Policy options to reduce passenger cars CO2 emissions after 2020

H.P.J. de Wilde
P. Kroon

February 2013
ECN-E--13-005

Acknowledgement

This report has been commissioned by the Netherlands Ministry of Infrastructure and Environment. The project is registered at the Energy research Centre of the Netherlands (ECN) under project number 51548.01. The authors like to thank Bas van Bree for his valuable contributions and Eppe Luken for reviewing the manuscript.

Abstract

The EU has set emission targets for new cars up to 2020 and is now preparing the post 2020 legislation. The present study aims to give insight in the design of policies to further reduce passenger car emissions after 2020.

Internal combustion engine (ICE) vehicles are now expected to enable deeper and less costly CO_2 emission reductions than envisioned until recently. However, even advanced ICE vehicles will not enable to meet the very stringent long term emission reduction targets for passenger cars. Therefore transport policies need not only to reduce emissions of ICE vehicles, but also ensure that electric and hydrogen vehicles are phased in timely, along with low-CO_2 electricity and hydrogen.

Current legislation to regulate tank-to-wheel vehicle emissions is based on CO_2-limits, expressed in g CO_2/km. On the short term it is important to maximize the efficiency of conventional vehicles. At the same time it is essential to foster the market introduction of electric and hydrogen vehicles, given their potential to reach eventually much deeper overall CO_2-reductions. When the market share of electric and hydrogen vehicles grows it becomes increasingly important to maximize their efficiency and to minimize their upstream CO_2 emissions. Maximizing both efficiency and overall CO_2-performance of all vehicle types - ICE, electric, and hydrogen - will be complicated to achieve with a single CO_2-based standard. At this point an efficiency-based standard is more effective, and may offer some additional benefits too. The current report provides basic directions of how such legislation could be shaped.

Contents

Summary

Background
The European Commission aims to reduce the emissions of road transport in 2050 by about 70% compared with today's levels. Passenger cars can relatively easily switch to electricity, whereas this is much more complicated for heavy duty road transport. In addition the volume of road transport is expected to double up to 2050. In order to reach the overall 2050 CO_2 reduction target, passenger cars therefore need to reduce their emissions to almost zero. As a start the EU has set legally-binding emission targets for new cars of 130 g CO_2 per km by 2015 and 95 g per km by 2020. Currently the EU is preparing the post 2020 legislation for passenger cars and vans. The present study is written against this background and aims to give insight in the design of potentially effective policies to further reduce passenger car CO_2 emissions after 2020.

Trends
Over the past few years fuel efficiency of cars improved substantially, although not yet enough to neutralise the effect of increases in traffic and car size. Nevertheless, recent developments have been fast. Advanced internal combustion engine (ICE) technologies are now expected to enable substantially deeper and less costly CO_2 emission reductions than envisioned until recently. However, even advanced ICE technologies will not enable to meet the very stringent long term emission reduction targets for passenger cars. Therefore transport policies need not only to reduce emissions of ICE vehicles, but also to ensure that electric and hydrogen vehicles are phased in timely, along with increasing production capacity of very low-CO_2 electricity and hydrogen.

Disadvantages of current regulations
The current CO_2 regulatory framework involves some limitations and possible negative side impacts[1]. For example, efficiency improvements of ICE vehicles may be dampened by the market uptake of electric vehicles, as their zero tailpipe emissions allow ICE vehicles to emit more. On the other hand, the rapidly increasing efficiency of ICE vehicles may limit the introduction of electric and hydrogen vehicles. This may occur when intermediate CO_2 limits - that were initially expected to be only achievable with zero emission vehicles in the fleet - also become achievable with advanced ICE vehicles.

[1] A complete overview of pros and cons of legislative options to reduce passenger car CO_2 emissions is provided in Table 1 on page 18.

Another issue is the distribution of renewable energy between sectors, especially electricity and hydrogen from renewable energy sources and sustainable biomass. Preferred use in passenger cars of renewable energy may result in lower availability for other sectors, along with associated higher CO_2 emissions.

Policy alternatives

Policies for efficient and low-CO_2 transport need to be ambitious in order to be in line with the 2050 goals. At the same time the goals need to be technically achievable and affordable.

Addressing both well-to-tank and tank-to-wheel emissions in a single overarching well-to-wheel regulation would require a very complicated and extensive policy framework, especially since multiple stakeholders are involved. For this reason the current legislation is split in complementary but separate regulations for the well-to-tank and the tank-to wheel parts of the emission chain. The well-to-tank emission legislation is covered largely by the Fuel Quality Directive, the Renewable Energy Directive, and the EU Emission Trading Scheme. The tank-to-wheel emissions are covered by the EU CO_2 and cars Regulation, based on emission limits currently expressed in g CO_2/km. An alternative way to regulate tank-to-wheel emissions would be an efficiency-based standard, expressed in MJ/km.

On the short term it is important to maximize the efficiency of ICE vehicles. At the same time it is essential to foster the market introduction of electric and hydrogen vehicles, given their potential to reach eventually much deeper overall CO_2 reductions than the ICE alternative. When the market share of electric and hydrogen vehicles grows it becomes increasingly important to maximize their efficiency and to minimize their upstream CO_2 emissions. Maximizing both efficiency and overall CO_2 performance of all vehicle types - ICE, electric, and hydrogen - will be complicated to achieve with a single CO_2-based standard. At this point an efficiency-based standard is more effective, and may offer some additional benefits too. For example, an efficiency-based standard enables to incentivize the overall efficiency of all vehicles types without mixing of well-to-tank and tank-to-wheel legislation. Moreover an efficiency-based standard can be detailed in such a way that, in addition to improving the efficiency of all car types, specific low-CO_2 technologies and fuels can be extra incentivized. The current report provides basic directions of how such legislation could be shaped.

In addition the growing share of zero emission vehicles is discussed in terms of drawbacks and possible solutions regarding: the CO_2 intensity of the electricity mix, the EU Emissions Trading Scheme (ETS), the Renewable Energy Directive (RED), the Fuel Quality Directive (FQD) as well as the biofuel and hydrogen markets.

1 Introduction

Road transport is the second biggest source of greenhouse gas emissions in the EU, after power generation. It contributes to about one-fifth of the EU's total emissions of carbon dioxide (CO_2). In order to limit the negative effects of climate change and to reduce the dependency on oil imports, the European Union (EU) aims to reduce its greenhouse gas (GHG) emissions by 80-95% below 1990 levels by 2050. The European Commission's white paper on transport (EU, 2011) states that the transport sector would have to cut emissions by at least 60% by 2050 compared with 1990 levels. This equals about 70% reduction compared with today's levels[2]. Passenger cars are responsible for around 12% of EU CO_2 emissions and can relatively easily be reduced. Therefore, the EU has developed an increasingly stringent framework for CO_2 emission limits for passenger up to 2020. Currently the EU is preparing the post 2020 legislation that aims to further reduce CO_2 emissions in line with the long term reduction targets.

There are three primary ways to reduce greenhouse gas emissions from transport (e.g. Dalkmann and Brannigan, 2007; EEA, 2012):

1. Avoiding the use of transportation where possible, e.g. through improved spatial planning or teleworking.
2. Shifting to more environmentally friendly modes such as public transport, cycling and walking.
3. Improving vehicle and fuel technology to improve the environmental efficiency of each kilometer travelled.

The current report focuses on the third way, by evaluating the various policy options to reduce passenger car CO_2 emissions after 2020. The way this technological potential could be realized highly depends on public acceptance and mobility behaviour. However, incentives to influence consumer choices and behavior are beyond the scope of the current study.

[2] Note that In the underlying calculationshydrogen was not taken into account as an option for the transport sector.

1.1 Research question and goal

How can policies after 2020 be shaped to effectively meet objectives of reducing passenger car CO_2 emissions? The current report aims to give insight in the design of potentially effective policies as input to discussion at the EU level. The current report evaluates the different legislative options and the possible design of post 2020 legislation. It provides directions how future policies could be shaped but does not aim to present a key solution or conclusion.

1.2 Scope

- Focus on passenger cars, where relevant also vans
- European Union
- Predominantly qualitative.

1.3 Background and trends

From voluntary to mandatory CO_2 targets
In the late '90s the associations of automobile manufacturers that sell cars in Europe[3] made voluntary agreements to reduce passenger car CO_2 emissions. These agreements involved an industry-wide target of 140 grams CO_2 per km for 2008 applicable to newly sold cars by all manufacturers. Unfortunately, the EU member states generally did not support these targets with substantial stimulation policies. Although more energy efficient cars were developed and produced the automakers did not meet the voluntary target. Because the target was not met the European Commission started to introduce mandatory targets. Early 2009 the first mandatory CO_2 emission standard for passenger cars in the EU was adopted, setting a target of 130 g/km for 2015 and a 95 g/km for 2020 (EU, 2009; Mock et al, 2012). Emission targets up to 2020 and possible developments thereafter are summarized in Figure 1.

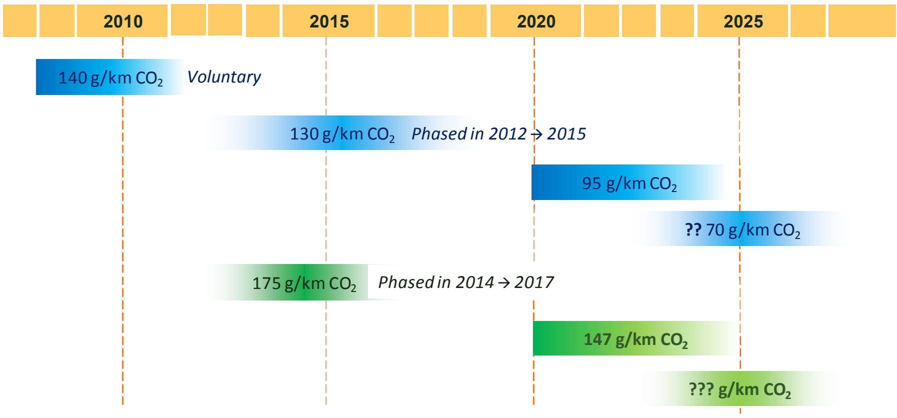
Fuel efficiency improvements
Over recent years there have been significant improvements in car fuel efficiency, and associated lower CO_2 emissions. Reductions are achieved by a combination of different technologies including: downsized engines with (double) turbocharging and direct injection, cylinder deactivation/cylinder-on-demand technologies, advanced transmissions, advanced valve train designs etc. (see e.g. Ricardo, 2011, 2012; CAR21, 2012). To further reduce CO_2 emissions hybridization and electrification of cars will continue. Electric driving has started but a breakthrough in battery performance is needed, or at least a combination of improvements and cost reductions by larger production quantities (see e.g. Kasab & Velliyiur, 2012). In addition hydrogen vehicles

[3] Manufacturers' associations include: European Automobile Manufacturers Association (ACEA); Japanese Automobile Manufacturers Association (JAMA); Korean Automobile Manufacturers Association (KAMA)

may become important too. So far, efficiency increase of passenger cars has not yet been enough to neutralise the effect of increases in traffic and car size (EU, 2012). As a consequence road transport is still one of the few sectors where emissions are still rising rapidly.

Several studies indicate that the 95 g/km CO_2 emission target by 2020 - that was recently detailed by the Commission (EU, 2012b) - is reasonably achievable. Afterwards more ambitious reduction targets are achievable (e.g. CAR21, 2012). Although uncertainties on technologies and costs inevitably increase when making longer terms projections several key studies indicate that CO_2 emissions in the order of 70 g/km are likely achievable around 2025. See e.g. Kasab & Velliyiur 2012; Kasab & Jackson, 2012. Similarly Bosch Engineering Diesel Systems, claims that a CO_2 targets of 70 grams per kilometer with optimized internal-combustion engines in 2025 is achievable (Leonhard, 2011). Furthermore DeCicco (2010) states that in 2035 passenger cars with diesel hybrid powertrains can reach emissions down to 65 g/km.

Figure 1: Overview of emission targets for passenger cars (blue targets) and vans (green targets) up to 2020. In addition possible targets around 2025 are indicatively shown. (Modified after Kasab and Jackson, 2012)



1.4 Costs of low CO_2 car technology

Several stakeholders argue that the financial impact of new technologies on vehicle prices is relatively modest. For example T&E (2012) points out that, especially over the last few years, cars have become more fuel efficient and cleaner, while at the same time consumer prices dropped. Other stakeholders however argue that the effect of regulations and standards on car prices is more complex (AEA, 2011). More stringent environmental regulations are usually expected to lead to higher production costs for additional technology and consequently higher car prices for consumers. But in practice it is difficult to couple potential price increases to a single vehicle efficiency regulation, as the EU regulations are rather a trajectory of incentives and targets than single steps. Also it is possible that car manufactures do not pass on all additional costs to consumers by reducing their margins and/or the margins of part suppliers. Several recent communications indicate that the additional costs to further reduce ICE car emissions to

95 g/km have dropped to about 1000 euro per car. This value is about twice as low as evaluated only 1-2 years ago (see e.g. Smokers 2011a, 2011b). A key advantage for consumers is the substantial saving on fuel costs over the cars lifetime resulting from the new efficiency improving technologies. According to the EU, cumulative fuel cost savings outweigh the additional cost of buying a more fuel-efficient car within five years (EU, 2012d).

1.5 CO_2 standards passenger cars

The EU Regulation on passenger cars is the first main measure of the EU Strategy to reduce CO_2 emissions from light-duty vehicles (cars and vans). The Regulation on cars is directly applicable in the Member States and does not need to be transposed into national law through national legal instruments.

2012 - 2015 target

In 2009[4], the EU set legally-binding targets for new cars to emit 130 g CO_2 per km. Under the Regulation, average CO_2 emissions from cars should not exceed 130 grams CO_2 per km by 2015 and should drop further to 95g/km by 2020. It represents a reduction of 19% compared with the 2006 level. The 130 grams target is being phased in between 2012 and 2015. As of 2012, manufacturers must ensure that 65% of the new cars registered in the EU each year have average emissions that are below their respective targets. The percentage rises to 75% in 2013, 80% in 2014 and 100% in 2015 (EU, 2012).

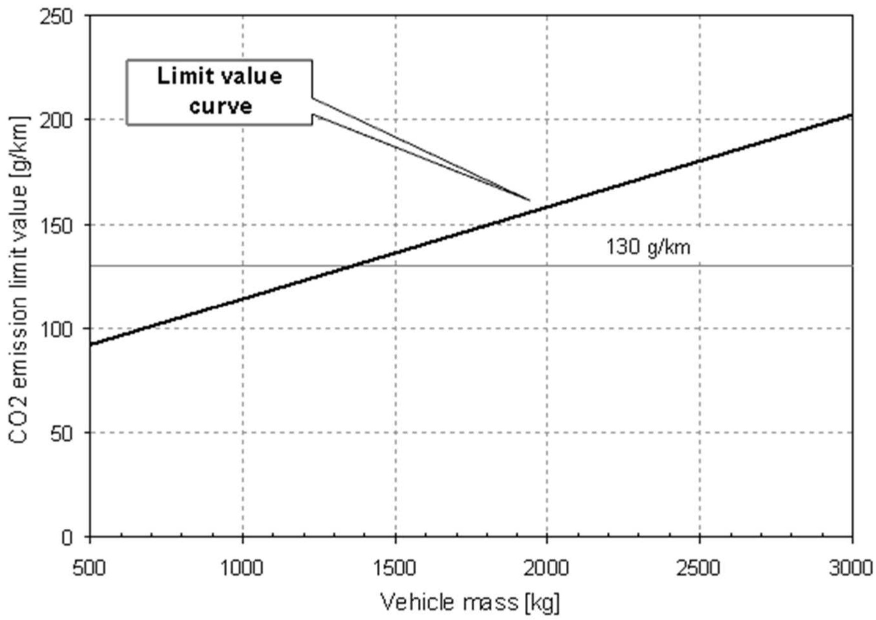
Car manufacturers have to ensure that the *average* of their new sales meets these levels. Individual car types can thus be above or below the limit. If car manufacturers exceed these limits they have to pay fines, as is explained in more detail in the next paragraphs.

Limit value curve

Emissions for each car type are established, according to its mass, on the basis of a so called *(emission) limit value curve*. The limit value curve is described in Annex I of the Regulation (EU, 2012). The limit value curve is set in such a way that a fleet average CO_2 emission target per km is achieved for the EU as a whole. The curve implies that heavier cars are allowed higher emissions than lighter cars, while ensuring that the overall fleet average target is met. This implies that manufacturers will still be able to make cars with emissions above their indicative targets as long as these are compensated by other cars which are below their indicative targets. The formula and mechanism of the limit value curve are illustrated in Figure 2.

4 Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty cars (23 April 2009).

Figure 2: The limit value curve for permitted specific emissions, as given in Annex I of the Regulation (EC) No 443/2009 (EC, 2009)



The formula for the limit value curve, underlying the 2015 target, is:
Permitted specific emissions of CO_2 = 130 + a × (M - M0)
Where:

M = mass in kg (of the vehicle for which the emission limit is determined).

M0 = 1289.

a = 0.0457 (i.e. the slope of the limit value 'curve').

Alternative metrics for mass

The Commission has commissioned studies on alternatives metrics than mass as a utility parameter for determining emissions targets for cars. The possible use of footprint (i.e. the surface between the wheels of a car) as alternative to mass would offer benefits on some aspects (e.g. Smokers et al., 2011a, b). However, the Commission recently announced to maintain mass as the metric (EU, 2012b, c, d).

Targets for individual manufacturers

Each manufacturer gets an individual annual target based on the average mass of all its new cars registered in the EU in a given year. In order to comply with the regulation, a manufacturer will have to ensure that the overall sales-weighted average of all its new cars does not exceed the limit value curve. As already pointed out, the curve is also set in such a way that emissions from heavier cars will have to be reduced more than emissions from lighter cars.

Penalties for not complying

If the average CO_2 emissions of a manufacturer's fleet exceed its limit value in any year from 2012 on[5], the manufacturer has to pay an excess emissions premium for each car registered. This premium amounts to € 5 for the first g/km of exceedance, € 15 for the

[5] Note that the % of the fleet required to meet the limit is gradually phased in between 2012 and 2015

second g/km, € 25 for the third g/km, and € 95 for each subsequent g/km. From 2019, already the first g/km of exceedance will cost € 95.

2020 target

The Commission has recently published the proposal for the regulation on how to reach the 2020 target of 95 g/km (EU, 2012b, 2012d). The proposed regulation describes how the 95g/km target for passenger cars in 2020 needs to be reached, including the penalties for exceeding the emission limits that will remain at € 95 for each g/km. The recent publication was preceded by a public consultation on road car CO_2 emissions (September to December, 2011) launched by DG CLIMA (2012). In June 2012 a draft version of the recently published proposed 2020 regulation 'leaked'. Reactions on the 'leaked' draft varied. The positions of the car manufactures differ but are generally conservative, just like their European branch organization ACEA. In contrast, some car part suppliers and their branches organizations generally feel that the Commission's target of 95 g/km strikes the right balance[6]. Longer term targets for 2025 and 2030 are in the preparation and consultation phase.

Post 2020 targets

According to the recently published proposal on the 2020 targets (EU, 2012b) it is 'desirable' to provide indications of how the regulation should be amended for the period beyond 2020 in order to enable the automotive industry to carry out long-term investments and innovation. Before 2015, the Commission will establish and publish the CO_2 emission targets for the period beyond 2020. These targets need to be based on an assessment of the necessary rate of emission reduction in line with the Union's long term climate goals and the implications for the development of cost effective CO_2 reducing technology for cars.

Targets for vans

The Commission has recently published the proposal for the regulation on how to reach the 2020 target of 147 g/km (EU, 2012c). The vans legislation is closely related to the legislation for cars, but there are some differences in targets and timing. The limit value curve differs in both its value and its slope because vans are heavier and emit more CO_2 than cars. Therefore, the limit value curve is flatter for cars, meaning that relatively more reductions are required from larger cars. This is not the case for vans, because there is little risk of an uncontrolled increase in the size of vans.

The implementation of the van legislation starts later than for cars because it was adopted later. The rules on derogations for small-volume manufacturers are also slightly different (EU, 2012; 2012c, d). Just like the regulation for cars, the regulation for vans is directly applicable in the Member States and therefore does not need to be transposed into national laws.

[6] For example JM Gales, CEO of the European Association of Automotive Suppliers (CLEPA) as quoted by Reuters June 14 2012: "Plans for a binding 2020 target to limit emissions to 95 g/km would add around 1,000 euros to the price of a car and that would be quickly paid off through savings in fuel consumption; 95 g/km is the optimum level for ambition and payback for consumer over a couple of years" http://www.reuters.com/article/2012/06/14/us-eu-cars-clepa-idUSBRE85D06220120614.

1.6 Bonus regulations and flexible mechanisms

Super-credits

This legislation aims at encouraging the development of very low-CO_2 technologies, despite the high costs involved, by giving 'super credits' for cars that (tank-to-wheel) emit less than 50 g CO_2/km. This will lower the manufacturer's average emissions as calculated by the Commission, making it easier to meet the target. Cars that emit less than 50 g CO_2/km qualify for a 'supercar' credit.

EVs are currently counted as zero-emission vehicles as they do not have tailpipe emissions. However, EVs have upstream CO_2 emissions, depending on the proportion of fossil fuel feedstock used to generate the electricity consumed by the EV. The same reasoning is valid for other zero-emission vehicles, notably hydrogen fuel cell vehicles (FCVs).

Currently in practice 'super credits' almost entirely relate to electric cars. When calculating the average emissions of each manufacturer's fleet, each low-emitting car will be counted according to the following scheme:

- 1 low-emitting car is counted as 3.5 cars in 2012 and 2013
- 1 low-emitting car is counted as 2.5 cars in 2014
- 1 low-emitting car is counted as 1.5 cars in 2015.

The current scheme expires as of 2016. By then also cars emitting less than 50g CO_2/km will be counted like all other cars.

Revised super-credit scheme 2020-2023

According to the recently published proposal on the 2020 targets for new passenger cars (EU, 2012b) a more stringent variant of the super-credit scheme for low emitting cars will be re-introduced in 2020: "Super-credits for cars emitting below 35 gCO_2/km are introduced between 2020 and 2023 with a multiplier of 1.3 and limited to a cumulative figure of 20,000 vehicles per manufacturers over the duration of the scheme".

Super-credits for vans

The super credit scheme for vans differs from that for passenger cars. The threshold for super credits is also 50 g CO_2 /km, but the timing of the scheme differs:

- 1 low-emitting van is counted as 3.5 vans in 2014 and 2015
- 1 low-emitting van is counted as 2.5 vans in 2016
- 1 low-emitting van is counted as 1.5 vans in 2017.

The scheme expires as of 2018.

In addition, there is a cap on the number of vans able to benefit from the scheme of 25,000 vans per manufacturer over 4 years.

E85 blend credits

Cars capable of running on a mixture of petrol with 85% ethanol (E85) will be considered, until the end of 2015, as having CO_2 emissions 5% lower than the level reported by the Member States. This reduction applies only where at least 30% of the filling stations in a Member State provide E85. In addition, the fuel must comply with the sustainability criteria set by other legislation.

Eco-innovations

Manufacturers may apply for credits for innovative CO_2 reducing technologies which are not accounted for in the current test cycle (Eco-innovations). Current examples of such eco-innovations are: solar roofs that provide power for auxiliary electrical systems; efficient lighting (e.g. LEDs); exhaust heat recovery. The total contribution of eco-innovation credits is limited to 7 g CO_2/km in each manufacturer's average specific target. The eco-innovation system it is an interim procedure until the test procedure is reviewed by 2014. Note that the recently published proposal on the 2020 targets for new passenger cars (EU, 2012b) states that: "Eco-innovations are retained when a revised test procedure is implemented".

Joint pools

Manufacturers can group together to form a pool which can act jointly in meeting the specific emissions targets. "In forming a pool, manufacturers must respect the rules of competition law; and the information that they exchange should be limited to average specific emissions of CO_2, their specific emissions targets, and their total number of cars registered" (EU, 2012).

Small manufacturers

Independent manufacturers who sell less than 10,000 cars per year and who cannot or do not wish to join a pool can instead apply to the Commission for an individual target (EU, 2012). In addition, smaller manufacturers benefit from provisions enabling them to have less demanding targets. The very smallest manufacturers registering less than 500 vehicles per year would be exempt from meeting the targets (EU, 2012b).

2

Policy alternatives

Generally policies for efficient and low-CO_2 transport need to be: ambitious and in line with the 2050 goals (EU, 2011), while at the same time technically achievable and affordable. The current chapter addresses starting points, key issues and possible solutions, thereby aiming to provide basic insight in effective policy design.

2.1 Objectives and boundary conditions

Goals

- Minimization of WTW CO_2 emissions of all cars and (fuel) chains. In line with the EU long term reduction ambitions and timing towards 60% reduction in 2050 compared to 1990, with a substantially larger effort for the passenger car segment.
- Maximize efficiency and minimize energy use of all car types, including: ICE, PHEV EV, FCV.
- Harmonization of test cycles for all car types.

Boundary conditions

- Minimize complexity.
- Optimal harmonization of all different incentives and complementary (WTT) policies (e.g. with FQD).
- Minimization of potentially unwanted impacts (such as disproportionally super-credits for ZEVs allowing/ extra emissions for ICEs).
- Incorporate or discard as much as possible ''additional measures'' such as the current 'eco innovations'.
- Passenger car regulation part of a larger regulation framework also including vans and heavy duty cars.
- Timely announcement of regulations to enable timely industry investments and planning: technology design and implementation of a car takes at least 5 years.
- Level playing field: the regulatory approach should not distort technology choice, although ensuring that zero emission vehicles will be timely phased in (see next section).

Other considerations
Light duty vehicles can relatively easily switch to electricity, or other potentially very low CO_2 energy sources, such as hydrogen. In contrast, electrification is much more difficult for heavy duty road transport and even more for aviation and shipping. Therefore biofuels need to be saved as much as possible for the long distance transport modes (De Wilde and Kroon, 2011). The situation is further complicated by the rapid growth of aviation and shipping. In order to reach the overall 2050 target for road transport of -70% CO_2 compared to the present situation (EU, 2011), light duty vehicles have to switch almost completely to electricity and/or hydrogen.

As described in Chapter one, advanced ICE technologies are now expected to enable substantially deeper and less costly CO_2 emission reductions than envisioned until recently. It should be noted, however, that real world and test cycle emissions differ substantially, with increasing divergence at lower test emissions (e.g. Kadijk et al., 2012; Mock et al., 2012). Eventually diesel hybrid powertrains may allow emissions as low as 65 g/km (DeCicco, 2010). However, from then on further emission reductions will hardly be possible, as the thermodynamic boundaries simply do not allow much further reductions with ICE technologies. This implies that ICE technologies will never be able to bridge the gap with the EU 2050 targets that require an almost complete decarbonisation of the light duty sector. In order to prevent such a 'lock in' of light duty vehicles approaching a CO_2 reduction bottom of about 65 g/km, electric and hydrogen vehicles need to be timely phased in, along with increasing production capacity of very low-CO_2 electricity and hydrogen. Simultaneously, even advanced ICE vehicles need to be phased out well before 2050[7].

2.2 Legislative split of the well-to-wheel chain

Addressing both well-to-tank (WTT) and tank-to-wheel (TTW) emissions, in a single overarching well-to-wheel (WTW) regulation would require a very complicated and extensive policy framework. Overall clarity improves by complementary but separate legislation for TTW and WTT emissions. Currently, the TTW legislation is covered by existing legislation, notably the Fuel Quality Directive (FQD; EC, 2009b), the Renewable Energy Directive (RED; EC, 2009c) and the EU Emission Trading Scheme (ETS). A key reason to keep the different legislations in the WTW chain separated is that they address different stakeholders. For example the CO_2 emission limits address car manufacturers; the RED addresses national governments; the FQD addresses refineries and fuel distributers; the ETS system addresses, amongst others, electricity producers and refineries. In addition consumers play an important role in their choices for vehicles and fuels and their travel and driving behavior. Addressing all these stakeholders by one overarching WTW regulation would inevitably involve (too) many challenges. At the same time the overall impact of the current set of regulations may improve by optimization of their aligning and by considering the different stakeholders involved.

[7] In addition the rapidly improving efficiency of ICE vehicles is increasingly difficult to combine with the high vehicle performance expectations of current consumers. Combining efficiency and vehicle performance is likely easier to achieve in both EVs and FCVs.

Both WTT and TTW regulatory frameworks are closely linked, especially since the ICE vehicle emissions are predominantly TTW, whereas (PH)EVs only have WTT emissions. In the current study we focus on the future lay-out of TTW regulations. Also emissions of the car production phase, which are relatively high for EVs, are not addressed in the current study. Further note that incentives to influence consumer choices and behavior, another key issue in transport policies, also are beyond the scope of the current study.

2.3 Main legislative frameworks

Two main ways to regulate TTW emissions can be distinguished:

1. A CO_2 standard, expressed in g CO_2/km
2. An efficiency standard, expressed in MJ/km.

The possible switch from the current CO_2 based standard to an energy efficiency based standard becomes especially relevant when EVs and other zero emission vehicles have reached a certain market penetration. As explained in paragraph 2.1, initially it is important to maximize the efficiency of conventional vehicles and at the same time stimulate the market introduction of zero emission vehicles as much as possible. Both these goals could be reached by increasingly stringent CO_2 limits. However, incentivizing the market uptake of zero emission vehicles may require more stringent CO_2 limits than envisioned until recently because the efficiency improvements in ICE cars are rapidly developing.

When the market uptake of EVs and other zero emission vehicles reach a certain level it becomes important to maximize their efficiency as well. This will be complicated with a CO_2 based standard. At this point an efficiency based standard is more effective, and may offer some additional benefits too. An overview of the key benefits and disadvantages of both ways to regulate TTW emissions of light duty vehicles is presented in Table 1.

Table 1: **Overview of pros and cons of legislative options**

	Pros	Cons
CO_2 standard [g CO_2/km]	+ Prolongation of current situation, relatively simple + Sufficiently stringent CO_2 limits will push (PH)EVs, hydrogen (fuel cell) cars and other low-CO_2 technologies + Technology neutral	- No incentives to increase efficiency (PH)EVs or hydrogen cars => additional policies needed. But only relevant after a certain threshold uptake (PH)EVs or hydrogen cars! - No incentive to decrease CO_2 intensity of (grid) electricity for charging (PH)EVs or hydrogen production => additional policies needed (such as ETS). - Difficult to separate the all-electric and fossil fuel propulsion part for PHEVs - E85 (currently) gets a 5% bonus. But what about biogas (CBG or LBG) or B100 (100% biodiesel)?
Efficiency standard [MJ/km]	+ Both ICE car, (PH)EVs and hydrogen cars incentivized to increase efficiency (and resulting lower CO_2 emissions). But ICEs, and (PH)EVs would require different targets! + Accounting for split over all electric and fossil fuel propulsion part for PHEVs easier than for CO_2 based legislation + Technology neutral	- No incentive for EVs and other low CO_2 cars (apart from balancing the efficiency targets for the electric and ICE drive train parts of PHEVs) - (PH)EVs efficiency need to be measured differently (grid to wheel) than ICE cars efficiency (tank to wheel) - but possibly combinable in the same test cycle.

The optimal design of the above described legislative frameworks requires:

- Several issues to be worked out in more detail.
- Policy directions to limit possible unwanted impacts.

In the next chapter the key issues, hurdles and directions to overcome them are discussed.

3

Drawbacks current legislation and possible solutions

The current CO_2 regulatory framework, involves several benefits but also shortcomings and unwanted side impacts, as summarized in Table 1. Some key disadvantages include:

- The uptake of ZEVs may limit the incentives to improve conventional cars.
- Preferred use of electricity or hydrogen from renewable energy sources may result in less renewable energy and higher CO_2 emissions for other sectors.
- The RED allows ‘’double counting’’ of sustainable biofuels for the transport sector, which may shift unsustainable biomass to other sectors.
- No incentive to increase the efficiency of (PH)EVs and FCVs.

In the next sections, some key issues of current policies are discussed in more detail and complemented with possible solutions.

3.1 Impact of (PH)EVs on the 95 g km limit[8]

Possible disadvantages of super-credits

In chapter 1, the 2020 CO_2 target of 95 g/km is described along with the penalties for not complying, as well as the currently existing flexible mechanisms and bonus regulations including the so called ‘super-credits’. Although super credits offer an extra incentive for manufacturers to invest in EVs and other alternative low-CO_2 power trains, resulting in a greater market offer of low emitting cars, there are also disadvantages:

- The ‘multiplier effect’ of the super-credits may weaken the effectiveness of regulations for conventional cars. Excess emissions of conventional cars are allowed

[8] Answer to the initial research question: *‘’How is the 2020 95 g/km standard currently designed, particularly regarding (PH)EVs and FCVs. And what will be the impact on conventional cars if large numbers of EVs and FCVs come in the market?’’*

to be compensated more than proportionally by vehicles emitting less than 50 g/km. This will lower the car manufacturer's average calculated emissions, making it easier to meet the emission reduction target.

- Also the super credit system does not provide incentives to improve the efficiency of EVs and hydrogen vehicles, which will be very important on the long term to meet climate targets (see e.g. De Wilde & Kroon, 2011).

Example of possible impact of super credits on conventional cars by 2015
In 2015 1 EV may be counted as 1.5 cars (see previous section). In 2015 the fleet average emission of cars needs to be below 130 g/km. Since regulation 443/2009/EC indicates that EVs are at least until 2015 counted as zero emission cars, this means that in 2015 each EV will allow 1.5 * 130 = 195 conventional cars to emit to emit 1 g CO_2/km more.

The overall weakening impact on emissions of conventional cars depends on the market penetration of EVs. Assuming that by 2015 EV sales will constitute less than 0,5% of all new car sales[9, 10, 11], the overall weakening impact on the conventional car fleet will be less than 1 g/km. So by 2015 the super credit scheme is only expected to have a limited weakening impact on emissions of conventional cars.

Impact After 2020
According to the current legislation the super credit scheme expires as of 2016 implying that cars with emissions below 50 g/km will be counted like all other cars.

However, *assuming* that the super credit system would be elongated until 2020 this would have a substantially larger weakening impact on emissions of conventional cars, because of the increasingly larger share of EVs in new sales. *Assuming* that EVs for example would still have a super credit multiplier impact of 1.5 and *assuming* that by 2020 EVs would constitute some 10% of new sales (Hanschke et al., 2009), this would result in a weakening of the emission target for conventional cars from 95 g/km to about 109 g/km. Note that in the above example of 10% EVs counting as zero emission cars, even without the super credit ‘multiplier effect’ the emissions of the conventional cars may increase to 105 g CO_2/km; see also (Smokers, 2010).

This example shows that extending the 2015 conditions for the super credit regulations would have a substantially weakening impact on the CO_2 legislation. In addition this example shows that at a growing share of EVs in new car sales it becomes important to account for WTW emissions - implying that EVs would not be counted as zero emission cars.

Policy alternatives

- To prevent 'super-credits' from weakening the CO_2 legislation, the number of cars for which the manufacturer can claim the credits could be limited to a certain number. Similarly to the current super credit regulation for vans, which - in contrast

9 For instance in the first 4 months of 2012 the Opel Ampere (PHEV) reached a market share of 0.3% in the Netherlands. In 2011 the sales of BEV reached a market share of 0.15% in the Netherlands.

10 Electrified cars will not exceed 15 percent of annual global new car registrations before 2025 – “Consumers are not prepared to make any concessions when buying an electric car” (KPMG, 2012).

11 Car price and range - two essential purchase criteria - are significantly less advantageous for EVs. Thus the market penetration of EVs might remain below expectations as potential buyers would rather stick to the lower-priced conventional car with a better overall performance (Van Essen en Kampman, 2011).

to the regulation for passenger cars - limits the number of vans able to benefit from the scheme to 25 000 per manufacturer[12] over 4 year time frame 2014-2017.

- Considering WTW emissions for EVs and hydrogen vehicles becomes increasingly important. Current emission regulation is based on tailpipe CO_2 emissions. However in electric cars, CO_2 emissions are transferred from the tailpipe to the electric grid. Depending on the proportion of electricity produced from fossil fuel on the grid, this results in an upstream emission which is not accounted for in the standard. By considering WTW emissions in future legislation this effect can be covered. Options to include WTW CO_2 emissions in the regulation are discussed in literature. See for example: Patterson et al. (2011). As argued in paragraph 2.2, there are good reasons to prevent a single overarching WTW regulation addressing both WTT and TTW emissions. Therefore chapter 4 shows some directions to shape future TTW efficiency standards in such a way that they also incentivize low upstream emissions for electric and hydrogen vehicles.

Recent developments
As described in paragraph 1.6 the European Commission has recently (July 2012) published a proposal on the 2020 targets for new passenger cars (EU, 2012b), that includes a more stringent variant of the super-credit scheme to be introduced between 2020 and 2023. Considering the above analysis on possible disadvantages of super-credits, the recent proposal by The Commission strives for a balance between incentivizing ZEVs and limiting negative impacts by:

- Requiring super-credits vehicles to emit less than 35 g CO_2 /km.
- Limiting the multiplier factor to 1.3 (i.e. 1 super-credit car is counted as 1.3 cars).
- Limiting the super-credit scheme to 20,000 vehicles per manufacturers over the duration of the scheme.
- Limiting the timeframe to 2020-2023.

3.2 Accounting for (PH)EVs in the test cycle

The accounting for plug-in hybrid cars[13] (PH)EV in the test cycle is an important issue[14]. Comparing hybrid cars with ICE cars and EVs, as well as incentivizing their efficiency, is getting more relevant with increasing numbers of (PH)EVs. Key aspects to consider include:

Separating electrically and ICE driven kilometers
Distinguishing between electrically driven kilometers and ICE driven kilometers is important to incentivize both the ICE technology and the electric drive train in the car.

[12] Note that the revised super credit scheme passenger cars for 20202023 (EU, 2012b) includes a cap of 20,000 vehicles per manufacturer.

[13] Note that different types of hybrid cars can be distinguished: (1) 'light' hybrids that cannot drive in all electric mode; (2) hybrids that can drive a limited distance in all electric mode, but that cannot be charged from the grid; (3) plug-in hybrids, that have a larger battery, can drive larger distances in all electric mode and can be charged from the grid.

[14] Note that the current (EU) test cycle- not yet accounting for grid electricity usage- displays a growing gap between test cycle emissions/car efficiency and the real life performance (Mock et al., 2012; Kadijk et al., 2012).

Basic starting points to make the separation comprise:

- Driving the test cycle separately in 100% electric mode and in addition separately in 100% ICE mode.
- As a next step a rule could be developed to define the standardized weighted average contribution of the electrical and ICE parts of the driveline[15]. The weighting standard could be determined by the capacity of the battery. For example, if a battery allows an all-electric driving range of 30 km, the electric energy use could be counted as 30%. However, average user driving patterns exhibit a large share of relatively short trips (EPRI, 2001). Therefore the benefits of a larger all-electric range do not linearly translate to additional all-electric driven car kilometers. So for example a 60 km all electric car range would not translate to twice as much all-electric km driven compared to the 30 km all-electric battery range car. For example the 60 km range could be counted as 45% of car energy use etc.
- The batteries in the mass market sold cars need to be completely comparable to the battery used for the type approval efficiency tests.
- In addition the battery need to be tested under representative ''real life'' conditions. Therefore the above indicated tests need also be carried out after e.g. 500 charge and discharge cycles.

Defining and quantifying the electrical efficiency of cars

- The electrical energy efficiency of a car needs to be based on the grid-to-wheel energy chain. This could be arranged by quantifying electrical efficiency in terms of kWh of input electricity from the grid required, relative to the km driven. For example, the test cycle could be carried out (a certain number of times) related to the overall amount of electricity used.

Harmonization of the CO_2 intensity values for grid electricity

- If the electricity consumption (kWh) is to be related to CO_2 emissions, it is very important to use all over Europe the same CO_2 intensity of the grid electricity for the calculations. Otherwise the same car type may have different CO_2 emission characteristics in different EU countries!

3.3 EVs impacting CO_2-intensity electricity mix[16]

The electricity for the growing fleet of EVs comes *in addition* to the current electricity demand by all other sectors. It is likely that the growing EV fleet will be powered by a relative large fraction of renewable electricity - driven by consumer preferences, marketing strategies, and the relatively large purchase power of individuals and companies buying and driving passenger cars. The preferential application of renewable electricity for charging EVs may lead to a less sustainable electricity mix remaining for the other sectors using electricity (industry, households, agriculture).

15 The rule to weight the average contribution of the electrical parts of the driveline of the (PH)EV needs to be adjustable to enable further policy optimisation, depending on the developments in (PH)EV market uptake, while at the same time offering sufficient long-term investment perspectives for industry. This could be arranged, for example, by including the rule in the appendix of the test cycle, rather than in the test cycle itself. Note that currently the electrical part of (PH)EVs is weighted (too) optimistically.

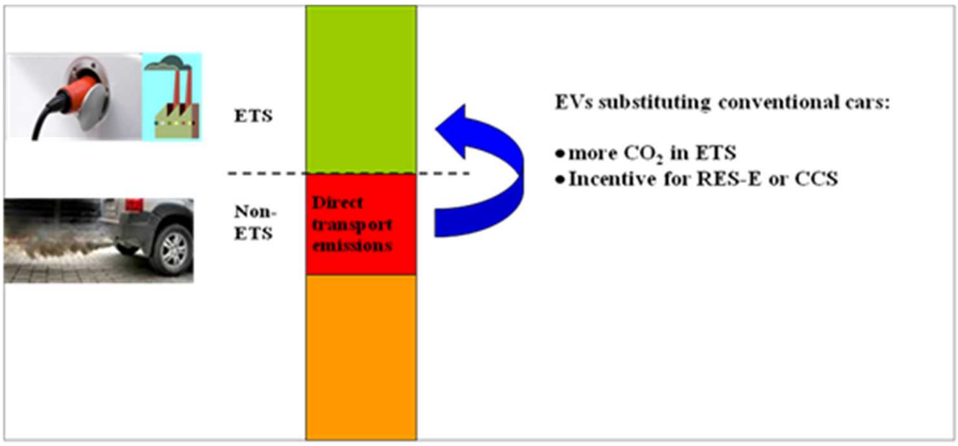
16 Answer to the initial research question: "If additional renewable electricity for EV charging is incentivized, to what extent makes this other sectors 'dirtier'? The same question regarding 'double counting' of biofuel use in the RED as well as preferred application of CO_2-poor hydrogen in the transport sector?

A possible policy to limit such negative effects may include setting a requirement to base calculations on the carbon content of electricity use for EVs on a mandatory EU wide realistic default value. At least for renewable electricity production with public subsidies. Note that the situation is getting more complex by the growing importance of 'Smart Grids', as 'Smart' EV charging can increase the efficiency and profitability of electricity from renewable sources.

ETS

The 'diluting' impact of a growing fleet of EVs on the renewable fraction in the electricity mix would in theory be compensated by the EU Emissions Trading Scheme (ETS) and the associated cap on CO_2 emissions from the power sector and industry. The ETS cap would be expected to compensate the additional demand for renewable electricity by EVs - by inducing additional production capacity of renewable electricity and/or additional CCS or other low-CO_2 electricity. This mechanism is visualized in Figure 3: .

Figure 3: Electric vehicles in the context of the European CO_2 emission trading system EU-ETS



As a consequence the additional electricity use for the growing EV fleet would theoretically not lead to additional CO_2 emissions elsewhere. However, in practice the compensation of the ETS system may work out less effective. Because of the following risks:

- The Power sector may argue that the ETS cap needs to be stretched if the EV electricity demand becomes substantial - thereby arguing that the conditions have changed too much since electricity use for the transport sector was not included in the negotiations leading to the current ETS system.
- Also the ETS system allows 'flexible' mechanisms to meet the CO_2 emission cap. These flexible mechanisms could be regarded as less watertight compared to the alternative of tighter EU transport CO_2 emission limits. Especially the JI[17] and CDM[18] instruments in the ETS could result in reduced real life emissions because they allow

[17] Joint Implementation (JI) is a mechanism under the Kyoto protocol for transfer of emissions permits from one Annex B country to another. JI generates Emission Reduction Units on the basis of emission reduction projects leading to quantifiable emissions reductions.

[18] The Clean Development Mechanism (CDM) is a mechanism under the Kyoto protocol for project-based emission reduction activities in developing countries. Certificates will be generated through the CDM from projects that lead to certifiable emissions reductions that would otherwise not occur.

for example that CO_2 emissions in the EU can be compensated by emission reductions of fluorinated greenhouse gases in non OECD countries.

However, before 2020 the impact of EVs on the electricity demand will be limited because of the still low share of EVs in the overall car fleet (see section on EV market penetration in paragraph 3.1). Therefore it is unlikely that the electricity sector will claim a larger CO_2 cap in the he current ETS system that expires in 2020. To prevent possible unwanted impacts of a growing EV share, the negotiations for the post 2020 ETS system could consider:

- To allow for additional CO_2 emissions in the cap, related to the growing share of EVs expected, and the associated additional electricity demand along with the CO_2 release from electricity production. The growing EV fleet, thereby substituting ICE cars, will result in prevented emissions of fossil fuel burning.
- Note that the ETS operates on the EU-level. In contrast, prevented fossil fuel emissions (by substituting ICE cars with EVs) are accounted for on the level of individual member states.
- An alternative option would be to also include road transport emissions in the ETS system.
- Preferably the future ETS (or a comparable cap and trade system) will be designed in such a way that it will be independent of the type and market penetration rates of new low CO_2 emission technologies and fuels.

In case the ETS system would not be prolonged after 2020 there would be no cap to dampen the negative impact on other sectors of preferentially charging EVs with renewable electricity. Consequently less renewable electricity would remain for the other sectors.

Example to illustrate EVs impact on CO_2-intensity electricity mix
The latest ECN *Reference projection on energy use and emissions* (Wetzels, 2012) indicates in 2025 an electricity demand of about 500 PJ in the Netherlands by all sectors combined. About 90 PJ of the total demand is expected to be supplied from renewable electricity sources (i.e. about 18%). The impact of the EV fleet in 2025 on the CO_2-intensity of the overall electricity mix can be indicatively estimated by making some assumptions. Firstly the assumption that the electricity demand by EVs in the Netherlands in 2025 or shortly afterwards will be between 2% (current policy scenario) and 5%. Secondly, the assumption that the EV fleet would be charged only with renewable energy. Under the above assumptions, the EV fleet in 2025 would lower the CO_2-intensity of the electricity remaining for the other sectors by as much as 10 to 25%. Note that this first order approach neglects the effects of: (1) EVs rather influencing the marginal electricity production than the average mix; (2) the potential beneficial role of EVs in buffering intermittent electricity; (3) additional renewable electricity capacity resulting from new EV sales that are directly coupled to the installation of additional renewable energy capacity (e.g. coupling of EV sales and new wind turbines).

Furthermore, the absolute increase in electricity demand from a large market uptake of EVs will be moderate. Even a complete electrification of the European car fleet would result in an additional demand in the order of 10-15% (Van Essen and Kampman, 2011)[19]. For the Netherlands the additional electricity demand of EVs would be higher, ranging from 19-20% for electrification of all passenger cars, to 24-25% if also all vans would drive electric. However, even the light duty car segment is not yet expected to switch predominantly to electricity in the coming two decades (De Wilde & Kroon, 2011).

3.4 RED - unwanted impacts

The EU Renewable Energy Directive (RED) sets a sector-wide target of 20% renewable energy in 2020 (EC, 2009c). In addition the RED requires 10% renewable energy in transport by 2020. Furthermore the commission wants to achieve 30% in 2030 in its 2050 roadmap. There is no specific target for renewable energy in electricity production. Electricity use from the transport sector lowers the amount of final energy use and lowers in this way also the amount of renewable energy. The decline in biofuels use in the transport sector, that would result from an increase in electric cars, could therefore be compensated by a lower amount of biofuels in other applications (e.g. heating purposes), while still reaching the same RED target. In this case the amount of renewable energy in the primary energy demand would slightly decrease. If electric cars would be charged with (additional) renewable electricity, also the same target could be met. In this case the amount of renewable energy in the primary energy demand would increase.

The RED targets are based on final energy consumption. One of the implications is that, for meeting the RED targets, it is favorable to convert biomass in biofuels for application in conventional cars compared to biomass conversion in (renewable) electricity to power EVs. For example, a feedstock of 130 PJ biomass could be converted in about 100 PJ biofuels, or alternatively in about 50 PJ renewable electricity. Remarkably, the first option is twice as effective in meeting the RED targets as the second option.

Policy alternatives

- Include petrol and diesel fuel for cars in the ETS.
- Providing stronger incentives to directly couple the growing EV fleet to a proportional increase in *additional* renewable electricity capacity.

3.5 FQD - unwanted impacts

The EU Fuel Quality Directive (FQD) forces the suppliers of road fuels to reduce the well-to-wheel CO_2 emissions (EC, 2009b). At the same time the RED requires 10% renewable energy in transport by 2020. On balance, it is likely that the combined targets of the FQD and RED directives will be met by a combination of all options with a relatively large share of biofuels.

19 Therefore it is likely that generating capacity will be able to meet the additional demand, at least in the short to medium term - although uncontrolled charging could significantly increase peak load and thus incur a high cost burden.

The application of 'double counting' biofuels[20, 21] as stimulated by the RED is dampened by the FQD. In broad, every 0,2% surplus reduction above the 6% FQD targets allows for the RED target of 10% to substitute 2% 1st generation biofuels by 1 % double counting biofuels (De Wilde & Roeterdink, 2010).

Policy alternatives

- Regulation ensuring that additional sustainable biofuel use in the transport sector will not come at the cost of less sustainable biofuels for other sectors. For example by requiring a level playing field for the percentage of sustainable biofuels for all sectors.
- At this moment the demand by the EU for biofuels reduces the possibilities in other countries to lower their own CO_2 emissions. This effect could be prevented if the EU would limit their demand to what would be available for the EU in a worldwide balanced biofuel supply and demand (pro rata biofuel distribution; see e.g. De Wilde & Kroon 2011).
- If there are other options available to make the energy consumption in a sector more sustainable, incentivize these options first before stimulating biofuels or biomass.

3.6 Impact CO_2 legislation on biofuel market[22]

Without additional regulations the market will result in dominant application of biofuels in passenger cars, because of the largest added value and the relatively large purchase power of the passenger car sector. Also the 'double counting' of sustainable biofuels as regulated by the RED may result in an additional shift of unsustainable biomass to other sectors.

For example *assuming* that the passenger car fleet in 2025 in the Netherlands would use about 20% biofuels (on an energy basis), what would be the impact on the biofuel market? The above example would equal an energy use of about 40 PJ relative to the expected baseline scenario of 10% biofuels equaling 20 PJ. The additional 20 PJ demand for biofuels, if not directly imported, would have a substantial impact on biofuels remaining for other applications. For example production of green gas and electricity, with expected biofuels demands by 2025 in the order of 45 PJ (mainly imported) and 40 PJ, respectively.

If the heavy duty road transport sector would also increase its biofuels use, the impact on sustainable biomass remaining for other sectors would become even larger.

[20] Note that the current legislation still contains loopholes enabling to switch unsustainable biomass into sustainable thus double counting biomass. E.g. the transformation of dubious vegetable oil into double counting used cooking oil by a symbolic frying exercise…….

[21] Note that the current scheme of "double counting" biofuels for the transport targets in the RED may change into a different system including double and quadruple counting biofuels, following the publication in October 2012 of the "Proposal for a Directive of the European parliament and of the amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources".

[22] Answer to the initial research question "How does the application of (double counting) biofuels in the transport sector affect the use of sustainable biomass in other sectors?"

However, it is unlikely that biofuel use in the passenger car segment and the heavy duty segment will peak at the same time (De Wilde & Kroon, 2011). This latter study projects biofuels use in the heavy duty road sector to accelerate mostly after 2030, along with the simultaneous phasing out of biofuels in the light duty sector.

If air transport would be forced to become substantially more CO_2 neutral, this would have a large effect on the demand for biofuels by aviation. In that case a high price competition with road biofuels will be likely.

3.7 Impact CO_2 emission on hydrogen market

Without additional regulation the CO_2 emission regulations and the market will result in dominant application of sustainable hydrogen in passenger cars, because of the largest added value and the relatively large purchase power of the passenger car sector.

As a consequence, the sustainable hydrogen remaining for other sectors would be less. However, currently there is no sustainable hydrogen demand foreseen from the other sectors before 2025, because of the high costs involved. So the current demand for hydrogen from the refineries and the chemical sector will remain to be based on fossil fuels (mainly gas). Capture and storage of CO_2 released during hydrogen production might be an option if the technology becomes commercially available at a large scale.

4

Possible design of post 2020 legislation

Initially it is important to foster the market penetration of electric and hydrogen vehicles as much as possible. However, when their market penetrations increase it also becomes important to optimize their overall CO_2 performances. This requires firstly to minimize the CO_2 emission related to production of hydrogen and electricity and secondly to maximize the efficiency of the drivelines of electric and hydrogen vehicles. These goals will be complicated to achieve with a CO_2 based standard. At this point an efficiency based standard is more effective and may offer some additional benefits. An efficiency-based standard (MJ/km) enables to incentivize the overall efficiency of all vehicles types without mixing of WTT and WTW legislation. In addition an efficiency-based standard allows extra encouragement of specific low CO_2 fuels and technologies. The next section provides basic directions of how such legislation could be shaped.

Calculation structure current legislation

The current regulation is based on a CO_2 standard and is expressed in g CO_2/km. It is designed in such a way that a certain limit is not exceeded by the sum of the average emissions of all different vehicle types, including: (1) ICE cars using fossil fuels, (2) ICE cars using biofuels, and (3) (PH)EVs and hydrogen vehicles. Presently known CO_2 emission limits are 130 g/km in 2015 and 95 g/km in 2020 (see chapter 1). Mathematically the maximum allowable overall fleet average emission in g CO_2 /km can therefore be depicted as:

$$\frac{X_{fossil} * EF_{fossil}\ [gCO_2/\mathrm{km}] + \ Y_{E85} * \ EF_{E85}\ [gCO_2/km] + \ Z_{EV} * 0\ [gCO_2/\mathrm{km}]}{X + Y + Z}$$

With:

X_{fossil} = number of new cars sold using fossil fuels

Y_{E85} = number of new cars sold capable of using E85

Z_{EV} = number of new cars sold using electricity

$EF_{fossil}\ [gCO_2/\mathrm{km}]$ = mean CO_2 emission of new cars using fossil fuels

$EF_{E85}\ [gCO_2/km]$ = mean CO_2 emission of new cars capable of using E85

Note that to improve the overall readability and clarity, the formula is initially limited to the following types of low CO_2 fuels/technologies:

- E85[23] as biofuel type, whereas the formula could be extended with a similar term for e.g. cars capable of running on B30 or B100[24].
- Only EVs are included in the current formula, to limit its overall length. However, EVs should be regarded as representative for all zero emission vehicle types, especially also hydrogen vehicles. Following the same approach the formula can be extended with and additional term for hydrogen vehicles.
- In addition a special line for plug in electric vehicles can be introduced.

Further note that the formula depicts average CO_2 emissions per vehicle type, allowing heavier cars to emit more than lighter cars, as long as the overall fleet average target is met.

Incentivizing the efficiency of electric and hydrogen vehicles

The above formula does not yet incentivizes to optimize the energy efficiency of EVs (and likewise hydrogen vehicles). This aspect becomes especially relevant when the numbers of EVs and hydrogen vehicles increase. Therefore, to stimulate electric cars (and likewise hydrogen vehicles) to be more CO_2 efficient the formula can be changed into:

$$\frac{X_{fossil} * EF_{fossil}\ \left[\frac{gCO_2}{\mathrm{km}}\right] + Y_{E85} * \ EF_{E85}\ \left[\frac{gCO_2}{km}\right] + \ Z_{EV} * \left\{Elec.use\ \left[\frac{kWh}{\mathrm{km}}\right] * EF_{elec.prod.}\ \left[\frac{gCO_2}{\mathrm{kWh}}\right]\right\}}{X + Y + Z}$$

With:

$Elec.use\ [kWh/\mathrm{km}]$ = mean grid electricity use of electric vehicles

$EF_{elec.prod.}\ [gCO_2/\mathrm{kWh}]$ = CO_2 emission factor for electricity production and distribution

Following the same approach as for EVs the formula can be extended with an additional term for hydrogen vehicles, based on the product of the mean hydrogen use (MJ H_2/km) and the mean CO_2 emission of hydrogen production (g CO_2/MJ H_2).

Limiting the regulation to the TTW part

However, by the above approach a mix of WTW and TTW legislation is introduced. As argued in the previous sections there are several arguments why such mixing needs to be prevented. The key disadvantage is that the overall CO_2 emissions of EVs (and similarly hydrogen vehicles) are determined by the product of vehicle energy use per km and CO_2 intensity of the production of electricity (or hydrogen). This would allow a very inefficient vehicle (e.g. a giant 4x4 hydrogen pick-up truck) to compensate its inefficiency by using a very low CO_2 fuel. In addition this approach would strongly enhance the preferred use of low CO_2 fuel in road transport, thereby lowering the amount available for other sectors. Furthermore, because the CO_2 intensity of the grid electricity differs per country, the above formulation would imply that the same car type would have different CO_2 emission characteristics in different countries!

23 E85 is a mixture of petrol with 85% ethanol.Until the end of 2015 cars capable of running on E85 will be considered, as having CO_2 emissions 5% lower than the level reported by the Member States.

24 B30 is a mixture of fossil diesel with 30% biodiesel; B100 is pure biodiesel.

As a solution, that also maintains the incentive to increase the efficiency of EVs (and likewise hydrogen vehicles), the formula can be changed into:

$$\frac{X_{fossil} * EU_{fossil}\,[MJ/\mathrm{km}] + Y_{E85} * \; EU_{E85}\,[MJ/km] + \; Z_{EV} * \left\{EU_{elec.}\,[MJ/\mathrm{km}] * \eta_{elec.prod.}\right\}}{X + Y + Z}$$

The above formulated average overall vehicle efficiency in 2020 needs to be below about 1,28MJ/km. This is equivalent with a CO_2 emission factor of 95 g CO_2/km.

With:

$EU_{fossil}\,[MJ/\mathrm{km}]$ = mean energy use of new cars using fossil fuels
$EU_{E85}\,[MJ/km]$ = mean energy use of new cars capable of using E85
$EU_{elec.}\,[MJ/\mathrm{km}]$ = mean energy use of EVs
$\eta_{\text{elec. prod.}}$ = proposed EU-wide default factor for the CO_2 intensity of the production of electricity (or hydrogen) from a primary energy source; (mandatory) value to be set.

In the above formula the incentive to increase the efficiency of EVs (and likewise hydrogen vehicles) is still there. However, by inclusion of the efficiency factor (η) for production of electricity (and similarly hydrogen) most of the disadvantages of the previous formula are prevented now. The CO_2 intensity factor (η) compensates for the energy loss in production and consumption of fossil fuels as primary energy source. Note that η is larger than 1, or in the case of 100% renewable electricity production approaches 1. The proposed CO_2 intensity factors for electricity and hydrogen need to be realistic default values. In addition the factors need to be mandatory, at least for renewable electricity or hydrogen production with public financial support.

Extra incentives for new low-CO_2 technologies

As a next step, the efficiency of the various new low-CO_2 technologies or fuels could be further incentivized by the inclusion of ‘bonus factors’. The bonus factors allow for an improved rating of targeted technologies, thereby making it easier for car manufacturers to meet the regulatory requirements. As a consequence the bonus factors will incentivize manufacturers to develop and market the targeted technologies and/or fuels. Table 2 provides an example of such a ‘bonus factor’ approach that allows tailored incentivizing of the different power trains and/or fuels.

Table 2: Example of applying a ‘bonus factor’ to further incentivize the efficiency of new low-CO_2 technologies and fuels

$\mathrm{Car}_{\mathrm{fossil}} * \mathrm{bonus}_{\mathrm{flexfuel}} \quad + \quad \mathrm{Car}_{\mathrm{Hydogen}} * \mathrm{bonus}_{\mathrm{Hydrogen}} \quad + \quad \mathrm{Car}_{\mathrm{Electric}} * \mathrm{bonus}_{\mathrm{Electric}}$

Bonus factor	Flex fuel	Hydrogen	Electric
Year			
2025	0,95	0,8	0,8
2030	0,95	0,85	0,85
2035	0,95	0,9	0,9

References

An et. al. (2011) Global overview on fuel efficiency and motor vehicle emission standards: Policy options for and perspectives for international cooperation. United Nations department of economic and social affairs. Commission on Sustainable Development. Nineteenth Session. New York, 2-13 May 2011. Background Paper No.3. CSD19/2011/BP3.

CARS 21 (2012) *Final Report High Level Group on the Competitiveness and Sustainable Growth of the Automotive Industry in the European Union*, 6 June 2012, pp 1-82.

Dalkmann, H. and Brannigan, C. (2007) Transport and Climate Change. Module 5e: Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities. Deutsche Gesellschaft für Technische Zusammenarbeit. Pp 1- 58.

De Wilde & Kroon (2011): Timing of technology roll-out for climate targets in transport. ECN report ECN-E--11-055. December 2011, pp1-77.

De Wilde & Roeterdink (2010) EU-beleid voor CO_2-emissiereductie in transport en de invloed op de Nederlandse brandstofmarkt en luchtkwaliteit. ECN report ECN-E--10-047, August 2010. (In Dutch).

DeCicco, J. M. (2010) A Fuel Efficiency Horizon for U.S. Automobiles. University of Michigan, September 2010, Report prepared for The Energy Foundation. http://www.hybridcars.com/files/fuel-efficiency-horizon.pdf.

DG CLIMA (2011) *What should happen after 2020?* Presentation December 6, 2011 at the stakeholder meeting on LDV CO_2 emissions.

DG CLIMA (2011b) Stakeholder meeting on CO_2 from light duty vehicles (Centre Borschette, Brussels, 06.12.2011). Summary of the meeting by the commission.

DG CLIMA (2012) European Commission, Directorate-general Climate Action, Directorate C - Mainstreaming Adaptation and Low Carbon Technology. *Reducing CO_2 emissions from road vehicles; results of the public consultation*, September 2011- December 2011. http://ec.europa.eu/clima/consultations/0012/index_en.htm

EC (2009) *Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles*.

EC (2009b): (FQD): Official Journal of the European Union 5.6.2009; 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.

EC (2009c): (RED): Official Journal of the European Union 5.6.2009 DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources.

EEA (2012) The contribution of transport to air quality. TERM 2012: transport indicators tracking progress towards environmental targets in Europe. EEA Report, No 10/2012. ISBN 978-92-9213-343-6.

EPRI (2001): *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options.* 1000349, EPRI, Palo Alto, California, July 2001.

EU (2011): European Commission White paper: Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system. Brussels, 23 March 2011.

EU (2012) website on Climate action in the transport sector: http://ec.europa.eu/clima/policies/transport/vehicle/cars/index_en.htm.

EU (2012b) Proposal for a regulation of the European parliament and of the counsil amending Regulation (EC) No 443/2009 to define the modalities for reaching the 2020 target to reduce CO_2 emissions from new passenger cars.

EU (2012c) Proposal for a regulation of the European parliament and of the counsil amending Regulation (EU) No 510/2011 to define the modalities for reaching the 2020 target to reduce CO_2 emissions from new light commercial vehicles.

EU (2012d) *Further CO_2 emission reductions from cars and vans: a win-win for the climate, consumers, innovation and jobs.* Europa Press Release Rapid, July 11, 2012, IP/12/771, http://europa.eu/rapid/pressReleasesAction.do?reference=IP/12/771.

Hanschke, C.B., et. al. (2009): *Duurzame innovatie in het wegverkeer; Een evaluatie van vier transitiepaden voor het thema Duurzame Mobiliteit*. ECN-E--08-076, ECN. Petten, Januari 2009.

Kadijk G., Verbeek, M., Smokers, R., Spreen, J., Patuleia, A., Van Ras, M., Norris, J., Johnson, A., O'Brien, S., Wrigley, S., Pagnac, J., Seban, M., Buttigieg D. (2012) Supporting Analysis regarding Test Procedure Flexibilities and Technology Deployment for Review of the Light Duty Vehicle CO_2 Regulations. Service request #6 for Framework Contract on Vehicle Emissions. Framework Contract No ENV.C.3./FRA/2009/0043. Final Report December 5, 2012.

Kasab & Jackson (2012). *Greenhouse Gas Reduction Potential Estimations for Light-Duty Vehicle Technologies in 2020-2025*. Presentation by Ricardo at the ICCT International Workshop, Brussels, 1 February 2012.

Kasab & Velliyiur (2012) *Analysis of Greenhouse Gas Emission Reduction Potential of Light Duty Vehicle Technologies in the European Union for 2020-2025.* Draft report by Ricardo Inc. prepared for: International Council on Clean Transportation (ICCT). Pp 1- 51.

KPMG (2012) Global Automotive Executive Survey 2012 Managing growth while navigating uncharted routes kpmg.com/automotive. January 2012, pp 1-57.

Leonhard (2011) Reducing CO_2 emissions with optimized internal-combustion engines. Paper by Dr. Rolf Leonhard, Executive Vice-President Engineering Diesel Systems at the 60th Automotive Press Briefing in Boxberg, June 2011.

Mock P, German J, Bandivadekar A, Riemersma I (2012) Discrepancies between type-approval and real-world fuel consumption and CO_2 values in 2001-2011 European passenger cars.

Patterson et al. (2011) *Preparing for a Life Cycle CO_2 Measure.* A report to inform the debate by identifying and establishing the viability of assessing a vehicle's life cycle CO_2 footprint 25 August 2011. Report RD.11/124801.5. Low Carbon Vehicle Partnership - Ricardo, August 2011.

Smokers et al. (2011a) *Support for the revision of Regulation (EC) No 443/2009 on CO_2 emissions from cars.* Service request for Framework Contract on Vehicle Emissions Framework Contract No ENV.C.3./FRA/2009/0043. Final report November 25th, 2011, pp. 1-364.

Smokers et al. (2011b) *Support for the revision of Regulation (EC) No 443/2009 on CO_2 emissions from cars.* Service request for Framework Contract on Vehicle Emissions - No ENV.C.3./FRA/2009/004. Presentation at Stakeholder Meeting, Brussel, December 6, 2011.

Smokers, R., et. al. (2010): *EU Transport GHG; Routes to 2050? Regulation for vehicles and energy carriers.* AEA, London. February 2010.

Smokers, R., et. al. (2010): *EU Transport GHG; Routes to 2050? Regulation for vehicles and energy carriers.* AEA, London. February 2010.

T&E (2012) Website of Transport & Environment, Brussels, Section on Cars and CO_2. Accessed May July 2012.

Urbschat and Bernhart (2009) Powertrain 2020 - The Future Drives Electric. Roland Berger Strategy Consultants www.rolandberger.com.

Van Essen en Kampman (2011) Impacts of Electric Vehicles. Summary Report by CE Delft, April 2011.

Van Essen en Kampman (2011) Impacts of Electric Vehicles. Summary Report by CE Delft, April 2011.

Wetzels (2012): *Actualisatie referentieraming 2020. Doorrekening energie, CO_2, NO_x, SO_2* (In Dutch; Working title. Report still in preparation). ECN, Petten, 2012.

List of abbreviations

ACEA	European Automobile Manufacturers Association
E85	Fuel blend with up to 85% ethanol and 15% gasoline by volume
ETS	Emission Trading System
EV	Electric Vehicle
FCV	Fuel Cell Vehicle
FQD	Fuels Quality Directive
ICE	Internal Combustion Engine (Vehicle)
JAMA	Japanese Automobile Manufacturers Association
KAMA	Korean Automobile Manufacturers Association
PHEV	Plug-in Hybrid Electric Vehicle
RED	Renewable Energy Directive
RES-E	Electricity from Renewable Energy Sources
TTW	Tank-to-wheel
WTT	Well-to-tank
WTW	Well-to-wheel
ZEV	Zero Emission Vehicle