEVs and plug-in hybrid vehicles;
- a reproduction of the fleet composition used in the 2011 White Paper [EC 2011] and,
- the SR1 report [TNO 2011] for the maximum reduction potential of conventional vehicles.

For the emissions of the ICEVs it is assumed that the lowest weighted average TTW CO_2 emissions, according to SR1, approximately 60 gCO_2/km, is reached in 2040 and maintained beyond 2040 (see Figure 86).
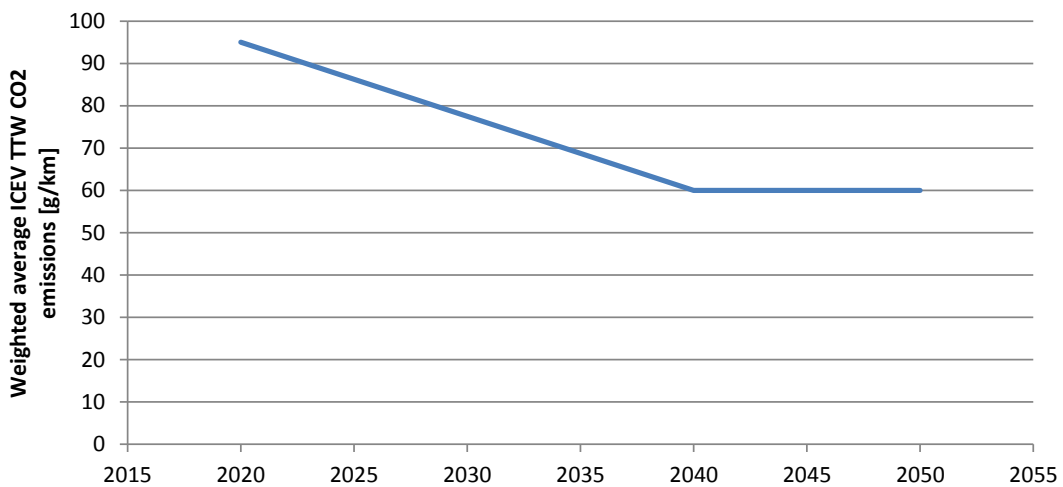

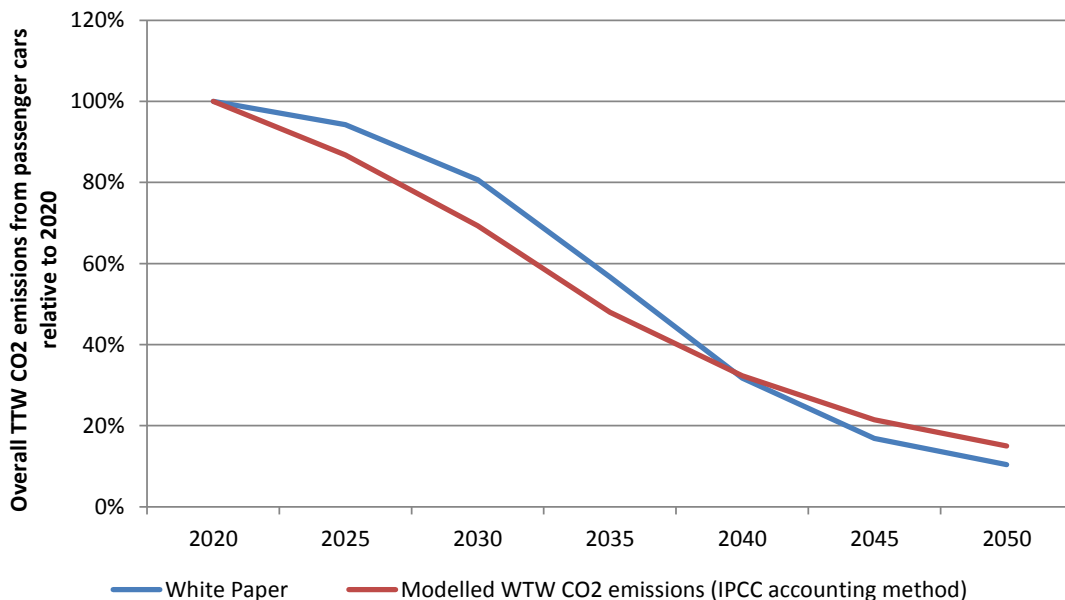Figure 86   Assumed average TA CO_2 emissions of new ICEV sales between 2020 and 2050

Figure 87   Average TA TTW CO_2 emissions of new sales between 2020 and 2050

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[72] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SEC:2011:0288:FIN:EN:PDF

Given the energy uses of alternative drive trains from the TREMOVE-PRIMES results, shares of alternative drive train types have been included in the new sales in such a way that the overall TTW CO_2 emissions reduction (according to the IPCC accounting methodology for biofuels) as presented in the White Paper, is approximated (Figure 87) a closely as possible.

Scenario 2: A trend towards FCEVs instead of BEVs.

In the White Paper a significant part of the CO_2 reduction results from the large scale introduction of battery-electric vehicles (BEVs) after 2025. While the share of BEVs is currently increasing, a number of manufacturers also invest part of their R&D resources in the further development of fuel cell electric vehicles (FCEVs) running on hydrogen. As this may at some point in the future result in a significant increase of FCEV sales rather than BEVs, a scenario has been constructed in which the BEVs from Scenario 1 are replaced by FCEVs. Since the FCEVs are expected to have higher annual mileages and the transport demand is conserved in all scenarios, the total sales of FCEVs in Scenario 2 are somewhat lower than the total sales of BEVs in Scenario 1.

As both powertrains have no CO_2 tailpipe emissions, the TTW decarbonisation level will be similar to that of Scenario 1 and will therefore also be close to that of the White Paper [EC 2011].

Scenario 3: Increased share of BEVs compared to baseline scenario

As was concluded in Service Request 1, increasing the share of EVs is close to being a cost effective measure for manufacturers to meet the 95 gCO_2/km passenger car target by 2020. As this target is expected to be lowered beyond 2020, the additional manufacturer costs for meeting the target with only ICEVs will increase even further, which may result in EVs being a very cost effective measure to meet future targets. Therefore the share of EVs has been even further increased, relative to Scenario 1, in a third fleet scenario.

As CO_2 emissions are currently regulated on a sales weighted average TTW [gCO_2/km] level for new registrations in a certain year, this increased share of EVs (with zero TTW CO_2 emissions) increases the maximum sales weighted average CO_2 emissions of other power train types, e.g. ICEVs. In other words, as a result of the further increase of ZEVs, manufacturers will have to reduce less CO_2 emissions from ICEVs. Since CO_2 is emitted at power plants to generate electricity for the EVs, this increased share of EVs will increase the overall WTW CO_2 emissions.

Scenario 4: Increased share of BEVs and decreased share of biofuels compared to baseline scenario

The tailpipe CO_2 emissions of a vehicle driving on biofuels are (very close to) equal to the CO_2 emissions of that same vehicle driving on conventional fossil fuels. Therefore the type approval TTW CO_2 emissions for a certain vehicle are independent of the share of biofuels in the used petrol or diesel mix. However, growing crops absorb the same amount of CO_2 as is emitted by burning biofuels. According to the IPCC accounting methodology, the TTW CO_2 emissions of vehicles running on biofuels are zero, while upstream GHG emissions are attributed to the agricultural sector and the energy sector.

In order to assess the sensitivity of the various metrics to the shares of biofuels, the amount of biofuels is lowered in this fourth scenario. This is done in such a way that the average decarbonisation rate (according to the IPCC accounting methodology) is equal to that of Scenario 1, with the same sales weighted average IPCC CO_2 emissions for ICEVs as in Scenario 1. In other words, the lower average IPCC CO_2 emissions (compared to scenario 1), as a result of the higher share of ZEVs (compared to scenario 1), is compensated by a lower share of biofuels. This results in only slightly lower biofuels shares compared to the other scenarios.
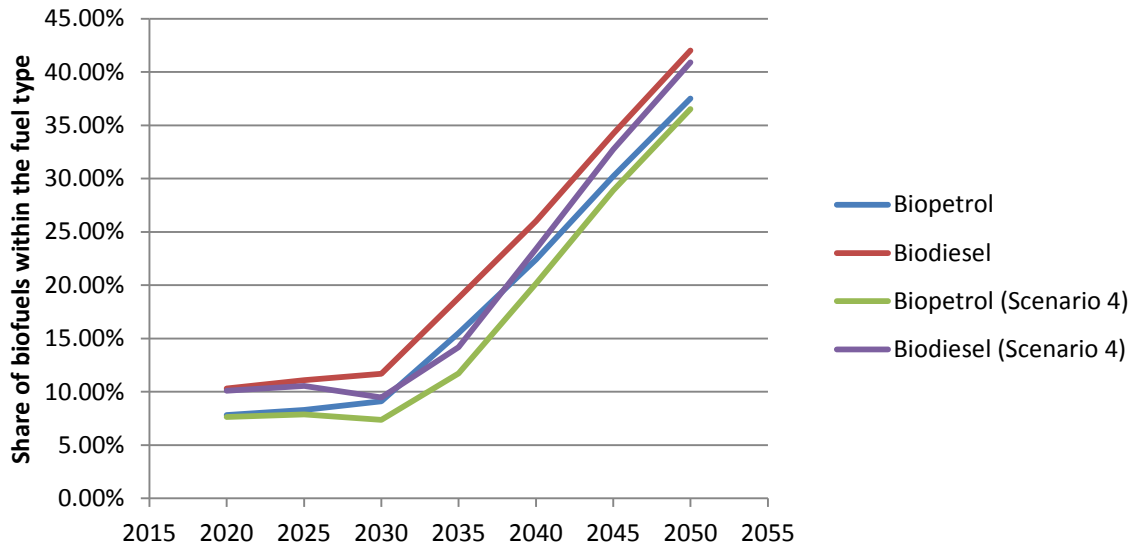
Figure 88   Shares of biofuels in the different scenarios assessed (blue and red lines for scenario 1, 2 and 3, green and violet lines for scenario 4)

Overall fleet

The fleet compositions for the different scenarios are depicted in Figure 29 to Figure 32 in section 5.3.

Although the PHEVs and BEVs are already the dominant drivetrains in the new registrations in 2030 (Figure 29), their share in the entire fleet only becomes dominant around 2040. This is because it takes time for the vehicles registered before 2040 to fade out.

Even though the share of non-ICEVs in the overall fleet increases gradually, their share in 2050 is over 90%. The share of ICEVs is therefore very limited in 2050. The main share of fossil fuels will be used by PHEVs in 2050 for all scenarios assessed.

B.3   Assumptions on TTW energy consumption

As explained above, the TTW energy consumption of vehicles with alternative powertrains is assumed constant in the model, while the energy consumption of ICEVs is the variable that is adjusted in the model to make sure that the target is met. Table 65 and Table 66 present the assumed TTW energy consumption factors.

For the modelling work presented in chapter 5, it was chosen to define the reference scenario on the basis of the main policy scenario underlying the assessments performed for the Commission's White Paper [EC 2011]. The detailed data in Table 65 and Table 66 have been reconstructed on the basis of a limited amount of more aggregated data available for the White Paper scenario. Assumptions motivating the numbers for specific technologies and years were not included in the available documentation.

Table 65   Assumed TTW energy consumption figures of vehicles with alternative powertrains

	TTW energy use [MJ/km]											
	Small				Medium				Large			
			electric energy use				electric energy use				electric energy use	
Year	BEV	FCEV	PHEV petrol	PHEV diesel	BEV	FCEV	PHEV petrol	PHEV diesel	BEV	FCEV	PHEV petrol	PHEV diesel
2020	0.50	0.99	0.25	0.18	0.57	1.22	0.29	0.19	0.68	1.49	0.38	0.31
2025	0.50	0.96	0.25	0.19	0.58	1.19	0.29	0.20	0.68	1.45	0.38	0.32
2030	0.50	0.94	0.27	0.19	0.58	1.15	0.31	0.21	0.68	1.41	0.39	0.34
2035	0.50	0.91	0.26	0.19	0.58	1.12	0.31	0.21	0.68	1.37	0.39	0.33
2040	0.50	0.88	0.26	0.19	0.58	1.09	0.30	0.21	0.68	1.33	0.38	0.32
2045	0.50	0.86	0.26	0.19	0.58	1.06	0.30	0.21	0.68	1.29	0.38	0.32
2050	0.50	0.83	0.25	0.19	0.58	1.03	0.29	0.20	0.68	1.25	0.37	0.31

Table 66   Assumed impact of the share of electric driving on the TTW CO_2 emissions of PHEVs, defined as a share of the TTW CO_2 emissions of equivalent ICEVs

PHEV TTW CO_2 emissions as share of ICEVs [%]	Small	Medium	Large
PHEV Petrol	49%	54%	42%
PHEV Diesel	49%	55%	52%

C Technology details

Details of research that led to the assessment of the impacts of technologies on average CO_2 and on utility parameters.

Weight of hybrid vehicles. plug-in hybrid electric vehicles. extended range electric vehicles and battery (full) electric vehicles

These were calculated by Ricardo. A summary of the conclusions reached is:

Vehicle technology	Size		
	Small – B segment	Medium – C segment	Large – D segment
Petrol hybrid vehicles 2020	1112 kg	1289 kg	1462 kg
Diesel hybrid vehicles 2020	1138 kg	1324 kg	1504 kg
BEV (FEV) 2020	1055 kg	1331 kg	1498 kg
BEV (FEV) 2030	1036 kg	1309 kg	1477 kg
PHEV petrol 2020	1139 kg	1316 kg	1487 kg
PHEV diesel 2020	1165 kg	1352 kg	1529 kg
EREV petrol 2020	1165 kg	1335 kg	1491 kg
EREV diesel 2020	1187 kg	1359 kg	1515 kg

*Specifications are taken as a sales-weighted average of those of the top 5 gasoline and top 5 diesel vehicles in each of the B. C & D segments for 2009 (2009 figures for UK market. Source: SMMT)

Unless otherwise stated all vehicle masses (including those taken from SR1) are for 2020 vehicle specifications. This means that there was an element of powertrain lightweighting assumed in the calculations for SR1. The values for the petrol and diesel hybrid vehicles are the same as those in Table 18 off SR#1 Final Report. The relative weight of each vehicle segment can be calculated from the data above. but the absolute increase relative to baseline ICE could not be calculated.

No ICE equivalent for 2020 was available. but 2009 baseline weights were estimated. The 2009 vehicle baseline was only used to calculate a glider mass for the small, medium and large segments for the SR1 analysis on which different 2020 vehicle specifications were then built. Therefore it is not really appropriate to compare the "baseline" with the other technologies directly as it is a 2009 not 2020 specification. These values are:

Vehicle technology	Size		
	Small – B segment	Medium – C segment	Large – D segment
Baseline (SR1 Table 14) **2009**	1.109	1.264	1.443

An alternative approach was used to estimate the impact on kerb weight of BEV (FEV) relative to conventional ICE. This used 2009 data for three FEV vehicles. each of which has a petrol ICE equivalent.

Vehicle	Mitsubishi Miev	Smart ForTwo	Ford Focus
Weight of FEV	1110	910	1674
Weight of conventional	900	770	1270 – 1471
Difference	210	140	203 – 404
Battery size	16	14	23
Increase in weight per kWh battery capacity	13.125	10	9-17

Based on this small sample the average increase in kerb weight for small vehicles is 180 kg whereas the mid-increase in kerb weight for the medium sized vehicle (the Ford Focus) is around 305 kg.

No data were available for large vehicles. However. it is presumed that the increase in weight is dependent on the size of the battery pack and the electric motors and that this scales with average vehicle weight with larger vehicles also having a somewhat extended range. Therefore an estimate of the average increase in kerb weight for large vehicles is 355 kg.

Footprint of hybrid vehicles. plug-in hybrid electric vehicles. and battery (full) electric vehicles

This was estimated by systematically considering the specification of a number of FEVs. and comparing these
- conventionally fuelled equivalent vehicle
- best seller in the same market segment
- top of the range vehicle appealing to affluent buyers interested in technology and
- vehicle with lowest CO_2 emissions in same market segment

Electric vehicles included in the analysis. and their footprints and footprint x height were:

Make – Model	Passenger car segment	Footprint	Footprint x height
Mitsubishi I MiEV	Mini-cars (Category A)	5.01	8.01
Smart forTwo Electric drive	Mini-cars (Category A)	3.79	5.87
Peugeot Ion & Citroen C-Zero	Mini-cars (Category A)	5.01	8.01
Tata Indica Vista EV	Super mini (Category B)	6.43	9.97
Renault Zoe	Super mini (Category B)	7.54	11.44
Nissan Leaf	Lower medium (Category C)	7.87	12.19
Vauxhall Opel Ampera	Lower medium (Category C)	7.88	11.27
Toyota Prius PHEV	Lower medium (Category C)	7.78	11.60
Ford Focus EV	Lower medium (Category C)	7.98	11.96
Renault Fluence ZE 4-d saloon	Lower medium (Category C)	8.36	12.21

Comparator vehicles and their key characteristics were:

Make – Model	Passenger car segment	Footprint	Volume
Hyundi i10 1.2 classic	Mini-cars (Category A)	5.69	8.76
Mitsubishi i	Mini-cars (Category A)	5.01	8.01
Smart ForTwo	Mini-cars (Category A)	3.79	5.87
Toyota iQ 1.33 Dual VVT iSports	Mini-cars (Category A)	0.00	0.00
Ford Fiesta 1.25 Zetec 5 dr	Super mini (Category B)	6.80	10.07
Mini Cooper D (Sport Pack)	Super mini (Category B)	6.28	8.83
Renault Clio 1.2 TCE Expression	Super mini (Category B)	6.80	10.18
Tata Indica Vista	Super mini (Category B)	6.43	9.97
VW Polo 1.2 Bluemotion	Super mini (Category B)	6.68	9.76
Ford Focus 1.6 TDCi Econectic	Lower medium (Category C)	7.98	11.96
Ford Focus 1.6 Zetec 5 dr hatchback	Lower medium (Category C)	7.98	11.96
Lexus CT200h 5dr hatchback	Lower medium (Category C)	7.62	10.90
Renault Megane 16 Dynamique 16V	Lower medium (Category C)	7.77	11.42
Toyota Prius T3	Lower medium (Category C)	7.78	11.60

Make – Model	Passenger car segment	Footprint	Volume
Vauxhall Astra 1.7 CDTi 16v S	Lower medium (Category C)	7.89	11.68
Honda Civic	Lower medium (Category C)	7.95	11.37

Characteristics of hydrogen fuel cell vehicles

No data for fuel cell vehicles was supplied in the SR#1 report. Therefore the approach used was the direct comparison of two fuel cell vehicles with equivalent conventional technologies. These were:
- Honda Clarity compared with Honda Accord
- Vauxhall/Opel HydroGen4 compared with Chevrolet Equinox
- Mercedes B Class compared with its ICE equivalents

Key characteristics of these vehicles were:

Vehicle	Weight (kg)	Footprint (m^2)	Footprint x height (m^3)
Honda Clarity	1628	4.44	6.52
Honda Accord	1462	4.42	6.53
Vauxhall/Opel HydroGen4	2010	4.99	8.40
Chevrolet Equinox	1706	4.99	8.40
Mercedes B Class F125 Fuel cell	1705	4.94	7.92
Mercedes B200 (petrol)	1348	4.95	7.94
Mercedes B200 Cdi	1438	as	above

The difference between the hydrogen fuel cell models and their ICE counterparts were that the FC vehicles were 166 (Clarity) 304 (HydroGen4) and 357 (Mercedes B class) heavier. The Clarity appears to be only moderately heavier than its ICE counterpart. but in contrast to the other two FC vehicles. it has quite a limited range (around 240 miles). The addition of a further fuel tank (pressure cylinder) would increase its weight by around 120 kg for a further 120 litre vessel.

The changes in the footprint. or footprint x height values were less than 0.5% in every case. i.e. essentially these utility parameters are unaltered by the change in power unit.

Lightweighting

Light-weighting is the reduction in vehicle weight through the use of lighter, usually more expensive. materials. In this study the following three categories of light-weighting have been assumed:

Mild light-weighting   around 10% reduction of body-in-white weight
Medium light-weighting   around 25% reduction of body-in-white weight
Strong light-weighting   around 40% reduction of body-in-white weight

The body-in-white weight of current vehicles has been assumed to be 28% of their kerb weight when complete. Using average vehicle kerb weights of 1.360 for passenger cars and 1.654 for light commercial vehicles and the factors above, the following is found:

	Mild light-weighting	Medium light-weighting	Strong light-weighting
Cars	38.1 kg	95.2 kg	152.3 kg
Light commercial vehicles	46.3 kg	115.8 kg	185.2 kg