Use and effectiveness of economic instruments in the decarbonisation of passenger cars

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Hans Nijland, Inge Mayeres, Ton Manders,
Hans Michiels, Mark Koetse, Reyer Gerlagh

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Author affiliation:
Hans Nijland, Ton Manders, Mark Koetse: Netherlands Environmental Assessment Agency (PBL), The Netherlands
Inge Mayeres, Hans Michiels: Flemish Institute for Technological Research (VITO), Belgium
Reyer Gerlagh: Tilburg University, The Netherlands

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ETC/ACM Technical Paper 2012/11
European Topic Centre on Air Pollution and Climate Change Mitigation
PO Box 1
3720 BA Bilthoven
The Netherlands
Phone +31 30 2748562
Fax +31 30 2744433
Email etcacm@rivm.nl
Website http://acm.eionet.europa.eu/

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Executive Summary

The European Commission aims at a 60 % reduction in CO_2 emissions from transport by 2050 compared to 1990 levels. The Commission stresses that the decarbonisation of the transport sector depends, firstly, on technology development towards clean and efficient vehicles based on conventional internal combustion engines and, secondly, on the deployment of breakthrough technologies in ultra-low-carbon vehicles. Legislation at European level could be supported by additional national policies, driving decarbonisation of the passenger car sector even further.

This report provides an overview of the economic instruments that the different EU-27 countries have implemented at a national level to decarbonise passenger cars in the *short and medium term*, in addition to European legislation. Economic instruments influence the consumers' choice of car type, car ownership and car use. Long-term impacts are generally two to three times higher than short-term (less than a year) impacts, as in the long run people may adapt their choice of transport mode, type of car and/or their choice of residential or work location. In general, increasing the costs of car use have greater impacts on social and recreational journeys than on commuter traffic or business trips.

Most Member States of the European Union charge a tax on car registration, car ownership and car use. Nine countries charge no registration tax, and five have no taxes on car ownership. In recent years, many EU countries have included a CO_2 component in their taxation system as well as tax exemptions for certain kinds of alternatively fuelled vehicles. Countries in the EU-27 that have reduced above average amounts of CO_2 emissions from new cars, usually have such a CO_2 component in their taxation system, whereas the opposite is true for countries that have reduced below average levels of CO_2 from new cars. National subsidies include those on specific technologies, commuting and on Research & Development. Local economic instruments are geared towards regulating car use.

Impact of taxes on car sales and car use

Based on new car sales data for 14 EU countries in the 2001-2010 period, the report shows that:

- A 10 % increase in weight accounts for about 8.4 % increase in CO_2 emissions, whereas a 10 % increase in engine capacity accounts for an increase in CO_2 emissions of a 0.8 %. Increase in engine power is insignificant for CO_2 emissions.
- Over the 2001-2010 period, due to weight increase alone, diesel and petrol cars have become less fuel efficient by 6 % and 2 % respectively.
- Corrected for fuel type, weight, engine capacity and engine power, over the same period cars have become some 23 % more fuel efficient.
- Using registration taxes to affect the shares of diesel and petrol cars appears to work, while annual road taxes and fuel taxes only have smaller and less reliable effects.
- An increase in income and in the number of cars per person or household both substantially increase the number of kilometres driven per person. Increasing fuel prices, however, have a negative effect on kilometres driven. For each 10 eurocents increase in fuel price the number of passenger car kilometres per capita

decreases by about 260 kilometres annually. Using fuel taxes is clearly effective in reducing the number of car kilometres per person.

Co-benefits for air quality policy

The report shows that policies to decarbonise the passenger car fleet may have positive or negative impacts on air emission policy, depending on the instruments used and the mechanisms involved.

Positive impacts on the emissions of certain air pollutants can be expected from policies aimed at:

- consumers buying lighter cars: a 10 % weight decrease will reduce NO_x emissions by 3% to 4%;
- reducing car use: a 10% reduction in car use will lead to a 10% reduction in polluting emissions. Fuel taxes, commuting subsidies, and, at local level, congestion charges, parking fees and tolls are the instruments that directly affect car use.

Negative impacts on the emissions of certain air pollutants may be expected from policies aimed at:

- consumers switching from petrol- to diesel-fuelled vehicles.

Positive or negative impacts on the emissions of certain air pollutants may be expected, depending on the technology involved, from policies aimed at:

- improving fuel efficiency by improving technology. Electric vehicles have clear advantages in terms of NO_x reduction.

Electric vehicles

Electric vehicles (EVs) are an example of a promising breakthrough technology in ultra-low-carbon vehicles, as referred to by the European Commission. Massive uptake of EVs may, in *the long term*, lead to a considerable reduction in CO_2 emissions, provided the electricity is generated from renewable sources. This report gives an overview of the current knowledge on the costs of EVs, their impacts on the environment and on the electricity sector. Costs and benefits of EVs, as compared to vehicles with a combustion engine, vary significantly between studies. This may be due to both methodological and local differences (e.g. in tax system). Most studies conclude that EVs are cheaper for individual users only if oil prices are high, many short trips are undertaken (high mileage) and battery charging opportunities are plentiful. An increased use of EVs puts more pressure on the electricity generation, especially if battery charging takes place during peak hours. In that case, new power plants would need to be built to provide additional peak power. With off-peak charging, much of the previously unused capacity could be efficiently employed. The environmental benefits of an increased number of EVs improve if electricity is generated from renewable sources. The profitability of providing vehicle-to-grid (V2G) services is highly dependent on the characteristics of the power market, since this will determine the level of the capacity payment (if any) and the energy payment. The estimates also depend on the assumptions about the vehicle characteristics, such as connection capacity, vehicle participation, battery costs and saturation rate of the market. It is therefore very difficult to generalise conclusions.

1. Introduction

This section shows the different options available to improve, avoid or shift traffic in order to decarbonise transport. In addition to planning, regulatory and information instruments, economic instruments play a role in most of these options.

Transport accounts for around a third of all final energy consumption in the EEA member countries and for more than a fifth of greenhouse gas emissions. Passenger cars alone are responsible for around 12% of EU CO_2 emissions (http://ec.europe.eu/clima/policies/transport/vehicles/cars/index_en.htm). For the first time ever the European Commission has proposed a greenhouse gas emission reduction target for transport. By 2050, CO_2 emissions by transport should be reduced by 60 %, as compared to 1990 levels (European Commission, 2011a). The Commission (2011b) stresses that the decarbonisation of the transport sector depends on technology development towards clean and efficient vehicles based on conventional internal combustion engines and on the deployment of breakthrough technologies in ultra-low carbon vehicles. The Commission stresses the crucial role of price signals for the transport system. Internalisation of externalities is part of the effort to align market choices with sustainability needs.

With the Regulation on CO_2 emissions from passenger cars and vans agreed (European Parliament and the Council of the European Union, 2009), the course towards a fleet of low-emission vehicles has been set. For passenger cars, the fleet average to be achieved by all cars registered in the EU is 130 grams per kilometre (g/km) by 2015, almost a 20% reduction in the average prior to the Regulation. The average emission targets under the Regulation are phased-in over the period from 2012 to 2015. Manufacturers must meet their average CO_2 emission targets in 65% of their fleets in 2012, 75% in 2013, 80% in 2014 and 100% from 2015. A target of 95g/km is specified for the year 2020. In July 2012, the European Commission presented a proposal on how to reach this target (European Commission, 2012). EU regulation will no doubt ascertain a further decarbonisation of European passenger cars.

Legislation at European level could be further supported by additional national policies, driving decarbonisation of the passenger car sector even further and support EU Member State action that aims to comply with the Effort Sharing Decision (European Parliament and the Council of the European Union, 2009). Table 1 shows that all European countries made progress in decarbonising their passenger car fleet since 2007. This may have been due to different economic and demographic developments, influencing the consumers' buying behaviour. The implementation of more stringent national policies, also influencing consumers' buying behaviour, is another factor explaining differences in progress.

This report pays particular attention to the support national economic instruments provide to the European Union’s decarbonisation policy for passenger cars. To date, a European-wide picture of which economic instruments are in use in the different EEA member countries, their impact, their cost-effectiveness and possible co-benefits in both the short and medium term is, lacking. While combined European and national policies may bring decarbonisation of passenger cars a lot further in the short and medium term, breakthrough technologies in ultra-low carbon vehicles are needed in the long term to reach the desired level of emission reductions. The electric vehicle is currently the most promising and most widely discussed example of such a breakthrough technology. To explore the opportunities and limitations of a broad introduction of electric vehicles, this report discusses which economic instruments are in place (at a national level, EU-wide) to stimulate consumers to buy and use electric vehicles. It also explores which impacts can be expected of an increased use of electric cars on related sectors, such as the energy sector.

	2007	**2008**	**2009**	**2010**	**2011**		**'07/'11**
Poland	153.7	153.1	151.6	146.2	146.0		-1.3%
Slovakia	152.7	150.4	146.6	149.0	144.9		-1.3%
Czech Republic	154.2	154.4	155.5	148.9	144.6		-1.6%
Hungary	155.0	153.4	153.4	147.4	141.7		-2.2%
Rumenia	154.8	156.0	157.0	148.5	140.8		-2.3%
Slovenia	156.3	155.9	152.0	144.0	139.7		-2.8%
Italy	146.5	144.7	136.3	132.7	129.5		-3.0%
Bulgaria	171.6	171.5	172.1	158.9	151.4		-3.1%
Cyprus	170.3	165.6	160.7	155.8	149.9		-3.1%
Spain	153.2	148.2	142.2	137.9	133.8		-3.3%
Estonia	181.6	177.4	170.3	162.0	156.9		-3.6%
Germany	169.5	164.8	154.0	151.1	145.6		-3.7%
Luxembourg	165.8	159.5	152.5	146.0	142.1		-3.8%
France	149.4	140.1	133.5	130.5	127.7		-3.8%
Portugal	144.2	138.2	133.8	127.2	122.8		-3.9%
Austria	162.9	158.1	150.2	144.0	138.7		-3.9%
Malta	147.8	146.9	135.7	131.2	124.5		-4.2%
Latvia	183.5	180.6	1769	162.0	154.4		-4.2%
UK	164.7	158.2	149.7	144.2	138.1		-4.3%
Belgium	152.8	147.8	142.1	133.4	127.3		-4.5%
Lithuania	176.5	170.1	166.0	150.9	144.3		-4.9%
Finland	177.3	162.9	157.0	149.0	143.9		-5.1%
Greece	165.3	160.8	157.4	143.7	133.1		-5.3%
Ireland	161.6	156.8	144.4	133.2	128.3		-5.6%
Denmark	159.8	146.4	139.1	126.6	125.0		-6.0%
Sweden	181.4	173.9	164.5	151.3	141.8		-6.0%
The Netherlands	164.8	156.7	144.7	135.8	126.2		-6.5%
EU-27	**158.7**	**153.6**	**145.7**	**140.3**	**135.7**		**-3.8%**

Table 1: average CO_2 emissions for new passenger cars per country 2007-2011 (source: EEA, 2012)Note: 2011 based on preliminary data.

Table 1 shows that the average annual CO_2-reduction in the European Union from 2007 till 2011 was 3.8 %. 13 Member States have achieved an above average CO_2 reduction from their new cars, whereas 12 Member States showed a below average CO_2 reduction. Table 5 shows that 12 out of 13 countries with above average reduction have implemented some sort of CO_2-component in their taxation system, whereas only 6 out of 12 of the countries with below average reduction have a CO_2 component. Although not statistically significant, it seems to indicate a positive relationship between CO_2 reduction and CO_2-taxation.

The following three research questions will be answered in the following chapters.

- What is the effect of economic instruments tackling passenger car use and sales on decarbonisation?
- What are the co-benefits of economic instruments for passenger cars in other areas?
- What are the barriers for economic instruments for passenger cars to be cost-effective and to achieve the desired decarbonisation outcome?

The first two research questions deal with the short and medium term, the last one focuses on the longer term.

This report takes European policies for decarbonising passenger cars, both economic and regulatory, as a starting point (see section 1.2) and explores what has been additionally done by different European countries in recent years. The present analysis focuses on:

- *Passenger cars*, as about half of all transport-related CO_2 emissions come from passenger cars, and most climate policies are also focusing on passenger cars (both with a traditional combustion engine (ICEV) as well alternatively fuelled vehicles (AFVs[1]) will be considered). AFVs will get special attention in Chapter 6. While the study will focus on passenger cars in general, specific submarkets such as company cars deserve special attention as they constitute around 50 % of European new car sales and are usually subject to a specific tax regime. Therefore, Annex 3 deals with company cars (as compared to privately owned cars).
- *Economic instruments* that directly affect ownership and use of passenger cars.
- *National instruments*. This implies that we exclude local instruments, such as toll charges and parking fees from an in-depth analysis, except for the overview in section 3.
- *Instruments that have already been in place for some time.* We focus on the 2001–2010 period, as we assume there is a fair amount of data available on these years, thus providing a sound basis for the analysis.
- *Test cycle emission data*. Due to data-availability, all emission levels referred to in this paper are the ones found in the certification test procedure (i.e. the New European Driving Cycle (NEDC) to be used for emission measurement). These levels are measured under laboratory conditions assuming a specific mix of different driving styles. In this sense, measurements are comparable, but they are not necessarily representative of real-world conditions. A study by TNO (Ligterink and Bos, 2010) on reported fuel consumption and mileage of 240,000 vehicles in the Netherlands showed that lower CO_2 emissions during testing did not correspond to a proportional reduction in real-world CO_2 emissions. The gap between real world and test-cycle emissions was more pronounced for the lowest emitting cars. This means that the effect of technology development might be smaller than expected, but there still

[1] Alternative fuel vehicles (AFVs) can be ICEVs that run on fuels other than traditional petroleum products (gasoline or diesel) or vehicles using a propulsion technology that does not involve solely petroleum being used in an ICE

would be an emission benefit in moving towards lower emissions. The gap between test cycle and real world emissions is even more pronounced in the case of emissions of polluting substances, especially for NOx from diesel cars (see e.g. Hausberger, 2006, Vonk and Verbeek, 2010).

After an overview in the remainder of this chapter of the several options to decarbonise passenger cars at European, national and local level, Chapter 2 will give a general theoretical overview of the economic instruments. It will answer the question what instruments do exist and what are their impacts in the short and in the medium term. Chapter 3 gives an overview of the instruments in place in the Member States of the European Union. Chapter 4 gives the results of a quantitative analysis of car taxes in 14 EU Member States. Chapter 5 deals with the co-benefits of policies to decarbonise transport. Chapter 6 deals with AFVs and especially one of the potential breakthrough technologies in the long-term, electric cars. The chapter addresses the following questions: What are the economic instruments in place to encourage the purchase and use of electric cars? What are the costs and benefits of electric vehicles, for individuals as well as for the society? What are the impacts of electric vehicles on the energy sector? Finally Chapter 7 presents conclusions drawn from the findings in the previous sections.

1.1 Options for decarbonising passenger cars

Several approaches exist to decarbonise passenger cars. In general, these approaches may be characterised as Avoid, Shift and Improve transport (EEA, 2010). More in detail, there are the following options to reach a significant reduction in CO_2 emissions:

1. Use of alternative fuels (e.g. biofuels, electricity, hydrogen) (Improve)
2. Use of more carbon-efficient cars (Improve)
3. Modal shift towards more carbon-efficient modes (Shift)
4. Increase in occupancy or load factor (Avoid/Shift)
5. Decrease in the number of trips (Avoid)
6. Decrease in the length of trips (Avoid)
7. More carbon-efficient driving style (Improve)

In realising each of these options, planning, regulatory, economic or information instruments play a role, see Figure 1.

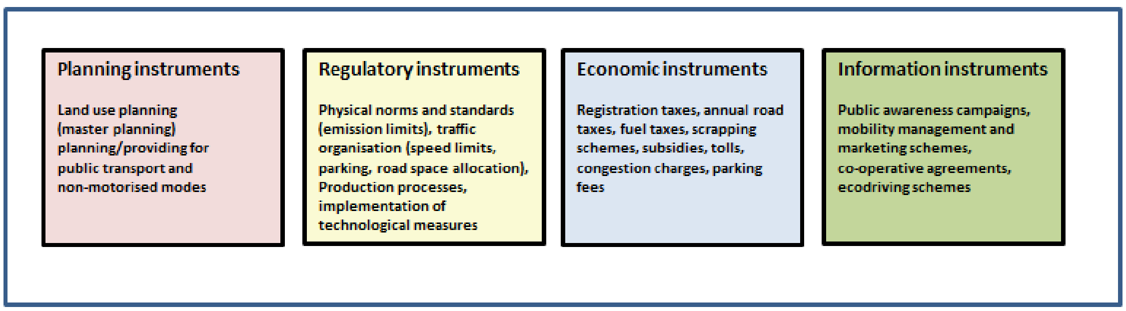


Figure 1: available policy instruments in the transport sector (source: Brannigan and Dalkman, 2007).

Option 1: Use of alternative fuels (e.g. biofuels, electricity, hydrogen) (Improve)

Cars driving with alternative fuels in general emit less CO_2 per kilometre. Table 2 illustrates this point. Thus, a policy aimed at stimulating the use of alternative fuels reduces CO_2-emissions. However, there are sustainability aspects such as direct or indirect land use, biodiversity and food prices that should be considered when targeting for a massive use of biofuels (see e.g. Bindraban et al., 2009).

Type of fuel	***CO_2 emission (gram/km)****
diesel	134.5
petrol	137.7
E85	165
Pure electric	0
Electric with range extender	27
LPG	125
NG-biomethane	119
Biodiesel	117

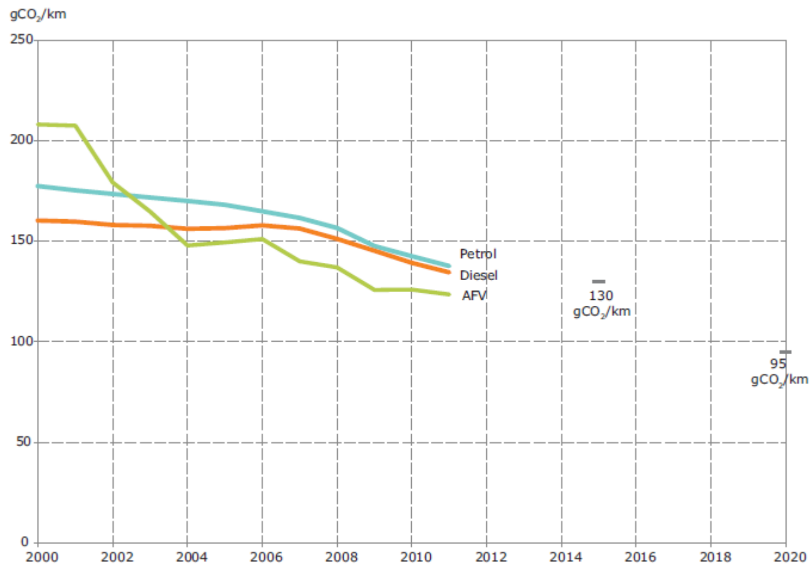
Table 2: Average EU-27 CO_2-emissions per km (source: EEA, 2012)

NB: Only exhaust emissions are considered. For electric monofuel vehicles the emission is null. For Petrol-E85, the petrol CO_2 emission is reported. For Biodiesel, the diesel CO_2 emission is reported. For LPG (Liquefied Petroleum Gas) and NG (natural gas) the respective LPG and CNG CO_2 emissions are reported.

Besides EU regulation on CO_2 emissions from passenger cars, EU instruments in place are the Biofuels Directive 2003/30/EC (EC, 2003), the Renewable Energy Directive (RED) 2009/28/EC (EC, 2009b) and the Fuel Quality Directive (FQD) 2009/30/EC (EC, 2009c) – where there is a requirement for 10% of renewables in transport.

National economic instruments are registration and annual road taxes differentiated by fuel type, taxes on fuel and tax exemptions for AFVs.

Option 2: Use of more carbon efficient cars (Improve)
Cars became more carbon efficient in the last decade, especially since 2008. An explanation for this big emission reduction is that in 2009 EU-regulations on CO_2-emission came into force (European Commission, 2009 a), replacing the failing agreements with the car manufacturers. Figure 2 (EEA, 2012) clearly shows the progress that has been made in recent years.



Note: The geographical scope of the data changes over time from the EU 15 to the EU 25 and the EU 27

Figure 2: Evolution of CO_2 emissions from new passenger cars by fuel (EU-27), EEA 2012

EU instruments in place are the regulations (No. 443/2009 (EC, 2009a) and No. 510/2011 (EC, 2011c)) setting CO_2 emission targets for new passenger cars and for light commercial vehicles. National economic instruments are fuel taxes, CO_2-dependent registration and annual road taxes and purchase incentives for low-carbon cars.

Option 3: Modal shift towards more carbon-efficient modes (Shift)
A policy to encourage people to use more carbon-efficient modes is one of the options to tackle the CO_2-problem. The aim can be to shift people from using the car towards using the train or the bicycle instead. The choice for a certain mode of transport has to do with supply and demand: when one does not possess a car, one has to use public transport, or share or rent a car. Where there is no (good) public transport connection, one may be inclined to walk, to cycle or to take the car. In the end, if there is a choice between different modes, it comes down to an individual weighing of time, money, environmental impacts, health and comfort. A policy to influence this weighing process has to take into account several obstacles:

- First, a modal shift from car to train often concerns commuter traffic, which occurs in rush hours and may cause capacity problems.
- Second, the car is often used for a multi-purpose trip, so-called chain mobility (e.g. first taking the children to day care, then continue to work, then make some business trips and, at the end of the day, on the way home, do some shopping). This is an obstacle for shifting towards the train.
- Third, commuting expenses are often compensated by the employer, especially if public incentives are in place to grant such compensations. In that case, consumer's become relatively insensitive to economic instruments.
- Fourth, making the train more attractive (either by improving services or by reducing transport tariffs) could lead to more train use. The additional train passengers do not necessarily consist of former car drivers only. On the

contrary, the majority might very well be originated from habitual train passengers (Hilbers et al. 2009).

Economic instruments in place are registration taxes, annual road taxes, fuel taxes, subsidies for public transport, road pricing, commuting compensations and their taxation, local congestion charges and parking charges.

Option 4: Increase in occupancy or load factor (Avoid/Shift)
Occupancy rates of passenger cars tend to decrease. Figure 3 illustrates this for the example of the Netherlands.

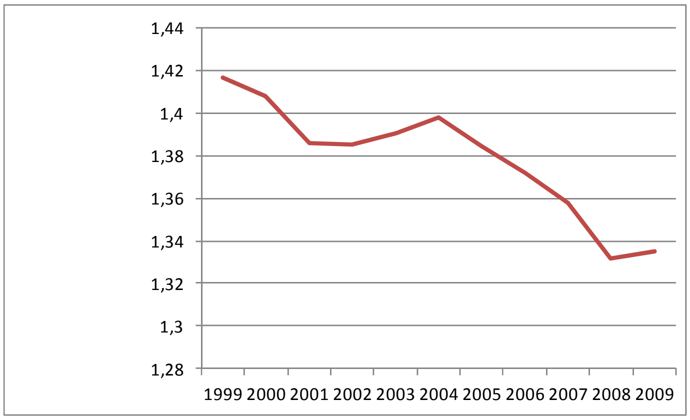


Figure 3: occupancy rate of Dutch passenger cars (source: OVG 2000-2004, MON 2005-2010)

In an effort to reduce traffic and to encourage car-pooling, some countries have introduced high-occupancy vehicle (HOV) lanes in which only vehicles with two or more passengers are allowed to drive. In Europe there are only few examples, i.e. Leeds (since 1998), Bristol, Madrid (since 1995) and Trondheim (since 2001). Car occupancy in Leeds increased from 1.35 in 1997 to 1.51 in 2002, in Madrid from 1.36 in 1997 to 1.67 in 1997 (ICARO, 1999). When high occupancy lanes are not combined with complementary measures, such as travel plans, car sharing initiatives, and improvements of public transport, the result may be a under-utilisation of road capacity and could cause extra delays on lanes not reserved to HOVs.

In some countries it is common to find parking spaces that are reserved especially for car-poolers. Many companies and local authorities have introduced carpooling schemes, often as part of wider transport programmes.

Option 5: Decrease in the number of trips (Avoid)
Increasing the price of transport will decrease the number of trips. Economic instruments that directly affect car use are most likely to have the biggest environmental impact. Economic instruments in place are fuel taxes, road pricing, congestion charges and parking fees.

Option 6: Decrease in the length of trips (Avoid)
Urban transport is responsible for about a quarter of total transport CO_2 emissions. Spatial planning is therefore *the* instrument to decrease trip length. When the distance to the city centre increases and the density of population decreases, car emissions dominate total emissions. As a result, compact cities have greater accessibility and therefore are

somewhat more energy and carbon efficient than a dispersed built environment. Mass transit in dense urban areas is attractive because of the low speed of cars. In addition to mass transit, other contributions can come from cycling and walking. (Bleijenberg, 2012). Increase of transport costs could, in the long term, influence the choice of residential or work place (see section 2 for more details). Economic instruments in place are fuel taxes, road pricing, congestion charges and parking fees.

Option 7: More carbon-efficient driving style (Improve)

Eco-driving, especially when supported by information and communication technologies (ICT), could reduce emissions per kilometre driven by up to 15% and it is expected that just by following the instructions of the shift indicators, emissions can already be reduced by 6% (European Commission, 2010).

2. Economic instruments in general

This section shows that economic instruments may influence choice of cartype, car ownership and car use. Long-term impacts are generally two to three times higher than short-term (less than a year) impacts, as in the long run people may adapt their choice of mode, car type and/or their choice for residential or work location. In general, increasing prices of car use have greater impacts on social and recreational trips than on commuter and business trips.

In recent years, the introduction of different economic instruments for passenger cars did not happen unnoticed. Congestion charging, road pricing, scrapping schemes, soot filter subsidies and CO_2-dependent registration taxes have been surrounded by much public debate. The instruments mentioned above all aimed, as most economic instruments, at the registration, ownership or use of passenger cars. Koopmans and Verhoef (2004) discern three types of impacts of economic instruments on:

1. Changes of behaviour;
2. Revenue and funding;
3. Equity.

The present analysis focuses on the first type of impacts, behavioural changes.

Pricing may affect travel behaviour in various ways. In the short term, it may affect consumer choices regarding the number of trips, the destination, the route, the mode, the time of departure and the driving style (Litman, 2008). In the long run, price measures may affect consumer choices regarding purchase of the (type of) car, the choice on where to work and where to reside. Influencing consumer choices with respect to the purchase of a new car in the long term clearly has strong links with technology development. If pricing policies gear consumers towards buying more fuel efficient cars (such as AFVs), this may stimulate industry to speed up the development of such cars.

The aim of a journey, price, travel time, environmental impacts, health, comfort and safety are all factors that influence the choice on whether or not, and if so, how and when, to make a trip. The aim of the journey is important in how sensitive a consumer is for the price. De Wit and Van Gent (1996) discern between lust and must-trips. Must trips are related to commuting, business travel and education, while lust trips are related to social and recreational motives.

Short term price sensitivity for must trips is considered to be very low. In general, short term (i.e. less than one year) price sensitivity for travel demand is lower than long term price sensitivity. Short term choices on car ownership, residential and working locations are usually fixed, whereas in the long term there is more flexibility to adapt to changing circumstances. Examples are buying a more fuel-efficient car as a reaction on rising fuel prices, moving closer to work, or finding a job closer to home. Therefore, the impact of changes in travel prices usually increases in the course of time.

Transport price elasticities[2] also depend on other factors, like income and psychological factors such as status and superiority. Price sensitivity is higher when the price of transport is higher compared to the income level. In other words, impacts of, for example, a fuel tax raise are expected to be higher in countries with lower income levels and are expected to be lower in time within one country when future incomes are higher. Furthermore, consumers tend to react sharper on increasing than on decreasing prices. Dargay and Gately (1997) showed this for fluctuations in fuel prices in the 1970s. Dargay et al. (2007) showed similar effects for the relationship between level of income and car ownership.

Steg (2005) showed that car use not only depends from factors such as speed, flexibility and comfort, but from psychological factors such as status, power and superiority as well. The more important the psychological factors are, the less price sensitive the consumer will be.

Price elasticities have been in the centre of the attention since the 1973 energy crises (Poltimae, 2011). A literature review of elasticities of road traffic and fuel consumption by Goodwin et al (2004) showed that most studies use data from the United States and the United Kingdom, but also from Canada, France, Germany, Belgium and other countries. They found that if the real price of fuel rose by 10 %, the volume of fuel consumed fell by about 2.5 % within a year and by 6 % in the longer run. Furthermore, when real income increased by 10 %, the total amount of fuel consumed rose by nearly 4 % within a year, and by over 10 % in the long run. It is a general tendency that long-term elasticities are substantially higher than the short-term effect, mostly by a factor of 2 to 3. Income elasticities are greater than price elasticities, mostly by a factor of 1.5 to 3. The review also showed that the United States have lower income and price elasticities of fuel consumption than Europe.

Another review by Graham and Glaister (2004) found that the mean short-term income elasticity of fuel demand was 0.47 within a year and 0.93 in the long-run. The mean short-term price elasticity was -0.25 within a year and -0.77 in the long run.

Similar results have been found in the meta-analysis by Brons et al (2008), namely a mean short-term price elasticity of -0.34 within a year and -0.84 in the long run.

Table 3 summarises the results from recent studies on income and price elasticities of car fuel use (adapted from Poltimae, 2011).

[2] Price elasticity is the the amount of change, in percentage terms, in the consumption of a good or service, e.g. transport, caused by a one per cent price change.

Authors and year of study	Country	Methodology	Data used	Long term income elasticity	Long -term price elasticity
Goodwin (2004)	USA, UK, Canada, France, Germany, Belgium, Denmark, Italy, the Netherlands, Austria, Sweden, Norway, Spain, Australia, Japan	Meta-analysis	Different studies	1.08	-0.63
Graham and Glaister (2004)	UK, Norway, Denmark, the Netherlands,	Meta-analysis	Different studies	0.93	-0.77
Brons et al (2008)	USA, UK, Canada, Egypt, Australia, Denmark, Korea, Taiwan, Kuwait, Mexico, India	Meta-analysis	Different studies		-0.84
Brännlund, Nordström (2004)	Sweden	AIDS[3]	Micro-data		-1.18
Labandeira et al (2005)	Spain	AIDS	Micro-data	1.79	-0.11
Barros, Pietro-Rodriguez (2008)	Spain	AIDS	Micro-data	1.25	-0.82
Asensio et al (2002)	Spain	Probit	Micro-data	0.90	
Sardianou (2008)	Greece	2SLS	Micro-data	0.52	
Aasnes, Larsen (2003)	Norway	2SLS	Micro-data	0.70	

Table 3: results of recent studies on price and income elasticities on car fuel use (source: adapted from Poltimae, 2011)

Table 3 shows that different elasticities between countries exist, even within a country there may be differences (here the example of Spain). These differences may partly be due to regional differences in the samples, differences in income over time (the higher the income, the lower the elasticity) and differences in car prices.

[3] AIDS stands for "Almost Ideal Demand System", an econometric model for estimating consumers demand (as first described by Deaton and Mullbauer, 1980).

A meta-analysis, as shown in Table 4, takes account of these differences and corrects for them. The table shows in more detail the results of one of the studies above (Brons et al, 2008). It shows, firstly, the different impacts that fuel price raise will have on car choice, car ownership, car use. Secondly, for all these impacts, long term elasticities are higher than short term elasticities.

	Short term (1 year)	**Longer term (5 – 10 yr)**
Car possession	-0.08	-0.24
Kilometres driven per car	-0.12	-0.29
Total kilometres driven	-0.2	-0.53
Fuel efficiency	0.14	0.31
Fuel use	-0.34	-0.84

Table 4: Summary of impacts of price changes Source: Brons et al., 2008

3. Economic instruments in the European passenger car sector

This section shows that most EU-27 countries have national taxes related to car registration, car ownership and car use. Nine countries have no registration taxes and five have no taxes on ownership. In recent years, many countries have included a CO_2 component in their taxation systems as well as tax exemptions for certain kinds of AFVs. Most EU-27 countries with above average reductions in CO_2 emissions from new cars have a CO_2 component in their taxation system, whereas the opposite is true for those countries that have a below average reduction in CO_2 from new cars. National subsidies comprise those related to specific technologies, commuting and Research & Development. Local economic instruments are geared towards regulating car use.

In 2007, the European Commission proposed a new strategy to reduce CO_2 emissions from cars up to 120 g CO_2/km by 2012 (EC, 2007), based on a set of measures to influence both the supply and demand sides of the EU market for cars and vans.

One of the main measures of the revised strategy consists of supply-side measures and especially the EU regulation to reduce CO_2 emissions from new cars and vans aimed at reducing the emissions of the new car fleet to 130 g CO_2/km by 2015, a measure expected to improve vehicle motor technology. Additional measures are aimed at further reducing the emissions by 10 g CO_2/km, which include other technological improvements and an increase in the use of renewables. Consumer-side measures are also envisaged, including an amendment to the car labelling directive (European Commission, 1999) and the encouragement of Member States to base road taxes on car CO_2 emissions. The present analysis focuses on economic instruments, mainly on a national level, and their additional impact on decarbonising passenger cars.

The following economic instruments for passenger cars are in place (situation per 1-1-2012) in one or more Member States, either at the national or at the local level. They influence consumer behaviour, and, depending on their design, may reduce CO_2 emissions (even if in certain instances this may not be the specific aim):

- Registration taxes
- Annual road taxes
- Fuel taxes
- Scrapping schemes
- Congestion charges
- Tolls
- Subsidies for consumers (e.g. on cars with a soot filter or on commuting)
- Subsidies for industry (R&D)

3.1. Taxes at national level

Most countries have taxes specifically aimed at buying, possessing and using passenger cars. Currently there is no direct link between these taxes and a recovery of the cost of infrastructure, even if in some instances this may originally have been the purpose. Taxes generate national revenues. Moreover, taxes can be used to provide incentives for consumers to buy less polluting cars by taxing high emitting cars relatively high and low emitting cars relatively low. A problem for national governments that arises from these double-purpose taxes is their possible success. If many consumers buy low emitting cars, tax revenues may decrease. This effect can be countered if definitions and class boundaries for low emitting cars are revised downwards periodically to ensure the necessary level of tax revenue and to maintain incentives to further reduce pollution.

3.1.1. Registration taxes

In the European Union, national registration taxes are based on cylinder capacity, emissions, price, horsepower, length, number of seats or a combination of any or all of these. Nine countries do not have registration taxes. They only apply VAT on new cars (i.e. Bulgaria, the Czech Republic, Germany, Estonia, Lithuania, Luxembourg, Sweden, Slovakia and the United Kingdom) and a relatively small registration fee to cover administrative expenses. Figures 4 and 5 show significant differences in the taxation level for registering a car (value added tax, VAT, excluded) in 13 Member States (for diesel and petrol cars separately). The figures are based on the average cars sold and show that, in general, diesel cars are taxed higher than petrol cars

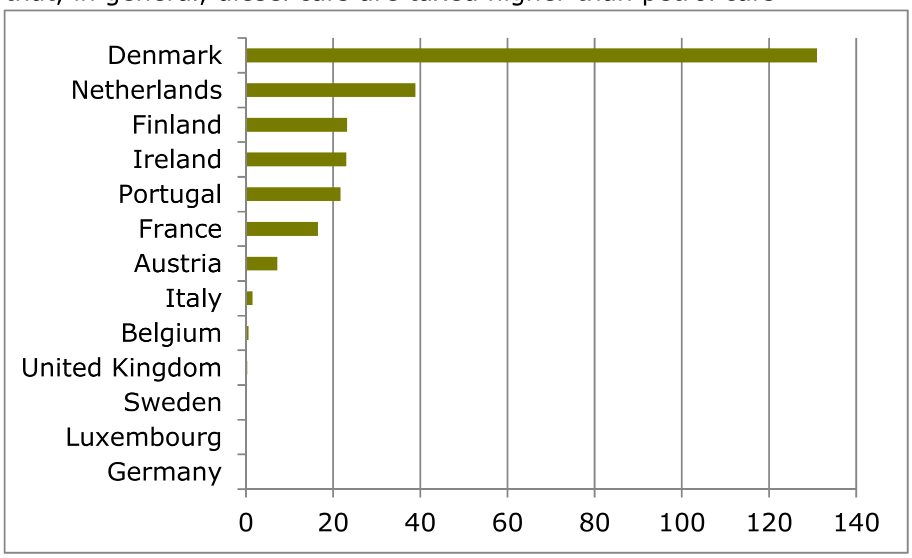


Figure 4: Tax percentage on registration of average sold new diesel cars in 13 European countries, 2010, VAT excluded (source: calculations based on ACEA 2011 and ICCT, 2001)

Note: tax percentages are based on averages, individual cars may have lower or higher percentages depending on the characteristics of the car and the national tax system.

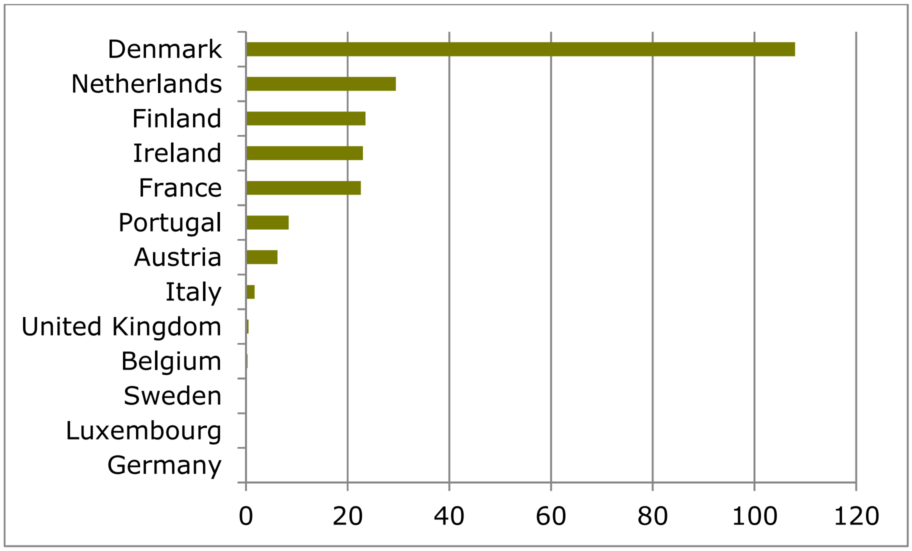


Figure 5: Tax percentage on registration of average sold new petrol cars in 13 European countries, 2010, VAT excluded (source: calculations based on ACEA 2011 and ICCT, 2011)

Note: tax percentages are based on averages, individual cars may have lower or higher percentages depending on the characteristics of the car and the national tax system.

3.1.2. Annual road taxes

In most countries, annual road taxes are based on weight, CO_2 emissions, cylinder capacity, horsepower or a combination thereof. In five countries (i.e. Estonia, Lithuania, Poland, Slovakia and Slovenia) no tax on ownership exists.

3.1.3. Fuel taxes

Figures 6 and 7 show petrol and diesel taxes respectively in EU-27 in 2012. The figures show that some of the Member States with high levels of registration taxes have high levels of fuel taxes as well (Netherlands, Finland, Denmark). Germany and the UK, that have relatively low levels of registration taxes, heavily tax the use of cars.

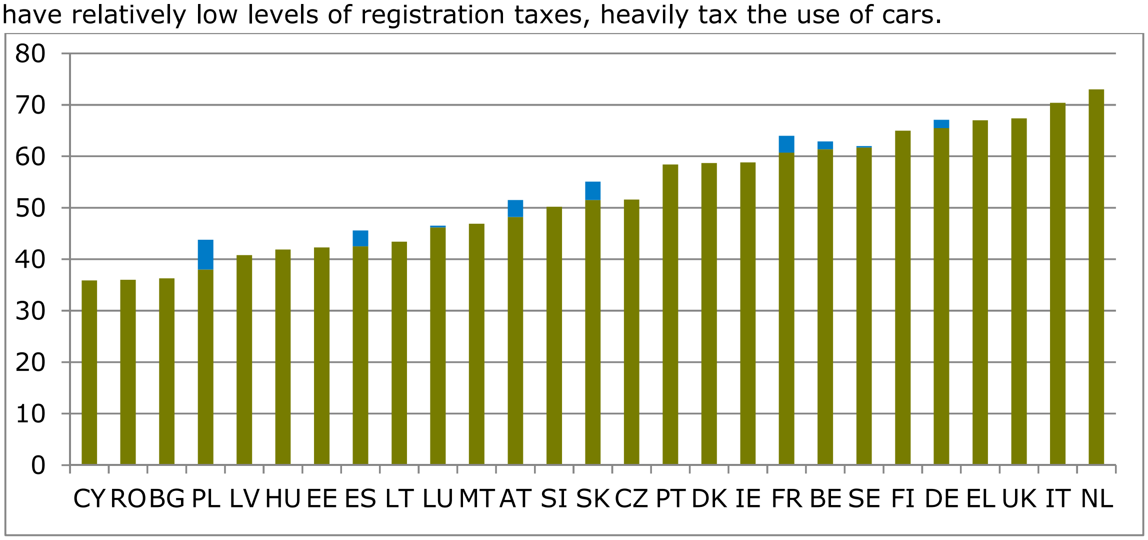


Figure 6: Petrol taxes (in eurocents, octane content <98) in EU 27. Blue bars indicate taxes for fuels with specific sulphur or biofuel content (source: DG Taxud, 2012)

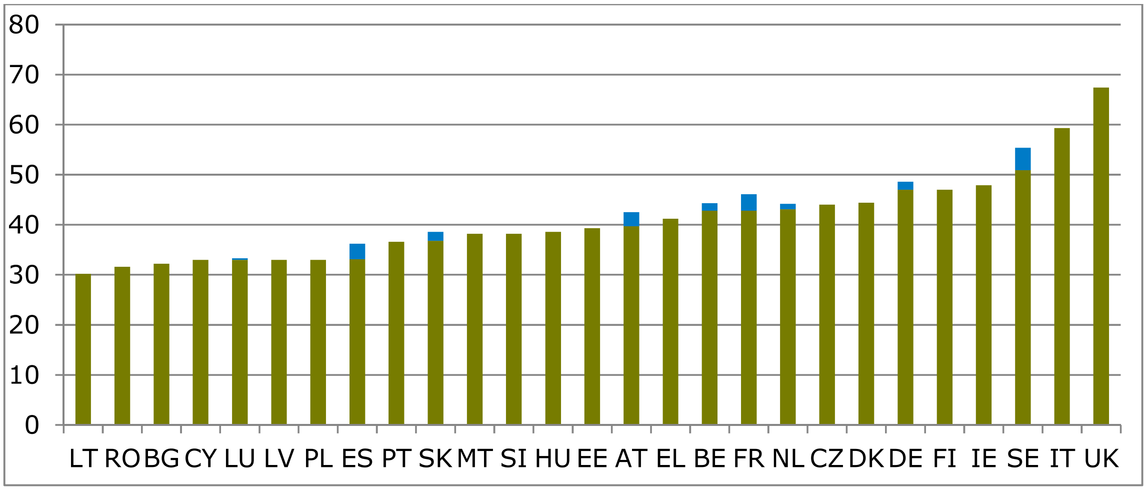


Figure 7: Diesel taxes (in eurocents) in EU 27. Blue bars indicate taxes for fuels with specific sulphur or biofuel content (source: DG Taxud, 2012)

3.1.3. Overview of national taxes

Table 5 shows that the registration tax and the annual tax for passenger cars are a function of the CO_2 emissions per km in many Member States, especially after 2005. At the same time, there are often exemptions for specific types of EVs. Some countries give an additional stimulus for the purchase of EVs by either households or businesses. In some cases measures are also taken at the local level. For information on national or local subsidies and taxes on a local level which may also play a role in the vehicle choice, we refer to the remainder of this section. The information is mainly distilled from the ACEA Tax Guide (2011 edition), IEA (2012) and the Policies and Measures database of EEA, updated with more recent information in some cases.

Concepts

In table 5, different kinds of EVs are mentioned. The following definitions are used here and in the remainder of the document:

- **Battery Electrical Vehicle (BEV)**: BEVs contain a large battery which is the only available power source in the vehicle. BEVs are driven by one or several electric motors. The battery is charged by connecting to the grid, through a normal socket or a charging pole. Currently, typical BEVs have a range of 100 to 180 kilometres.
- **Hybrid Electrical Vehicle (HEV)**: besides an electric motor, an HEV also contains a combustion engine which can often operate either separately or together, depending on the architecture chosen by the manufacturer. During driving, the combustion engine and the electric motor work together to optimize fuel consumption. There is a small battery that is charged and discharged to avoid wasting fuel, e.g. charging to allow braking energy recuperation, or discharging to allow the electric motor to supply additional torque during acceleration. The all-electric driving range of HEVs is very limited (only a few kilometres).
- **Plug-in Hybrid Electrical Vehicle (PHEV)**: a PHEV is an HEV that adds a plug, a charger and a larger battery so it can be charged with electricity from the grid. As with HEVs, different kinds of motor architectures are possible (serial, parallel

or combined line-up of electric motor vs. combustion engine). Here we do not distinguish between PHEVs with smaller and larger battery packs and low-speed and full-speed electric capacities of the vehicle and take them all together as PHEVs since their architecture shows a large level of similarity (battery allowing external recharging, electric motor, internal combustion engine). One generally speaks of PHEVs in terms of their all-electric range (AER) or the number of fossil fuel kilometres that they can replace when fully charged by driving an equivalent PHEV instead of an ICEV: this number is then added as a suffix to denominate the electric range capabilities (e.g., PHEV20). The range of PHEVs is typically between those of HEVs and BEVs.

- **Fuel Cell Electrical Vehicle (FCEV)**: a FCEV uses an electric motor for its propulsion. The electricity is generated on-board in the fuel cell which uses hydrogen that is stored in a pressurised tank within the car. It refuels at a hydrogen gas station. Its range is around 500 km.

	Registration tax				Annual road tax				
Country	**Yes / no***	**CO_2 component?**	**Electric vehicle exemptions**	**comments**	**Yes / no**	**CO_2 component?**	**Electric vehicle exemptions**	**comments**	**Other economic instruments**
Austria	Yes	Yes: since 2008; before: fuel consumption	The purchase of vehicles exclusively powered by electricity is exempt from NoVA tax for new vehicle purchases	The Normverbrauchsabgabe (NoVA) tax depends on fuel consumption and incorporates a bonus-malus system depending on emissions per km of CO_2, NO_x and particles, and depending on engine	Yes	Partially	Vehicles exclusively powered by electricity are exempt from the motor-based insurance tax		
Belgium	Yes	Yes: since 2008 (with changes over time)	PHEV, hydrogen powered and exclusively electric powered vehicles are exempt from the registration tax in Flanders - In the two other regions and for leased cars, the registration tax is based on fiscal horsepower	- In Flanders the registration tax for cars registered by a private individual or a company car owned by the company itself, takes into account the CO_2 emissions per km, fuel type, vehicle age and registration year; - The Walloon region operates a bonus-malus system for private purchasers that favours vehicles with relatively low CO_2 emissions (up to a certain maximum catalogue value that depends on the propulsion system)	Yes	No			<u>Subsidies on technology:</u> Companies: - 120% deductibility of electric cars - Social contribution on the income in kind related to the private use of a company car depends on the CO_2 emissions per km Households - Value of benefit in kind for company cars depends

									on CO_2 emissions. - Personal income tax deduction of 30% of the purchase price, with a maximum of €9,190 for the purchase by a private person of cars, multi-purpose cars and minibuses exclusively powered by an electric motor - Personal income tax deduction of 40% of investment by a private person in electric charging facilities outside his house, with a maximum of €250
Bulgaria	No	n.a.			Yes	No			
Cyprus	Yes	Yes: since 2005		The registration tax and registration fee depend on cylinder capacity and CO_2 emission rate	Yes	Yes		The road tax is reduced by 15% for vehicles with < 150 g CO_2/km	<u>Subsidies on technology:</u> - Subsidy of €683 for the purchase of

									new cars with less than 120 gCO_2 /km and of electric cars. - Subsidy of €1,196 for hybrid vehicles.
Czech Republic	No	n.a.			Yes	Partially	Electric, CNG, LPG, hybrid and E85 vehicles are exempt from the road tax		
Denmark	Yes	Yes	- BEV and FCEV are exempt from the registration tax until the end of 2015	- The registration tax depends on fuel consumption compared to standard fuel consumption	Yes	Yes: since 2001	- BEV and FCEV are exempt from the annual tax until the end of 2015	- The annual green owners' tax is based on fuel consumption and fuel type.	<u>Subsidies on technology:</u> The benefit in kind related to private use of a company car incorporates an environmental fee equivalent to the green owners' tax
Estonia	No	n.a.			No	n.a.			
Finland	Yes	Yes: since 2008		Purchasing tax promotes low-emission vehicles	Yes	Yes: since 2011	Lower taxes for PHEVs and BEVs	Annual tax promotes low-emission vehicles	<u>Fuel taxes:</u> Tax levels for transportation fuels are based on energy content, CO_2 emissions and local air quality.
France	Yes	Yes: since 2008	Regions may exempt electric and hybrid	- The registration tax is determined at the regional level and	Yes	Yes: since 2009	Green vehicles (vehicles driving	Ownership tax: - Vehicles	

			vehicles partially or totally from this tax	depends on the fiscal power rating, which is a function of the engine power and the CO_2 emissions per km. - Annual eco-label for the average CO_2 emissions per km of passenger cars on new vehicles with a bonus-malus system that favours vehicles with relatively low CO_2 emissions			exclusively or not on electricity, LPG and E85 fuel) are exempt from this tax	with high CO_2 emissions per km pay a malus - tax on company cars depends on CO_2 emissions per km	
Germany	No	n.a.			Yes	Yes: since 2007	- EV owners (cars fed entirely or predominantly from mechanical or electrochemical energy stores) are exempt from the circulation tax for a period of 5 years. After that the tax for EVs will depend on the weight.	- The circulation tax on passenger cars consists of a base tax that depends on cylinder capacity and a CO_2 tax.	
Greece	Yes	No			Yes	Yes: since 2011	For cars registered up to 31/10/2010: - hybrid and hydrogen powered vehicles with	For cars registered after 31/10/2010: The circulation tax depends on the CO_2	

							engine capacity ≤ 1,929cc and electric vehicles are exempt from circulation tax - hybrid and hydrogen powered vehicles with engine capacity > 1,929 cc pay only half of normal circulation tax	emissions per km. It is zero for cars with up to 100 g CO_2/km	
Hungary	Yes	Yes	Electric and hybrid (Euro V) cars pay a lower registration tax		Yes	No			
Ireland	Yes	Yes: since 2008	- Relief from paying the vehicle registration tax: up to €1500 (hybrid vehicles), €5000 (BEV) and €2500 (PHEV)	- The tax rate of the vehicle registration tax for passenger cars depends on the CO_2 emissions per km. The tax rate is applied to the Open Market Selling Price of the vehicle	Yes	Yes: since 2008		For private cars registered after 1/7/2008 the ownership tax depends on the CO_2 emissions per km	Subsidies on technology: - €5000 grant for PHEV and BEV in addition to vehicle registration tax relief - Companies: accelerated capital allowances are available for companies purchasing cars with low CO2 emissions

									- Companies: 20% VAT deduction for purchase of car primarily used for business purposes and with CO_2 emissions < 156 g/km
Italy	Yes	Yes	Some regions levy a lower tax for registration and transfer acts for LPG, CNG or electric vehicles or vehicles with CO_2 emissions <120 g/km		Yes	Partially	Exemption from ownership tax for electric vehicles in the first 5 years after the first registration and exemption of 75% afterwards in some regions		Local measures: Financial incentives for the purchase of EVs in a number of municipalities, often combined with the definition of measures to limit or ban the circulation of additional polluting vehicles
Latvia	Yes	Yes: since 2010	Electric cars are exempt from this tax	Motor vehicle registration tax depends on CO_2 emissions per km	Yes	No			
Lithuania	No	n.a.			No	n.a.			
Malta	Yes	Yes: since 2009			Yes	Yes			
Luxembourg	No	n.a.			Yes	Yes: since 2009		Annual tax depends on the CO_2 emissions	Subsidies on technology: Prime CAR-e programme:

								per km	- €750 for cars with CO2 emissions ≤ 100 g/km (160 g/km for specific conditions). - €1,500 for cars with CO2 emissions ≤ 90 g/km This subsidy will be abolished in 2013 - €5 000 for 100% electric cars and cars with CO_2 emissions ≤ 60 g/km (e.g. PHEV). This subsidy will be reduced in 2013. For the 100% electric cars the subsidy is paid only if one has a 100% renewable energy contract.
The Netherlands	Yes	Yes: since 2006	Tax exemption for EVs and FCEVs	- Registration tax consists of a net list price component and a CO_2	Yes	Yes: since 2009	- EVs and FCEVs are exempt until	- Road tax depends on dead-	<u>Subsidies on technology:</u> For leased cars,

				component. - Tax exemption for gasoline cars ≤ 110 g CO_2/km and diesel cars ≤ 95 g CO_2/km			2015	weight, type of fuel, region and CO_2 emissions per km	the income in kind that is related to the use of the company car for private purposes depends on the CO_2 emissions per km. It is zero for electric cars or hybrids without a diesel engine. Criteria will become stricter in the future.
Poland	Yes	No			No	n.a.			
Portugal	Yes	Yes: since 2006	BEV are exempt from this tax	The car tax consists of a cylinder capacity component and a CO_2 emissions component	Yes	Yes: since 2009	BEV are exempt from this tax	- The circulation tax consists of a cylinder capacity component and a CO_2 emissions component	Subsidies on technology: - €5,000 for the first 5,000 EVs - Corporate tax deduction for fleets that include EVs Local measures: - Preferential parking areas for EVs in city centres
Romania	Yes	Yes: since 2009	- No registration tax on electric and hybrid vehicles	- CO2 dependent	Yes	No			

Spain	Yes	Yes: since 2008		The tax rate of the special tax is determined by the regional governments and depends on the CO_2 emissions/km	Yes	No			<u>Subsidies on technology:</u> Regional governments provide subsidies for the purchase of cars with alternative energies
Slovakia	No	n.a.			No	n.a.			
Slovenia	Yes	Yes: since 2011			No	n.a.			
Sweden	No	n.a.			Yes	Yes: since 2006	- Green cars (including a.o. electric cars): exemption during 5 years; whether a car is a green car depends on the CO_2 emissions, PM emissions, fuel or electricity consumption	- Vehicle taxes are based on several factors, including weight, fuel and CO_2 emissions per km	<u>Subsidies on technology:</u> - As from January 2012 super-clean-car rebate: €4300 euro for cars that do not emit more than 50 g CO_2/km - Tax reduction on income in kind related to private use of company cars for EVs or HEVs <u>Local measures:</u> - Some local authorities have reduced parking charges for eco vehicles - PHEV and EV

									are exempt from the congestion charging scheme in Stockholm
United Kingdom	No	n.a.			Yes	Yes: since 2001	-	- Vehicle excise duty rates depend on CO_2 emissions/km. - Vehicles with < 100 g CO_2/km are exempt from vehicle excise duty - The first year rate of VED is zero for cars ≤130 g CO_2/km	<u>Subsidies on technology:</u> - Company car taxation: tax depends on CO_2 emissions; employers and employees are exempt from income and national insurance contributions for electric cars and vans; the fuel benefit charge for company cars depends on the CO_2 emissions - Businesses can relieve the entire cost of cars < 110 gCO_2/km, electric cars or electric vans against taxable profits in the year of registration - Plug-in car

									grant: 25% of price of a qualifying car with a maximum up to £5000 - Plug-in van grant: 20% of price of a qualifying van with a maximum up to £8000 <u>Local measures:</u> - London congestion charge: vehicles < 100 g CO_2/km are exempt - Some local authorities provide exemptions or a reduced parking charge for electric cars

Table 5: Economic instruments for encouraging fuel efficient and electric cars in EU Member States as of 1-1-2012

** registration fees covering administrative expenses are not considered*

n.a. = not applicable

Source: ACEA (2011), IEA (2012), Belgian FPS Finance, Belgisch Staatsblad and Luxembourg Ministry of Sustainable Development and Infrastructure (www.car-e.lux), Zimmermannova (2012)

Given the aim of this report, Table 5 focuses on economic instruments. For a survey of other measures to promote EVs (e.g. funding of research programmes, setting up of charging infrastructure, regulatory measures), we refer to IEA (2012).

3.2. Subsidies at national level

In addition to taxes, different kinds of subsidies exist at national level.

3.2.1. Scrapping schemes

The goals of car scrappage schemes are generally twofold: improvement of air quality and support of the national car industry. The effects of the scrappage policies on CO_2 emissions are not clear and are highly dependent on the detailed design of the scheme and of possible rebound effects. The effects reported consist in either a slight decrease or increase in CO_2 emissions (Van Wee et al., 2011). The effects of the additional manufactured cars (lifecycle impacts) may be significant and entail an increase in the life-cycle emissions. Other effects reported consist in higher road safety and impacts on car manufacturing industries (car sale boosts).

Equity concerns are often raised as the cash-for-replacement schemes might exclude people who cannot afford to buy a new car, despite the incentive. This means that the system would fail to cover a significant share of old cars. Most of the effects are observed within the first two years of the scheme. The strength of the effects is predominantly determined by the subsidy level.

Some other observations on car scrappage schemes (Nemry et al. 2009) are:

- Scrappage schemes are successful only if future cars emit considerably less than old models, so that additional emissions from car manufacturing and End of Life are offset.
- Unless the policy is permanent, the effects are temporary. Car sales increase only during the period the policy is maintained. After the end of the period, car sales drop. The observed emission reductions during the policy implementation period rapidly disappear after it is no longer in place.
- As an age limit is generally introduced, some people tend to delay the envisaged scrappage. This may result in a drop in car sales and car scrappage, just before the start of the scrappage program.
- Some people tend to buy a bigger car than the car they had before. They may also travel more with the new car (e.g. due to enhanced reliability, higher energy efficiency)

Around 2009, several countries introduced some form of scrapping scheme. Currently, only France has a limited scrapping scheme (i.e. a bonus of 300 euros is given if the purchase or lease of a new vehicle with CO_2 emissions of 110 g/km and less is combined with the scrapping of a vehicle aged 15 years or more (ACEA, 2011).

3.2.2. Subsidies to promote innovation

To speed up the introduction of new, cleaner or more fuel-efficient technologies, these technologies are often (mostly temporarily) subsidised at national level, either through tax exemptions or directly by means of a consumer discount on the product. Examples in the recent past are subsidies on soot-filters. AFVs are currently subsidised in many countries (e.g. electric and hybrid vehicles). For a more in depth overview of these subsidies, we refer to Table 5 and Section 6.

3.2.3. Subsidies for commuting

Some countries subsidise commuting by way of tax exemptions. This clearly enhances transport demand and therefore CO_2 emissions.

For instance, employers in the Netherlands can currently compensate their employees for commuting expenses by up to 0.19 EUR/kilometre without paying taxes, regardless of the transport mode and the distance travelled. Abolishing this subsidy is currently being discussed. Research findings on the potential impacts of the abolishment are summarised in Table 6. They clearly point towards a decrease in transport demand.

passenger kilometres by car	Passenger kilometres by public transport	Vehicle hours lost
-2% to -4%	-2% to -5%	-10% to -15 %

Table 6: Impacts of abolishment of commuting subsidy (Hilbers et al., 2012)

3.2.3. Subsidies for industry (R&D)

The car industry may, under strict conditions (i.e. maintaining a level playing field) receive subsidies for research and development (e.g. for electric vehicle technology). In this report, this is not elaborated further, as industrial policy falls outside the scope of this research.

3.3. Taxes and subsidies at local level

A variety of regulations exist on a local level. Some of the main categories are mentioned here to provide a complete overview of existing economic instruments.

3.3.1. Tolls

In many countries, road users have to pay a toll or buy a vignette before they are allowed to drive on certain roads. Table 7 provides an overview of the existence of tolls and vignettes in Europe.

country	Toll on highways	Toll on bridges/tunnels	Vignette
Croatia, France, Hungary, Italy, Norway, Portugal, Poland, Slovakia, Spain	x		
Austria, Bulgaria, Czech Republic, Hungary, Macedonia, Montenegro, Romania, Slovakia, Slovenia, Switzerland			x
Belgium, Denmark, Netherlands, Sweden, UK		x	

Table 7: existence of tolls and vignettes in Europe (source: http://en.wikipedia.org/wiki/List_of_toll_roads and own verification)

Both vignettes and tolls put a price on infrastructure use. Prices may vary according to environmentally related car characteristics to influence consumer behaviour. Tolls usually apply to a one-time use of a particular piece of infrastructure, whereas vignettes are valid for a certain period (usually a year) for all motorways.

Since there is no relationship between vignette ownership and infrastructure use, a vignette once purchased does not provide incentives to reduce car use. Consumers may even increase their use of the infrastructure to make sure they 'get the most out of their money'.

3.3.2. Congestion charges

Use related charges have been on the policy agenda for several decades. Singapore was the first to implement the Electronic Road Pricing system in 1998. In the cities of London, Stockholm and Milan similar schemes were introduced in 2003, 2007 and 2008 respectively. The main reasons for introducing these use related charges are to improve accessibility in heavily congested urban area and to improve air quality. Li and Hensher (2012) give an overview of the effects of the congestion charging schemes in these cities (see Table 8). The reduction in car traffic amounts to 15% to 20% in all four cities. The use of public transport increased substantially. Results for air quality are less clear. For London no consistent evidence of improved air quality resulting from the congestion charging scheme was found (Kelly et al, 2011,). For Stockholm and Milan positive effects on air quality are reported (Borjesson 2012; Rotaris et al. 2010).

Impact of the projects		Congestion charging schemes		
	London	**Stockholm**	**Milan**	**Singapore**
Reduction in traffic (vehicles four or more wheels) entering the zones in charging hours	18%	Trial: 22% after implementation: 18%	14.2% (23% during morning peak hours)	40-45% (area licensing scheme) 15% electronic road charging
Reduction in cars entering the zones in charging hours	33%	Not available	Not available	70%
Change in traffic beyond charging hours	Observed peak traffic after charging hours in the first year, normalised in the coming years	Observed peak traffic after charging hours in the first year, normalised in the coming years	Observed peak traffic after charging hours	+23%
Change in traffic round the charging zone	-5%	+10%	-3.6%	Not available
Change in traffic in the inner road	+4%	+5%	Not available	Not available
Increase in speed inside the charging area	30% (from 14km/h to 18 km/h)	30-50% (33% in the morning peak hours)	4%	20%
Change in speed in the inner road	Not available	Not available	Not available	- 20%
Increase in bus speed inside charging area	6%	Not available	7.8% attributed to charging zone in combination with bus lanes	Not available
Increase in the use of public transport	Above 7 % totally, 37% in bus passengers entering the zone	9%	6.2% totally, 9.2% in metro passengers	21%

Table 8: Effects of congestion charging schemes (source: Li and Hensher, 2012)

3.3.3. Parking fees

To use the scarce space in the inner city efficiently and to improve urban quality, most European cities have a scheme of parking fees in their (inner) cities. A variety of different schemes exists, such as with or without free parking for electric vehicles, and reduced tariffs for inhabitants or handicapped. It falls outside the scope of this report to elaborate on this aspect.

4. Analysis of the role of taxes in decarbonising the fleet

Based on data on new car sales in 14 countries in the period 2001-2010, this section shows that:

- A 10% increase in weight accounts for about 8.4% increase in CO_2 emissions, whereas a 10% increase in engine capacity accounts for an increase in CO_2 emissions of 0.8%. Increase in engine power does not significantly increase CO_2 emissions.

- in the 2001-2010 period, due to weight increase only, diesel- and petrol-fuelled cars became less fuel efficient, by 6% and 2%, respectively.

- Corrected for fuel type, weight, engine capacity and engine power, cars have become some 23% more fuel efficient in that period. This is due to technological progress.

- Using registration taxes to affect the shares of diesel and petrol cars appears to work, while annual road taxes and fuel taxes only have smaller and less reliable effects.

- An increase in income and an increase in the number of cars per person or household both lead to substantial increases in the number of kilometres driven per person. Increasing fuel prices, however, has a negative effect on kilometres driven. For each 10 eurocents increase in fuel price the number of car passenger kilometres per capita decreases by about 260 per year. Using fuel taxes is clearly effective in reducing the number of car kilometres per person, ceteris paribus.

EU policy is one of the drivers behind the observed decarbonisation of the European car fleet. The economic crisis and national taxation systems are others (see e.g. Kieboom 2010 for an analysis for the Netherlands). The question remains to what extent national taxation systems, as described in the previous section, have supported the *observed* decarbonisation of the passenger car fleet in Europe.

Section 4.1 analyses the mechanisms behind the decarbonisation, using descriptive statistics. The next section (4.2) deals with the influence of taxation systems on these mechanisms, based on econometric modelling techniques (random effect panel estimates) to isolate the influence of taxes on the observed decarbonisation of the fleet. The advantage of using random effect estimates is that they show the magnitude of certain factors (for instance taxes) and their statistical significance corrected for other relevant factors and taking into account variation in time and space. Annexes 1 and 2 provide a detailed description of the data and methods used in chapters 4 and 5.

4.1. Drivers of decarbonisation

The share of AFVs in of total new sales in Europe is small (0.1 – 0.3 % from 2001-2006). After a peak of 3.8 % in 2009, the share of AFV in new passenger car sales dropped to 1.4 % in 2011 (EEA, 2012), caused mainly by the significant drop in new LPG vehicle-registrations in France and Italy. While chapter 6 deals specifically with AFVs, this chapter focuses on the remaining 98.6 % of new passenger car sales, i.e. petrol and diesel cars in 14 countries for which data were available (i.e. Austria, Belgium, Denmark, Finland, France, Germany, Greece, Italy, Ireland, Luxembourg, the Netherlands, Portugal, Sweden, United Kingdom).

Figure 8 shows CO_2 emissions of new cars in these 14 countries between 2001 and 2010. The average emission of newly bought passenger cars dropped from 169 g CO_2/km in 2001 to 143 g CO_2/km in 2010 in the 14 countries. Especially since 2007, emissions were reduced considerably.

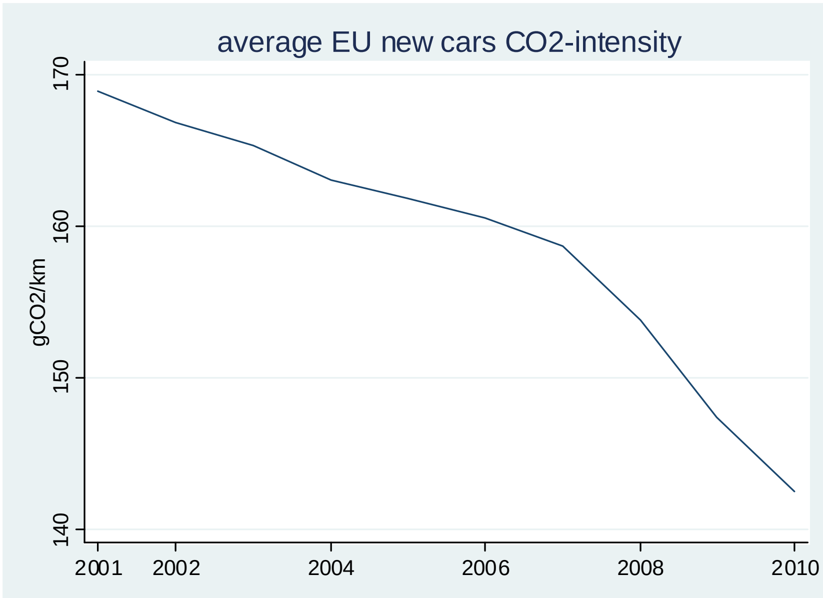


Figure 8: average CO2 emissions from new cars in 14 EU-countries (source: ICCT data)

There are two main mechanisms that can explain the improved efficiency. First, through technological change, all car types may have become more fuel-efficient. Second, consumers may have changed their behaviour (see also Chapter 2) by moving towards more fuel-efficient types. They may have decided to buy a hybrid or a diesel car instead of a petrol car or, within a fuel-type, consumers may have chosen more fuel-efficient sub-types, e.g. by buying lighter cars.

4.1.1. Improving fuel efficiency via technology improvement

There is noteworthy variation between countries in diesel and petrol efficiency improvements. A large part of this variation can be explained by differences between countries and years in the cars' features, such as weight, engine size, and horse power. We estimated the effect of these attributes on CO_2-emissions by linear regression. Results are shown in Table 9. The table shows that a 10% increase in mass increases the CO_2 emissions per kilometre driven almost one-on-one, by about 8.4%. A 10% increase in engine size increases CO_2 emissions by about 0.8%. Engine power is insignificant. These findings are well in line with the analysis by Kieboom et al. (2010) of Dutch new car sales between 1998 and 2007, albeit that they found a somewhat larger contribution of engine capacity (2% to 3% rise in CO_2 emissions at a 10% increase in engine capacity). Although there are country specific differences in car fleet, it is reasonable to assume that the relationships found hold for other European countries as well. It means that without the observed increase from 2010 to 2011 in average weight (from 1364 kg to 1384 kg, EEA, 2012), average CO_2 emissions would have been 1.5 %, about 2 g/km, lower.

For cars with the same mass and engine capacity, a diesel vehicle has about 23% lower CO_2 emissions. The variation unexplained by mass, engine and fuel type features, nor by the time-trend, is 2.5%.

	Ln(gCO_2/km)	**p-value**
Mass [Ln(kg)]	0.84	0.000
Engine capacity	0.08	0.027
Engine power	0.00	0.888
Diesel	–0.23	0.000
Time-fixed effects	Yes	
Country-fixed effects	No	
N	319	
R-within	0.88	
Sigma_e	0.025	

Table 9: Relation between CO_2 emission/km, engine capacity, engine power, mass and fuel-type (source: PBL- regression analysis of ICCT-data)

When corrected for the findings of the table above, Figure 9 shows the first mechanism, efficiency improvement. Each line represents CO_2 emissions per fuel type for one country over the years, corrected for weight, engine capacity and engine power. It shows that diesel and petrol cars both became in average some 23 % more fuel efficient over the 10 years, showing the same pattern for diesel and petrol.

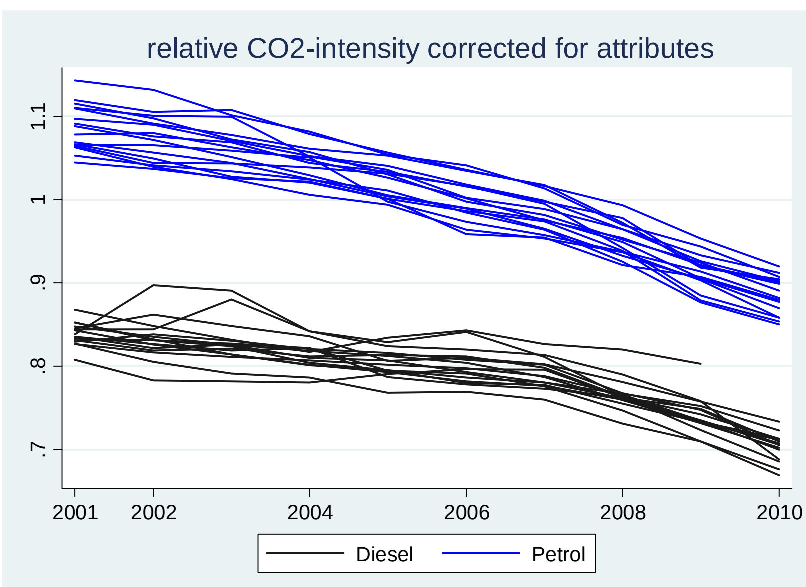


Figure 9: average CO2 emissions per country per fuel type in the 14 EU-countries, corrected for weight and cylinder capacity (source: analysis of ICCT-data)

4.1.2. Improving fuel efficiency via consumer choice

Fuel shift

The second mechanism, adaptation of consumer choice by shifting fuel type, is illustrated by the last column of Table 10. Diesel and petrol both account for about half of sales in the 14 EU-countries, with a slight increasing trend towards more diesel sales. As diesel cars emit less CO_2 than petrol cars, ceteris paribus, the increasing share of diesel cars would mean a reduction of CO_2 emissions.

Lighter cars

Consumers may also change their behaviour by buying lighter (or heavier) cars as shown in Table 10. Although there is a huge variation between the 14 countries, diesel cars are on average heavier than petrol cars. Furthermore, diesel cars became some 7 % heavier in the period 2001-2010, whereas petrol cars only gained 2 % in weight. Similar findings can be observed throughout Europe, with an increase in weight in 2011 for both diesel and petrol cars (EEA, 2012). Based on our findings, an increase in weight obviously counteracts decarbonisation efforts.

	weight of diesel car	weight of petrol car	% diesel
2001	1409	1192	37
2002	1425	1197	48
2003	1437	1207	51
2004	1448	1225	49
2005	1466	1232	50
2006	1495	1237	52
2007	1509	1236	54
2008	1505	1237	54
2009	1501	1219	48
2010	1513	1220	54

Table 10: Average weight (in kg) of new petrol and diesel cars in 14 EU-countries and the share of diesel 2001-2010 (source: ICCT, 2011)

4.2. Influence of national taxation systems on decarbonisation

Having analysed the underlying mechanisms (technological improvement, customers choosing to shift fuel or buy lighter cars), the questions remains what influence national taxation systems have on the observed decarbonisation. The next section deals with that topic. In section 4.2.1 we focus on the impact of taxation systems on fuel shift, as this can be one of the ways to decarbonise the fleet (see section 4.1.2.). In section 4.2.2. the impact of taxation systems on car use is analysed.

4.2.1. Influence of national taxes on share of diesel cars in new car sales

Because essential data were missing for Greece we excluded Greece from our analysis, implying we have 130 observations (10 years for 13 countries). As diesel fuelled cars emit less CO_2 than petrol fuelled cars, the dependent variable in our model is the share of diesel cars. We use the random effects panel estimator for our analysis, i.e. we estimate random effects per country (the fixed effects model produces similar results).

Variable	**Coeff.**	**Standard error**	**p-value**
Constant	0.501	0.057	0.000
2002 (d)	0.048	0.030	0.111
2003 (d)	0.095	0.031	0.002
2004 (d)	0.143	0.032	0.000
2005 (d)	0.179	0.035	0.000
2006 (d)	0.269	0.042	0.000
2007 (d)	0.314	0.046	0.000
2008 (d)	0.334	0.046	0.000
2009 (d)	0.326	0.042	0.000
2010 (d)	0.370	0.045	0.000
GDP per capita (ln and centred)	-0.222	0.136	0.103
Difference in sales price (in 1,000 euros)	-0.030	0.005	0.000
Difference in annual road tax (in 1,000 euros)	-0.013	0.106	0.903
Difference in fuel price (in euros)	-0.026	0.174	0.883
NOBS	130		
R2 adjusted	0.437		

Table 11: modelling results of diesel share and the influence of income, sales price, annual road tax and fuel price on the share of diesel (source: analysis based on ICCT, Eurostat and ACEA-data); d= dummy variable

As explanatory variables we include a dummy (0/1) variable for each year in the sample (with 2001 included in the constant), GDP per capita in purchase power standards[4], and

[4] Data on income per capita in PPS (Purchase Power Standards) were readily available from Eurostat from 2002 onwards. For the reference year 2001 we assumed GDP was equal to GDP in 2002. For modeling reasons (to avoid 'meaningless' GDP per capita dummy variables with value 0, we used logarithmic GDP per capita values which were then centred around the mean GDP per capita).

the absolute differences in sales price, annual road tax and fuel price (at the pump) between diesel and petrol cars.[5] Estimation results are presented in Table 11.

The pattern found for the different years in the sample indicates that diesel cars have become more popular over the years, as indicated by the rising coefficient in the second column. This pattern is statistically significant (last column) and is independent of changes in income, sales prices, annual taxes and fuel prices and other differences between countries, as these factors have been controlled for in the model. Differences in fuel price and annual road tax have decreasing effects on the share of diesel cars, but both effects are small and statistically insignificant. Sales price differences on the other hand have a substantial negative and statistically significant effect on the sales share of diesel cars. Using a registration tax to increase the sales price of a diesel car relative to its petrol counterpart by 1000 euros, decreases the share of diesel cars in new car sales by 3%. In other words, using registration taxes to affect the shares of diesel and petrol cars appears to work, while annual road taxes and fuel taxes only have small and highly unreliable effects.

4.2.2. Influence of national taxes on car use

We estimated a model on car passenger kilometres. Data on car passenger kilometres, number of cars and population were obtained from Eurostat. The dependent variable in this model is the number of car passenger kilometres per year (in thousands) divided by the population, resulting in car passenger kilometres per capita per year. As explanatory variables we include a constant, GDP per capita, the number of cars per capita, and fuel price. The latter is a weighted average of petrol and diesel fuel prices, with the respective new car sales shares used as weights. Although it is preferable to use petrol and diesel shares in the total car fleet as weights, these data are not readily available for the countries used in the analysis. Estimates are presented in Table 12 (fixed and random effects per year produce very similar estimates).

Variable	b	Standard error	p
Constant	9.29	1.08	0.000
GDP per capita (ln and centred)	3.02	1.14	0.009
Number of cars per capita	9.25	2.27	0.000
Weighted fuel price (in Euro)	-2.62	0.76	0.001
NOBS	73		
R2 adjusted	0.200		

Table 12: OLS estimates on car passenger kilometres per capita per year (in thousands) (source: analysis based on ICCT, Eurostat and ACEA data)

The results show that GDP per capita and number of cars per capita have strong positive effects (column b) on the number of car passenger kilometres per capita. These effects

[5] We also used percentage differences in sales price, annual tax and fuel price, but the model with absolute differences performed better in terms of explanatory power and also produced more plausible results.

are statistically significant (see column p). Stated differently, an increase in income and an increase in the number of cars per person or household both substantially increase the number of kilometres driven per person. Increasing fuel prices, on the other hand, have a statistically significant (last column) negative effect on kilometres driven (column b). For each 10 cents increase in fuel price the number of car kilometres per capita decreases by about 260 kilometres per year. Using fuel taxes is effective in reducing the number of car kilometres per person, ceteris paribus, whereas fuel taxes are not effective in influencing prospective car buyers in the decision whether to buy a diesel or a petrol fuelled car. These findings are in line with the fuel price elasticities discussed in chapter 2. They are corrected for the influence of the current economic crisis, as most of the influence of the crisis is reflected in the impact of the explanatory variable GDP per capita.

5 Analysis of co-benefits for air pollutant emissions

This section shows that policies to decarbonise the passenger car fleet may have positive or negative impacts on air emission policy, depending on the instruments used and the mechanisms involved.

Positive impacts can be expected from policies aimed at:

- consumers buying lighter cars: a 10 % weight decrease will reduce NO_x emissions by 3 % to 4 %
- reducing car use: a 10 % reduction in car use will lead to a 10 % reduction in polluting emissions. Fuel taxes, commuting subsidies, and, at local level, congestion charges, parking fees and tolls are the instruments that directly affect car use

Negative impacts may be expected from policies aimed at:

- consumers switching from petrol to diesel

Positive or negative impacts may be expected, depending on the technology involved, from policies aimed at:

- improving fuel efficiency by improving technology. Electric vehicles have clear advantages in terms of NO_x reduction.

Policies for decarbonising the transport sector may have benefits or trade-offs in other areas. The challenge lies in designing an effective decarbonising policy while maximising benefits in other sectors. The present analysis focuses on NO_x and PM10, as data are readily available for these substances (be it test cycle data only, see chapter 1).

In the previous section we discerned two mechanisms for improving the efficiency of new cars. First, through technological change, all car types may become more fuel-efficient. Second, consumers may change their behaviour by moving towards more fuel-efficient types, e.g. from petrol to hybrid or diesel cars or by buying lighter cars. In this section we will analyse which impacts on air emissions can be observed in the 14 European countries in the 2001-2010 period via these different pathways. We used the same data as in the previous chapter. The results of the analysis can be used when designing new climate and air policies, focusing on their interlinkages.

5.1. Improving the fuel efficiency of new cars

Improved fuel efficiency in traditional petrol and diesel cars can have impacts on the emissions of polluting substances. In general, one is inclined to say that using less fuel means emitting less NO_x and PM10 as well, ceteris paribus. Moreover, cars need to comply with the European emission-standards (Euro standards, expressed in microgram/km). Therefore, the improved fuel efficiency of certain technologies may be counteracted by less efficient air emission abating technologies. Whether the improved fuel efficiency leads to positive or negative impacts depends on the mechanism involved.

5.1.1. Improving fuel efficiency via technology improvement

Direct injection, one of the means to improve fuel efficiency and to reduce CO_2 emissions, is known to have negative impacts on air polluting emissions. Vice versa, progress in the field of air polluting emission reduction may have impacts on CO_2 emissions.

The EU has made considerable progress on reducing emissions of NO_x and PM10, mainly due to the implementation of Euro-standards, enforcing technological progress in the field of air emission abatement technologies (by optimising the combustion in the engine and by exhaust after-treatment by means of soot filter or catalysts). Figure 10 shows a considerable decrease in the average NO_x and PM10 emissions from new cars throughout the years in the same 14 EU countries as in Section 4. The technological progress that drives this emission decrease is not completely without trade-offs for CO_2 emissions. The use of soot filters and catalysts may lead to a decrease in fuel efficiency (van den Brink et al., 2004, Carslaw, 2005).

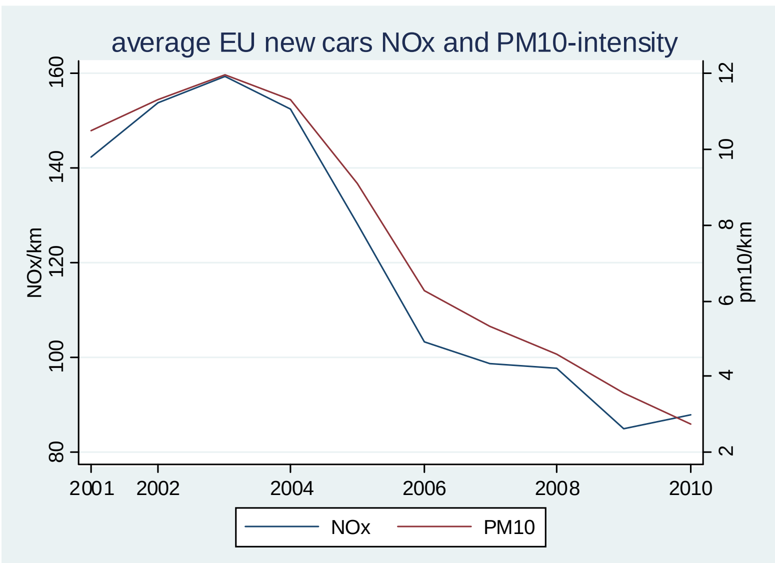


Figure 10: Average PM10 and NO_x emissions for 14 EU countries

AFVs were excluded from our analysis because of their small sales share. However, they are a technology type that in the long term might considerably add to decarbonising the transport sector (see Chapter 6). What their impact will be on polluting emissions depends largely on the type of AFV.

Differences in NO_x emissions between conventional and hybrid cars cannot be clearly determined. Available data show great variability which currently cannot easily be attributed to hybrid vehicle advantages (Helms et al, 2010). Schwingschackl (2009) arrived to similar conclusions, based on the PHEM model by the University of Graz (see Figure 11) The figure also illustrates that plug-in hybrids with range extender and full electric cars will have clear advantages in terms of NO_x-emissions as compared to ICEVs.

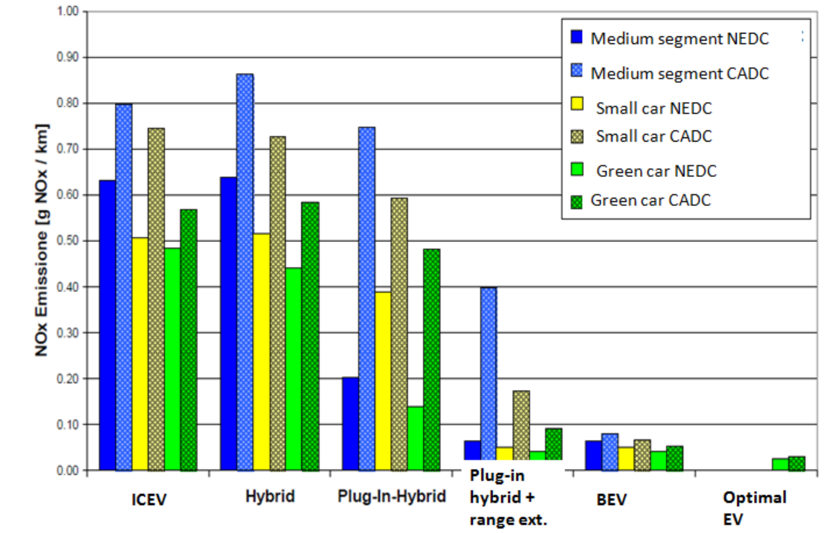


Figure 11: NO_x emissions/km by ICEV and different types of AFVs under two types of testing procedures, NEDC and CADC (Schwingschackl, 2009)

5.1.2. Improving fuel efficiency via changes in consumer choice

Fuel shift

Consumers may be inclined to buy more fuel efficient cars as a reaction on economic instruments favouring such cars. In general, AFVs and diesel cars are more fuel efficient than petrol cars. Diesel cars emit much more NO_x and PM10 per kilometre driven than petrol cars, as shown in Figures 12 and 13. This explains the initial increase in NO_x and PM10 emissions between 2001 and 2003, when the share of diesel vehicles increased substantially. A decarbonisation policy resulting in a dieselation of the fleet therefore may have trade-offs in terms of increased emissions of NO_x and PM10.

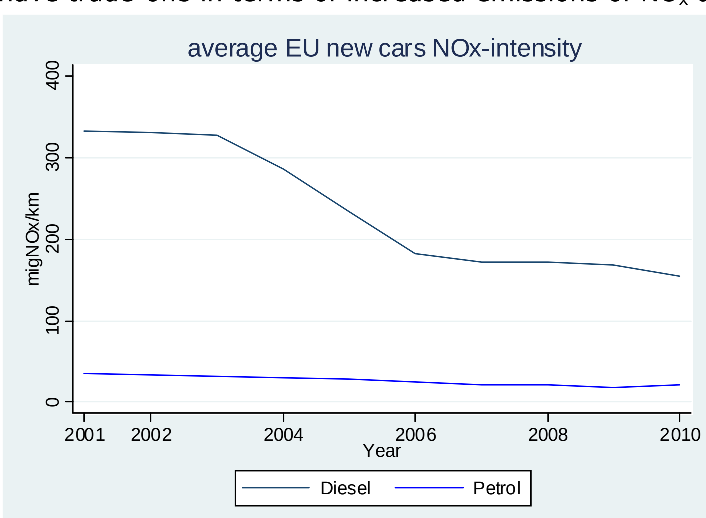


Figure 12: Average new car NO_x emission for 14 EU countries

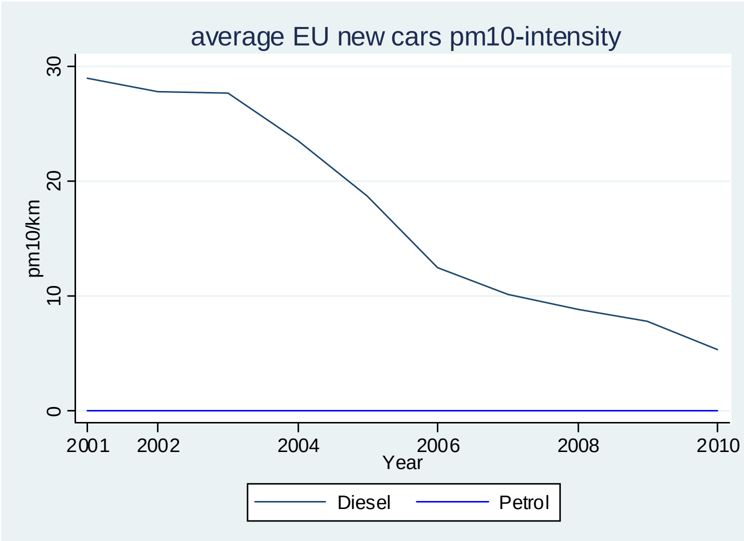


Figure 13: Average new car PM10 emission for 14 EU countries

Indeed, as Table 13 shows, for every percentage point increase in the share of diesel cars, the average vehicle NO_x emissions increase by 240 units, and the average vehicle PM10 emissions by 20 units. In relative terms, if the share of diesel increases by 1 per cent, NO_x emissions increase by 0.42%, and PM10 emissions by 0.92%.

	NO_x	**PM10**	**NO_x double-log**	**PM10 double-log**
Share of diesel	240 (0.000)	20 (0.000)	0.42 (0.000)	0.92 (0.000)
Time-fixed effects	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes
N	160	160	160	160

Table 13: relation between share of diesel and emissions of NO_x and PM10 (analysis based on ICCT data)

Buying lighter cars

A second type of behavioural response relevant for decarbonisation policy is consumers moving towards more fuel-efficient cars within the same fuel type, e.g. by buying lighter cars. This might have distinct co-benefits in terms of polluting emissions. The relationship between weight and air pollutant emissions is however not clear. It is sometimes argued that new cars are tuned as to just comply with their Euro-standard. Lighter cars would indeed use less fuel, but not necessarily have less air pollutant emissions, as producers might cut a bit on air pollutant abatement technology as well.

To analyse the relation between weight and emissions, we used the Dutch RDW-database, which contains detailed temporal data on emissions and weight for thousands of different European model types of passenger cars. A regression analysis was performed on cars sold in 2003 (Euro 3) and cars sold in 2011 (Euro5). We used double-logs as model specification. In double log form the estimated regression coefficient can be interpreted as elasticity. The results are shown in Table 14.

	Euro 3			**Euro 5**		
	elasticity		**significance**	**elasticity**		**significance**
petrol	-0.15	N=8160	0.530	0.309	N=7868	0.000
diesel	0.348	N=379	0.025	0.397	N=5344	0.000

Table 14: Results of regression analysis on the relation between NO_x emission and weight per Euro-class of (source: PBL, using RDW database)

The regression analysis shows that within the Euro-3 class, there is a positive and statistically significant relation between weight and NO_x emissions for diesel cars only. A 10 % weight increase for diesel cars will result in a 3.5 % increase in NO_x emissions.

Within the Euro-5 class, this relation is even more statistically significant for both petrol and diesel. A 10% increase in weight will result in 3% and 4 % more NO_x emissions for petrol and diesel cars respectively. Therefore a decarbonisation policy geared towards influencing consumers to buy lighter cars, will in most cases have co-benefits in terms of reducing air pollutant emissions.

Reducing car use

A third type of behavioural response, as explained in Chapter 2, could be a reduction in car use. Policies aimed at reducing greenhouse gases in the transport sector by reducing car use always have co-benefits on air emissions as well. Economic instruments in place that directly affect car use are fuel tax and commuting subsidies, and at a local level congestion charges, parking fees and tolls (see Section 3 and 4)

6. Cross-sectoral analysis for electric vehicles

Costs and benefits of EVs compared to ICEVs vary significantly between studies. This may be due to methodological as well as local differences (e.g. in tax system). Most studies conclude that EVs are cheaper for the individual if oil prices are high, many short trips are undertaken (high mileage) and recharging opportunities are plentiful. An increased use of EVs puts more pressure on the electricity generation, especially if recharging takes place during peak hours. In that case, new power plants would need to be built to provide additional peak power. With off-peak charging, much of the previously unused capacity can be efficiently employed. The environmental benefits from an increased level of EVs improves when electricity is generated from renewable sources. The profitability of providing V2G services is highly dependent on the characteristics of the power market that is considered, since this will determine the level of the capacity payment (if any) and the energy payment. Estimates also depend on the assumptions about for example vehicle characteristics, connection capacity, the participation rate of the vehicles, battery costs and the saturation rate of the market. It is therefore very difficult to draw generalised conclusions. Finally, none of the studies surveyed here have made full cost-benefit analyses. Even when emission impacts (local pollutants or greenhouse gasses) or other external effects are considered, the benefits are not expressed in monetary terms.

6.1. Introduction

Aim and approach

According to IEA (2011) 'the next decade is a key "make or break" period for electric vehicles and plug-in hybrid electric vehicles: governments, the automobile industry, electric utilities and other stakeholders must work together to roll out vehicles and infrastructure in a coordinated fashion, and ensure that the rapidly growing consumer market is ready to purchase them.' Many EU Member States have put into place economic instruments to promote the uptake of electric vehicles (EVs). However, their uptake is still limited (see below).

This chapter considers some of the barriers to the introduction of EVs and analyses whether the interactions between the electric vehicle fleet and the electricity sector may offer potential to lower these barriers.

Chapter 6.2 presents the state of deployment of EVs. Various factors affect the decision to buy an EV or not, one of which is economic considerations. By using economic instruments, governments try to influence the decision process of prospective car buyers by altering the elements of their cost-benefit analysis.

Chapter 6.3 discusses the relevant literature on the cost-benefit calculations of the introduction of the electric vehicles on the market. We distinguish between two broad groups of studies: a first group exclusively focuses on the private cost of EVs (sum of the upfront investment costs and operational costs during the lifetime, taking into account taxes and subsidies). Its outcome will co-determine whether it is interesting for an individual or a company to buy an electric vehicle or not. Secondly, we consider a number of social cost-benefit analyses. Such studies try to assess firstly the social cost of reducing CO_2 emissions by promoting EVs and secondly whether the promotion of EVs is attractive from the social rather than private point of view.

Chapter 6.4 considers the interactions with the electricity sector in depth. Firstly, in the case of electrification, CO_2 emissions may be shifted from transport to the electricity sector. The reduction of CO_2 by the promotion of the EVs will depend on the size of the EV fleet, the loading patterns of the vehicles and the characteristics of the power generation sector. Secondly, the costs and benefits of EVs will change if vehicle-to-grid services are used. We will discuss how these aspects may lower the barriers for EVs. The interactions between the light vehicle fleet and the electricity sector were also explored in Hacker et al. (2009). In this report we take their analysis as a starting point, but consider a number of more recent studies as well, focusing more on the economic analysis. Other cross-sectoral issues are not explored any further, such as the implications of increased levels of electrification on the markets of rare earth materials (lithium, neodymium, yttrium, lanthanum etc.) that are important for batteries and electric motors (Hacker et al., 2009; Offer et al., 2010). Moreover, the environmental issues related to the production, use and recycling of these materials fall beyond the scope of our analysis.

The literature review aims to provide guidance on the importance of including the impacts on other sectors in the evaluation of electric car policies, to give a qualitative description of these impacts and to summarize how they could be included in future exercises.

6.2 Overview of economic instruments for encouraging electric vehicles

Table 15 provides statistics about the deployment of EVs and HEVs in a selection of EU countries (IEA, 2012). It is clear that in 2011, the share of EVs and HEVs was still very small. The same is true for the new vehicle registrations in 2011 (Table 16). Table 17 presents the ambitions that are put forward by a number of EU Member States, based on IEA (2012).

	EV fleet	**HEV fleet**	**Total fleet**
Austria[a]	353	4,792	4,441,027
Belgium	321		5,241,089
Denmark	845	695	2,200,000
Finland	76 (EV) + 9 (PHEV)	3,973	2,958,568
Germany[b]	2,307	37,256	42,302,000
Ireland[a]	44	5,325	1,952,522
Italy[a]	404	27,159	36,751,711
The Netherlands	1,124	71,937	8,597,000
Portugal	233		4,515,500
Spain	367	32,865	22,277,244
Sweden	366	21,389	4,401,352

Table 15: Passenger car fleet in a selection of EU Member States: Total, EV and HEV fleet (situation on December 31, 2011, unless otherwise stated)

a: December 31, 2010; b: January 1, 2011
Source: IEA (2012)

Country	New EV registrations	Share of EV in total new registrations	Country	New EV registrations	Share of EV in total new registrations
Austria	631	0.18%		597	0.66%
Belgium	281	0.05%		5,443	0.31%
Bulgaria	0	0.00%		0	0.00%
Cyprus	164	1.12%		306	0.61%
Czechia	56	0.03%		0	0.00%
Germany	1,566	0.05%		0	0.00%
Denmark	365	0.21%		847	0.15%
Estonia	56	0.33%		89	0.03%
Spain	386	0.05%		203	0.13%
Finland	28	0.02%		5	0.01%
France	2,677	0.12%		155	0.05%
				12	0.02%
Greece	0	0.00%		19	0.03%
Hungary	325	0.69%		1,088	0.06%
				15,299	0.12%

Table 16: New passenger car registrations in 2011 in EU Member States: EV registrations and share of EV registrations in total registration, preliminary data

Source: EEA (2012)

	Goals
Austria	250,000 two-axle EVs (including PEVs) by 2020 (National Energy Strategy of 2010)
France	replace 2 million ICEVs by EVs and hybrids by 2020
Germany	1 million EVs and 500,00 fuel-cell-powered vehicles by 2020
Ireland	10% of all passenger cars will be electric by 2020
Netherlands	1 million EVs by 2025
Spain	70,000 EVs by the end of 2012 and 250,000 by 2014
Sweden	By 2030 Sweden should have a vehicle fleet that is independent of fossil fuels

Table 17: Goals for the introduction of EVs in a selection of EU Member States

Source: IEA (2012)

6.3. Private and social cost-benefit analyses of electric vehicles for the transport market

The attractiveness of EVs can be analysed both from a private and a social point of view. One of the factors that prospective car buyers will take into account is how the private cost of an EV compares with that of a comparable ICEV. Here we focus on this economic decision process, keeping in mind that other factors (e.g. driving range, safety issues, uncertainty about standards, image building) may also play a role. The private cost will be influenced, *inter alia*, by the economic policy instruments that are in place. The private cost benefit analysis is relevant for the determination of the likely uptake of EVs. Alternatively, one can compare the social cost of reducing a tonne of CO_2 by the promotion of EVs with that of taking other measures.

Private lifecycle cost of electric vehicles

To get an idea of the economic attractiveness of buying an electric vehicle, all upfront investment costs (e.g. related to vehicle, battery, registration tax) and all types of operational costs (e.g. related to fuel, insurance, maintenance) can be compared with the costs related to a corresponding ICEV. For example, Offer et al. (2010) conducted such an exercise for BEVs, FCEVs and Fuel Cell Hybrid Electric Vehicle (FCHEVs). Their analysis revealed that BEVs and FCHEVs will probably be the cheapest vehicles (on a lifetime basis) by 2030. The results display a clear preference towards FCHEVs, in which the hydrogen fuel cell is used as back-up capacity (range extender) when the batteries (rechargeable from the grid) are depleted. The authors expect this vehicle architecture to be relatively cheap (small battery pack and small hydrogen tank) while providing significant savings over short-distance trips.

Werber et al. (2009) found BEVs to be competitive to ICEVs when the battery capacity remains within certain limits. Indeed, the shorter the required range, the smaller the BEV battery cost will be. BEVs are therefore at the moment interesting as long as they are used for short trips.

Other authors are much more sceptical regarding the cost advantages of BEVs (Prud'homme, 2010). The 'private surcost' of a BEV (the extra private cost of a BEV compared to an equivalent ICEV) is calculated to be around €12,000 on a lifetime basis (for a 2010 BEV in France). This cost disadvantage can only be avoided by combining a substantial drop in BEV purchase costs (e.g. a massive decline in battery cost) with an increase in the electric efficiency and a significant spike of oil prices. Crist (2012) extends this exercise to a comparison of three BEV types with their ICEV counterparts, using recent price figures for BEVs available on the market (data from Renault). Taking into account a subsidy of €5,000 and depending on the car segment considered, the BEV surcost is €4,000 to €5,000 over the vehicle's lifetime. With higher daily mileages (e.g. 90 km/day), he finds a benefit of €4,000. The latter case often involves breaking through into very specific niches (high daily mileages, frequent deliveries, frequent charging opportunities) comparable to those considered by Werber et al. (2009).

Other authors investigated the private lifecycle costs of PHEVs and HEVs. The conclusions of Shiau et al. (2009) regarding PHEVs are similar to the ones made by Werber et al. (2009) on BEVs: these vehicles are cost-competitive with ICEVs when the battery capacity (and consequently, the battery cost) stays within certain limits. PHEVs with an all-electric range of around 11 km are found to be the most cost-effective solution. On the other hand, Simpson (2006) found that a convincing case for PHEVs can only be made when assuming a scenario of significantly higher fuel prices and a massive drop in battery costs.

Lipman and Delucchi (2006) exclusively focus on private lifecycle costs of HEVs and compare them to the cost of an equivalent ICEV. They conclude that a mild hybrid (i.e., equipped with regenerative breaking, idle stop & go, and the electric motor merely as power assistance to help the ICE) with some advanced fuel-saving modifications (reduced weight and rolling resistance, transmission modifications, and gasoline direct injection) performs best of all HEV categories considered in terms of lifecycle costs.

The conclusions drawn from each of these analyses strongly depend on the assumptions made by each of the authors. To increase the comparability, Table 18 summarises the most important assumptions made in the baseline scenarios. The table shows that the baseline assumptions greatly differ on some points. For the sensitivity analyses on these baselines, we refer to the specific articles. In general EVs become more attractive when gasoline/diesel prices increase, electricity prices fall, battery costs fall or when people have a higher mileage (consisting of frequent shorter trips). With a higher discount rate the attractiveness of EVs rises if battery costs are paid annually, and falls when battery costs are paid at the time of purchase of the vehicle.

Study	Annual mileage (miles)	Vehicle life (yr)	Gasoline price	Electricity price	Battery price	Discount rate (%)
Offer et al. (2010)	100,000 (total)	n/a	2-4.5 USDUSD/gallon (2010-2030)	0.13 USDUSD/kWh	1,000-250 USDUSD/kWh (2010-2030)	0
Werber et al. (2009)	15,000	12	USDUSD3/gallon	0.104 USD/kWh	500 USDUSD/kWh	7
Prud'homme (2010)	10,000 km	15	Oil: 75-170 USD/barrel (2010-2025)	0.11 USD/kWh	455 USD/kWh	4
Crist (2012)	11,000-23,400 km	15	Oil: 90-203 USD/barrel (2012-2027)	0.1229 €/kWh	495 €/kWh	4
Lipman & Delucchi (2006)	n/a	15	1.46 USD/gallon	n/a	225 USD/kWh	3.9
Shiau et al. (2009)	12,500	12	3 USD/gallon	0.11 USD/kWh	1,000 USD/kWh	5
Simpson (2006)	15,000	n/a	3 USD/gallon	0.09 USD/kWh	n/a	0

Table 18: Baseline assumptions of private lifecycle cost studies of electric vehicles

Social costs and benefits of electric vehicles

Apart from the costs and benefits to the car owners and users, the social desirability of EVs can only be assessed if additional elements like external and indirect effects are taken into account.

Impacts on the external costs of transport

The electrification of transport could reduce carbon dioxide (CO_2) emissions, in that way mitigating global warming. However, the effectiveness of such a strategy depends on the carbon intensity of the electricity sector (Prud'homme, 2010). Crist (2012) stresses the importance of the carbon intensity of marginal electricity generation rather than average electricity generation (the latter largely influenced by the baseload source used). In countries where the majority of additional electricity is generated by coal or gas, the CO_2 benefit from switching to BEVs is not a priori clear. This pitfall could be largely overcome by exploiting baseload capacity as much as possible (i.e. shifting battery charging to off-peak periods). For France, Crist (2012) finds that the CO_2 emission reduction potential from the switch from a ICEV to a BEV ranges from 18 to 50 tonnes of CO_2 over the vehicle's lifetime, depending on the specific model and mileages considered. The net impacts on CO_2 emissions will be considered in detail in Section 6.4.

Air pollution is another external cost category. None of the studies included in this literature review thoroughly focuses on this aspect, except for Prud'homme (2010) and Crist (2012) who explicitly use monetary values of air pollution[6] in their social cost calculations.

Noise is a transport externality that is often overlooked. Nevertheless, at low speed, EVs emit considerably less noise than ICEVs (see Figure 14). A substitution of the existing fleet by EVs could significantly improve noise levels in urban, densely populated areas (Lipman and Delucchi, 2006). A total electric passenger car fleet could lead to a 30 % reduction of noise annoyance in urban areas (Verheijen and Jabben, 2010). Because of their low noise emissions at low speeds, it is being debated whether EVs are more dangerous than ICEVs for cyclists and pedestrians in urban traffic. Although, to date, no convincing evidence exists, Japan and the United States are preparing legislation that obliges EVs to add sounds at low speeds.

In literature, the link between the electrification of the fleet and energy security is often mentioned (Offer et al., 2010; Shiau et al., 2009; Simpson, 2006; Werber et al., 2009). ICEVs exclusively depend on fossil fuels and by shifting to EVs, the degree of oil dependence could be significantly reduced. The extent of the reduced level of oil dependence will depend on the country-specific electricity mix.

[6] Prud'homme (2010) uses a cost for local pollution of €0.006/km driven, whereas Crist (2012) uses a higher value (€0.01/km).

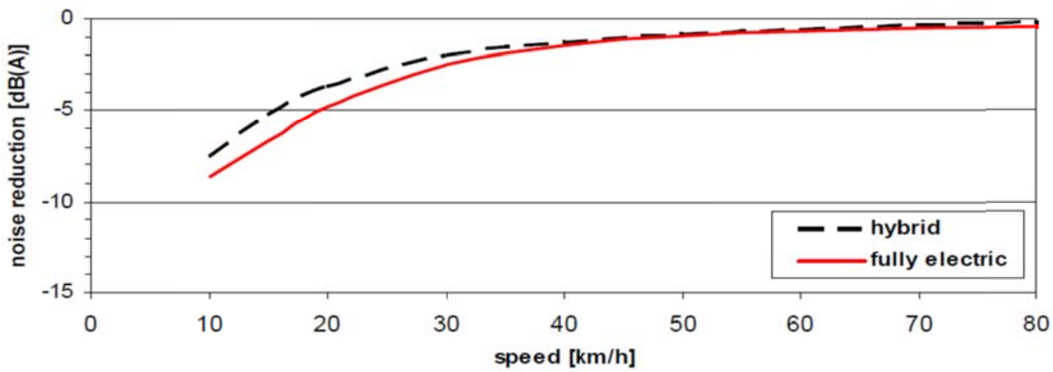


Figure 14: Noise emission reduction of electric and hybrid vehicles at different speeds, compared to ICEV, which serves as the reference with 0 dB(A) reduction

Source: Verheijen & Jabben, 2010

Other impacts

A wide-spread introduction of EVs is sometimes seen as an opportunity to foster domestic economic growth (Shiau et al., 2009). New markets indeed create new business opportunities. Strong competition can be expected between the countries/world regions that are active in this high tech sector.

If no fossil fuel subsidies are in place, the negative budgetary impact may be another relevant element as a result of missed fuel tax revenues and subsidies awarded to buyers of EVs (Prud'homme, 2010; Crist, 2012). This revenue loss will have to be compensated by increasing other taxes or by reducing government spending in other areas.

Results

Prud'homme (2010) and Crist (2012) find that for the baseline scenarios the social surcost of a BEV is currently higher than the private surcost: €14,000 in the first study (for a 2010 BEV in France) and €7,000 (compact van) to €12,000 (sedan and compact model) in the second one (for a 2012 BEV in France). In order to assess the cost-effectiveness of EVs for reducing carbon emissions, this social surcost needs to be divided by the CO_2 reduction that can be realised by replacing the ICEV by and EV. For the sedan and compact models considered by Crist (2012) the cost per tonne of CO_2 abated ranges from €500 to €700. Figure 15 presents the results of the sensitivity analysis for the compact model. The first bar gives the social cost per tonne of CO_2 abated under the baseline assumptions. The other bars give the cost if one or more of the baseline assumptions are changed. For example, if the ICEV purchase price is 20% higher than in the baseline, the social cost per tonne of CO_2 abated drops from approx. 700 euro to approx. 500 euro. The graph shows that for the most typical scenarios in the sensitivity analysis the social costs of CO_2 abatement by means of BEVs continues to be high.[7] It drops significantly with a high annual mileage or when the purchase costs of ICEVs increases, while that of the BEV and the battery falls. Similarly, a compact van that drives a lot of kilometres is found to have a relatively low cost per tonne of CO_2 abated (about €140/tonne of CO_2).

[7] Note that when the CO_2 content of electricity is high (as in the EU coal case), the social cost per tonne of CO_2 abated is very high, as the social surcost of the BEV is then divided by a very low reduction in CO_2 emissions.

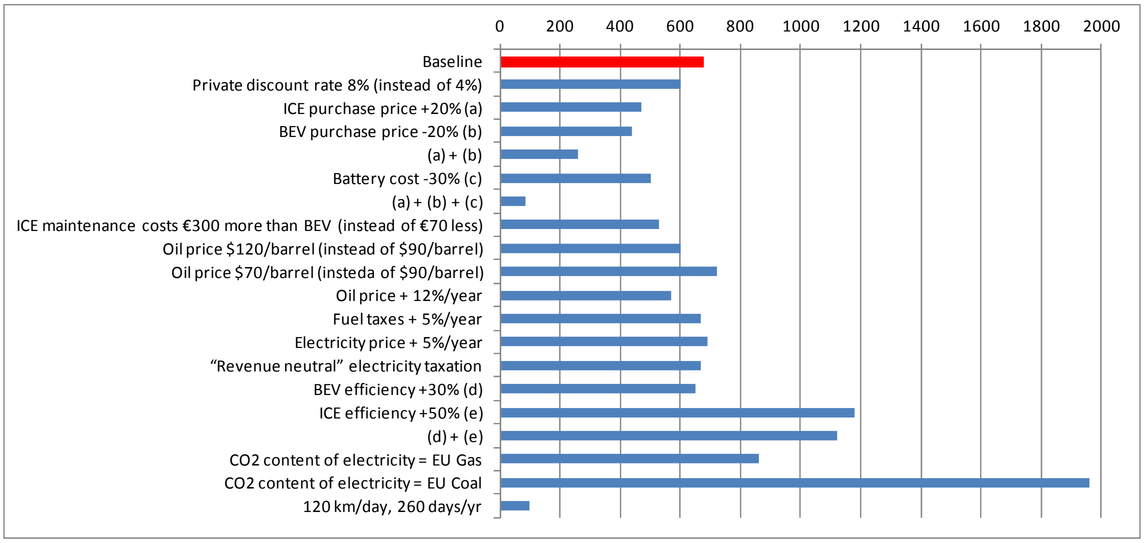


Figure 15: social cost per tonne of CO_2 abated (euro): sensitivity analysis for a 5-door compact BEV (Crist, 2012)

6.4. Cross-sectoral impacts of the electrification of the light vehicle fleet

Introduction

In this section we consider the interactions between the light vehicle fleet and the electricity generation sector and the implications for the reduction of greenhouse gases. At this moment the two energy systems are still separate. However, as envisioned by Kempton and Tomić (2005b), the two systems may converge towards each other in the following ways: "(1) the vehicle fleet will provide electricity storage and quick-response generation to the electric grid, (2) electricity will complement or displace liquid fuel as an energy carrier for a steadily increasing fraction of the vehicle fleet, and (3) automated controls will optimize power transfers between these two systems, taking into account their different but compatible needs for power by time-of-day".

EVs may produce benefits for the electricity generation system. Efficiency gains may be realised if the vehicles can be charged in a smart way. In the long term, the vehicles can also provide so-called vehicle-to-grid (V2G) services when they do not drive[8]. This could be a market mechanism through which EVs could become more attractive and provide synergies with other public policies.

Various possibilities can be envisaged for the V2G services (Kempton & Tomić, 2005b). The most expensive and therefore least interesting option is to increase the battery size beyond what is required for the transport function of the vehicle. A second option, which may be more interesting economically (see below), is that the V2G services are rendered by fleets of vehicles with known and fixed schedules. A third option is to draw V2G services from a large group of separate vehicle owners, using intelligent controls. The smart grid technology that should make all of this possible is discussed in Morgan (2012).

[8] Blom et al. (2012) perform a social cost-benefit analysis of the gradual implementation of smart grids – which would make possible the provision of V2G services – in the Netherlands as from 2020. They show that the benefits would outweigh the costs and discuss the steps that need to be undertaken to realise such a system.

Concepts

A distinction can be made between different power markets that are each controlled in real time by the grid operator: baseload power, peak power and ancillary services (Kempton & Tomić (2005a). Baseload power is the bulk power generation that runs round-the-clock. Peak power refers to power that is generated during periods with predictable high demand. The ancillary services are used to maintain grid reliability, balance supply and demand and support the transmission of electricity from the seller (producer) to the purchaser (consumer). Of relevance here are mainly spinning reserves and regulation. In a European context regulation corresponds approx. to primary reserves and spinning reserves to secondary reserves. Spinning reserves are a type of operating reserves that can be called upon quickly in case of failures. They are used only for a limited number of times per year and must be able to last up to one hour. Regulation is used to fine-tune the frequency and voltage of the grid by ensuring a match between load demand and generation. In the case of regulation up, power generation is increased, while with regulation down it is reduced. Compared to spinning reserves, regulation is used more frequently (many times a day), has to be able to respond much faster (within less than a minute) and is used for shorter durations. EV could also provide emergency back-up power to home residents. However, this is not considered further in this report.

The next paragraphs discuss the implications of the convergence between the two energy systems for the electricity sector and the carbon emissions of the electricity sector and light vehicle fleet. We also present some estimates of its consequences for the cost-benefit analysis of EVs by considering the revenues that EV owners could obtain by providing V2G services. Unfortunately, to our knowledge, no studies are available providing a social cost-benefit analysis taking into account all of these aspects.

Impact on power system and carbon emissions

EVs offer the potential to increase the efficiency of the national energy system, to help reducing CO_2 emissions and to enable the system to integrate large shares of renewable energy. The additional benefit is that transport related energy demand would also be (partly) captured by the EU's emission trading scheme.

The impacts on the power system and the CO_2 emissions can be expected to depend highly on the generation mix. The charging regime and the use of V2G services also play a role.

We illustrate these aspects by a number of recent studies[9], showing the main mechanisms that are at work and looking at the interaction with renewable energy. The studies considered here give information on the impact on emissions, not on the associated social benefits.

For the US State of Texas, Sioshansi and Denholm (2009) shed light on the impact of V2G services on the electricity generation system and the emissions of CO_2, SO_2 and NO_x, for different penetration rates of PHEVs. Here we consider a 15% share for PHEVs. The PHEVs are taken to be fully loaded in the morning, but the timing of the charging is optimised in order to improve the efficiency of the electricity generation.

When the PHEVs do not provide V2G services, they lead to an increase in the CO_2 (+1.17%) and SO_2 (+0.86%) emissions by electricity generation. The NO_x emissions

[9] For an overview of other studies, see Hacker et al. (2009).

during the non-ozone season also rise (+0.86%), while they fall during the ozone season (-1.59%), thanks to load shifting and improvements in generation efficiency through flexibility in PHEV charging. Note that for capped emissions, an increase means that this must be compensated elsewhere, while a decrease results in permits that can be sold.

When the PHEV fleets are used for providing spinning reserves, the emissions of the three pollutants are mostly reduced as compared to the case without V2G. This is because the PHEVs diminish the need for electricity production in Texas by natural gas fired generators. An implication is that the impact is larger for CO_2 and NO_x than for SO_2. With the V2G services the increase in CO_2 emissions can be limited to 0.86%. When taking into account that the PHEVs replace ICEVs, the net impact is that the SO_2 emissions rise, due to the increase in generator emissions from vehicle charging loads, 22% to 33% of which is provided by coal fired generators. The CO_2 emissions fall, as do the NO_x emissions during the ozone season.

Another study that illustrates the importance of the electricity mix and the charging schemes, relates to Great Britain in 2030 (G4V project, 2011a). It pays attention to the interaction between renewable energy and EVs. Without EVs the projected generation capacity in the 2030 the GB-power system would consist of gas (35%), wind (35%), coal (20%) and nuclear (10%), and approx. 8% of wind energy is curtailed[10]. The EV shares are varied between 0% and 100%. In all scenarios electricity production costs (excl. capital costs and battery degradation costs) are minimised, given a required level of system reliability and respecting various constraints. Since CO_2 emissions are capped, an opportunity cost of CO_2 emissions is included in the fuel costs (with higher CO_2 emissions permits need to be bought). EVs may be used for primary, secondary and tertiary reserve.

The charging strategies turn out to be very important. Uncontrolled charging leads to a net increase in CO_2 emissions (after accounting for the avoided emissions of ICEVs) because in the GB-power system of 2030 the additional electricity would be delivered mainly by coal fired plants. At a 50% EV share the CO_2 emissions would rise by approx. 5%.

With controlled charging, charging is spread across periods of low net demand. This reduces peak demand and ensures a maximal use of conventional plants at low marginal cost. Compared to uncontrolled charging, less additional capacity is required, thanks to the modest rise in peak demand and the better use of wind energy. Less additional capacity is needed with bidirectional (i.e. with EVs both charging from the grid and providing electricity to the grid) than unidirectional charging. Wind curtailment is reduced substantially and more so with bidirectional charging. At a 50% share of EVs the wind curtailment is brought down to 1-2%. It is also found that the two controlled charging strategies converge at high EV shares. As there is less wind curtailment and the additional electricity is produced by gas fired units, net CO_2 emissions fall, and more so for bidirectional charging at lower levels of EV penetration. With a 50% share of EVs the net CO_2 emissions are reduced by approx. 20%.

The importance of taking into account the local conditions when designing the tariff scheme for charging is illustrated by a study for Spain, Portugal and Greece in 2020 (Merge project, 2012). With more modest shares of EVs than the previous two studies (0.5% to 2%), it simulates the impacts of charging tariff profiles that are the same in the three countries, whereas Spain and Portugal have the highest wind curtailment during the night and Greece during the day. The resulting equivalent CO_2 emission rate of an EV

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[10] Wind curtailment means that some or all of the turbines within a wind farm are shut down.

is found to be 70-82 g/km for Spain, 24-43 g/km for Portugal and 159-187 g/km for Greece. This means that there will be a net reduction in emissions when replacing an ICEV by an EV in Spain and Portugal, while in Greece the net impact on CO_2 emissions will be small or negative depending on the ICEV that is replaced.

When intermittent renewable energy sources provide a large share of power supply, matching fluctuating supply with fluctuating demand will require additional resources (Kempton & Tomić, 2005b; Morgan, 2012). Without the contribution of the light vehicle fleet, the cost of renewable electricity can be high. The cost and emissions would be lower if the EVs provide services to the grid. Back-up could be realised by means of fuelled vehicles (fuel cell and hybrid running motor generator). Storage could be provided by BEVs and PHEVs.

Kempton & Tomić (2005b) estimate how many vehicles would be required in the US to provide support to the grid in case of a large share of photo-voltaic (PV) or wind energy. If PV provides most of US peak power, there is a need for storing electricity from the solar peak to the load peak. They estimate that if 26% of the fleet were BEVs under V2G contract, a minimum storage buffer requirement 0.75 to 1h could be realised, assuming that all vehicles are available half of the time. If wind power provides one half of total US electrical energy, the resulting increase in regulation needs (minute to hour fluctuations) could be met if 3.2% of the light vehicle fleet were BEVs. For operating reserves (spinning and non-spinning) the minimum shares depend on the vehicle technology: 8% (FCEV), 38% (BEVs) and 34% (PHEV driving in charge sustaining mode). Ensuring 20% of firm capacity (dedicated storage) could be met when FCEVs have a share of 23%.

A study for Denmark in 2020 by Lund & Kempton (2008) gives additional insights into the synergies between BEV and renewable energy sources. In an energy system with a high share of combined heat and power (CHP), they vary the amount of wind power between 0 and 45TWh/year. Once again the outcomes of the introduction of BEVs depend on the charging regimes. They consider 4 of these: (i) night charging, (ii) intelligent charging that takes place as much as possible when there is excess power, (iii) cars that do not only charge intelligently but can also provide power back to the grid when there is not enough power, and (iv) cars that fall under the same regime as (iii) but that have a battery storage capacity that is three times as large.

Without EVs and as wind power gains in importance, excess power rises, starting already at low wind shares. CO_2 emissions fall as the share of wind power increases, but this levels off at around 10-15 TWh/year. If larger wind penetration is coupled with 100% BEVs, the excess power is reduced because the demand for electricity rises. Refinement of the charging strategies diminishes excess power even further, but the marginal benefit of the different refinement steps falls, partly due to the absence of regulation services in the study. 100% BEVs in combination with wind power allow for realising a larger reduction in CO_2 emissions than wind power alone. For example, with 20 TWh of wind power the CO_2 emissions would fall from approx. 40 to 35 Mton/year.

Druitt & Früh (2012) show that in the UK flexible charging by EVs may be very effective for reducing the variability in the national load profile on time scales from 15 minutes to an hour. With 10 million EVs the daily load fluctuation would be reduced to levels below the current ones, at a wind capacity of 37 GW (corresponding to the UK’s goal of 30% renewable electricity in 2020). A large part of demand would become base load. They claim that a high share of EVs would enable to integrate larger capacities of wind power and nuclear power and to contribute to the decarbonisation goals. When the cars also provide V2G services the effectiveness of EVs to balance the system increases.

The value to EV owners of providing V2G services

Could the ability to provide V2G services change the relative attractiveness of EVs to their potential buyers? This depends on the net revenues that EV owners could receive from providing V2G services. When these are zero or negative the EV owners will not be willing to provide V2G services. However, when they are positive, the provision of V2G services could be considered as an option and could make it more attractive to use an EV. The net revenues are equal to the difference between the revenues and the costs. In general, the revenues consist of the capacity payment (if any) and the revenue earned or money saved on the energy market. The costs include only the costs that are additional to the ones that are incurred for the transport function of the EV. They equal the sum of the capital cost of the additional equipment for the V2G services, the additional wear costs and the cost of buying or producing the electricity that is sold to the grid (Kempton & Tomić, 2005a). If the participants in the V2G market are aggregated into a single controllable power resource, the costs of the aggregation should also be included (see e.g., G4V 2011b).

Here we present a selection of results[11] for the US (Table 19) and Europe (Table 20). Since the context is important, we do not simply present the annual revenues, but also briefly sketch the situation that is considered in each study. Finally, we point out that most of the studies compute the profitability at current market prices. However, in some cases insight is also given in what could happen at higher levels of EV penetration.

Estimates for the United States

Kempton & Tomić (2005a) give an estimate of the net revenues for BEV and FCEV providing peak load power, spinning reserves and regulation. They find that V2G can be profitable in the case of ancillary services where a capacity payment is combined with an energy payment. The annual net revenue of a BEV providing regulation services in the California Independent System Operator market (CAISO) is substantial. The provision of spinning reserves by a FCEV is found to be economically interesting only with a good combination of market prices and moderate capital costs. Without capacity payment V2G may generate net revenues when the electricity price is high, e.g. in some peak power markets. Illustrative figures given for FCEVs show that the outcome is highly dependent on the cost of hydrogen, market price and match of peak time to vehicle availability.

A similar method was applied by Williams and Kurani (2007) for a number of vehicle types, V2G services and maximum connection capacities for the residential case. The results are more conservative, and cover a wide range of values.

[11] The monetary values reported here are not corrected for inflation.

Study	**Power market**	**Service provided by EV**	**Estimate of annual net revenue to EV owner**
Kempton & Tomić (2005a)	CAISO	BEV regulation	USD 2,554 (10 kW) USD 1,731 (15kW)
		FCEV spinning reserves	Only profitable under specific conditions
		FCEV peak power	Profitability highly dependent on cost of H_2, market price and match between peak and vehicle availability
Williams & Kurani (2007)	CAISO	Regulation Spinning reserves Peak power	-USD66 to USD4,859 -USD65 to 1,039 -USD145 to USD717
White & Zhang (2011)	NYISO	PHEV peak reduction	Low or negative
		PHEV regulation	USD243-USD537 (1.33kW) USD2,410-USD4,656 (10 kW)
Tomić & Kempton (2007)	NYISO en CAISO	Regulation down, fleet of commuting cars	USD190-USD510
		Regulation up+down, company fleet	USD5,800-USD84,000
De Los Rios et al. (2012)	New England	Regulation up + down, company fleet	USD1,400 for BEV USD 1,250 for PHEV

Table 19: Value to EV owners of providing V2G services: case studies for the US

White and Zhang (2011) consider the use of PHEVs for peak reduction on high electricity demand days and/or regulation on a daily basis for the New York Independent Systems Operator (NYISO) in 2007, 2008 and 2009. With peak reduction only, the profitability is low or even negative, depending on the battery degradation costs. Using V2G for regulation purposes is substantially more profitable. Variation in the market prices and different assumptions about the charging rate and the battery degradation costs lead to a range of values.

Some studies indicate that vehicle fleets could be an interesting niche since their behaviour is often known beforehand and fixed. Tomić & Kempton (2007) look at the economic viability of EV fleets in the New York State (NYISO) and CAISO power market. In the case of 100 Th!nk city cars used by city commuters with chargers at home and at the commuter station, the annual net profit from providing regulation down services ranges from USD190 to USD510 per vehicle, depending on the market prices of V2G. It is less profitable to also provide regulation up. With 252 Toyota RAV4 vehicles that are used for meter reading during the day and parked after 3pm, it turns out to be very lucrative to provide both regulation up and down, with an annual net revenue of USD5,800 to USD84,000 depending on market prices and the fleet power.

In another study on a V2G enabled fleet, this time for the New England power market, the fleet consists of 250 vehicles used for pickup/delivery services with an average route length of 70 miles (De Los Rios et al., 2012). With the existing taxes and subsidies, the costs of EVs and PHEVs first of all turn out to be lower than those of ICEVs, making it an attractive option even without the V2G revenues. Moreover, the PHEVs and BEVs generate additional revenues from providing V2G services. The annual revenues are highest when both regulation up & down is provided.

Estimates for Europe

Study	**Country**	**Service provided by EV**	**Estimate of value to EV owner**	**Remarks**
Larsen et al. (2008)	Denmark	Secondary + tertiary reserves	€70 to €2060/year	Costs not considered
Edison project (2011)	Denmark	Regulation	Not interesting, but possibly more attractive with more renewable energy	
Camus et al. (2009)	Portugal	Secondary + spinning reserves	-€50/year	Net cost
Andersson et al. (2010)	Sweden	Regulation down	€20/month	Net revenue; capital costs not included
		Regulation up+down	Negative net revenue	
	Germany	Primary regulation	€30/month	Net revenue; capital costs not included; connection capacity of 3.5 kW
		Secondary regulation	€50/month	
		Tertiary regulation	€80/month	
Hartmann & Ozdemir (2011)	Germany	Revenue maximising storage	Lower cost difference between EV and diesel car	With low battery costs + less than 20% of battery used for V2G
Druitt & Früh (2012)	UK	Flexible charging + battery used as source of electricity	€186 to €500/year	Capital costs not included; with 2 million EV revenue would be only 1/3 of this estimate

Table 20: Value to EV owners of providing V2G services: case studies for Europe

Larsen et al. (2008) consider the revenues that can be realised by EVs in Denmark, a country with a high share of wind energy. No analysis is made of the costs. In this case the payments for the provision of secondary and tertiary control can be considerable, with values depending on the type of service that is rendered and the power of the connection. The demand for ancillary services could be covered if less than 10% of Danish cars have V2G capabilities. Another study for Denmark (Wu et al., 2011), is however much less optimistic. It concludes that with the current regulating power market setup, it is not very attractive for EV users to provide regulating services but indicates that this could change as the importance of renewable energy sources increases.

Camus et al. (2009) analyse the Portuguese market. Using average prices for regulation services in 2009 they arrive at an annual revenue of €250 per vehicle providing secondary and tertiary regulation. However, this is lower than the annual costs of the extra equipment and additional wear and tear (€300), implying a negative net revenue.

The profitability of primary, secondary and tertiary regulation by PHEVs in Sweden and Germany is the topic of Andersson et al. (2010). The electricity generation mix is significantly different in the two countries. In Sweden hydro-energy and nuclear power are the dominant sources, while thermal energy is dominant in Germany. The paper simulates the revenues generated by 500 PHEVs during four months in 2008, while the implementation at a larger scale is not studied. The revenues consist of capacity payments, profits for selling regulation down (= savings from charging at the regulation down price rather than the normal electricity price) and regulation up (= price received for selling regulation up – price of electricity that one had to buy – costs of battery degradation). The additional capital costs are not included.

In Sweden it turns out that it is not attractive to provide regulation services, since the capacity payment is small and the regulation prices are close to the spot price. By restricting the system to regulation down only, it could become more attractive. For Germany the revenues that can be realised on the three markets are higher thanks to the high capacity payment in Germany and the larger difference between the prices for regulation up and down. An increase in the connection capacity (from 3.5 to 15kW) would have a large positive impact on the revenues: they would increase to €260/month for primary control and €390/month for secondary control.

The German market is also studied by Hartmann & Özdemir (2011). They compare the costs per km in 2030 of an EV with that of a ICEV diesel car, assuming a use of storage such that revenues for the vehicle owners are maximised. This could lead to revenues of up to €0.68/day per EV. At a battery cost of €217/kWh (corresponding to the German goal for 2030) and without V2G services, driving an EV would be cheaper than driving an ICEV if one drives at least 10,000 km annually. If less than 20% of the battery is used for V2G services, this reduces the cost differential between an EV and a conventional diesel. However, if more than 20% of the battery is used for V2G services, the higher revenues from V2G services are outweighed by the higher battery degradation costs. With a doubling of the battery costs, the break-even between an EV and conventional diesel without V2G services is only reached at 45,000 km and the provision of V2G services does not have a large impact on the break-even distance.

Druitt & Früh (2012) consider the UK electricity market and calculate the benefits of demand management (flexible charging) and the use of EV batteries as a source of electricity. The provision of demand management would lead to charging costs that are one third lower than the costs with a standard fixed electricity price. When the EV batteries can also be used as a source of electricity and only a limited number of EV owners provide these balancing services, the annual revenue depends on the participation rate, i.e. the time during which the vehicles are plugged into the network. It would be around €190 with a standard participation rate and €500 with a high participation rate. In the latter case this is larger than the annual charging costs. These figures already include the battery degradation costs and conversion losses, but not yet the additional capital costs.

<u>Evolution of the value to EV owners in the future</u>

As more vehicles are available for providing V2G services, one may expect that the prices for V2G services will change and that this will probably reduce the net revenues from providing these services.

While many studies point out that the revenue estimates could change in a more mature market, the quantification of this evolution not common. Druitt and Früh (2012) consider the revenues for the UK case as the EV share grows. As can be expected, when more vehicles participate in the balancing market, balancing revenues fall. With 2 million EV the annual revenue per vehicle would equal only one third of the levels that could be realised at low penetration rates.

Sioshansi and Denholm (2010) find that the value to PHEV owners from energy and ancillary service payments as well as reduced driving costs in the Texas power system would range between USD123 per year for a 15% PHEV share and USD224 per year for a 1% PHEV share. In the latter case a PHEV owner can recover the additional costs of a PHEV compared to a conventional vehicle in about 7.5 years, while this would be about 9 years if no V2G services were provided. However, since the study does not consider regulation services, the value to the PHEV owner is likely to be underestimated.

7 Discussion and conclusion

To further decarbonise the passenger car fleet, planning, regulatory, economic and informative instruments are available. The present ETC/ACM technical paper gives an overview of the economic instruments for passenger cars aimed at influencing consumers' choices about acquisition, ownership and car use at national level in the European Union. Nine countries do not charge registration tax, and five impose no ownership tax. In recent years, many countries have included a CO_2 component in their taxation system. This can be seen as a national effort on top of the existing European policy to decarbonise the passenger car fleet in the *short and medium term*. European Union Member States that have reduced CO_2 emissions from new cars to a larger degree than the average, usually have a CO_2 component in their taxation system, whereas the opposite is true for countries that have reduced CO_2 lower than average emissions from new cars. Whether there is a direct relationship between the CO_2 component in the taxes and the CO_2 reduction observed cannot be concluded from this analysis. More factors than taxes alone play a role. Kieboom et al. (2010) performed an in-depth analysis of Dutch new car sales in the 2008–2009 period. They attributed around 60% of the observed CO_2 reduction to increased fuel efficiency of new cars, resulting from EU policy, another 20% to the Dutch taxation system and about 20% to the economic crisis. More clarity on this issue would require more modelling estimates with explicit CO_2 prices derived from the different national taxation systems.

Data on new car sales in 14 countries, in the 2001–2010 period, showed that:

- a 10% increase in weight accounts for about 8.4% increase in CO_2 emissions, whereas a 10% increase in engine capacity accounts for an increase in CO_2 emissions of 0.8%. Increase in engine power was found to be insignificant for CO_2 emissions per kilometre. Based on the finding above, in the 2001–2010 period, diesel and petrol cars became between 6% and 2% less fuel efficient due to weight increases only.
- corrected for fuel type, weight, engine capacity and engine power, cars became some 23% more fuel efficient over that period. This is due to technological progress only.
- using registration tax to affect the shares of diesel and petrol cars appears to have worked, while annual road tax and fuel tax only had smaller and less reliable effects. This result (based on observed developments) adds to the results from an ex-ante study (based on expected developments) by COWI (2002). Outcome of that study was a potential for further decarbonisation of the European car fleet by 3.3% to 8.5%, depending on country and types of taxes involved, *but with unchanged diesel shares as a boundary condition*.
- an increase in income and in the number of cars per person or household both substantially increase the number of kilometres driven per person. Increasing fuel prices, however, have a negative effect on kilometres driven. For each 10 eurocents increase in fuel price the number of passenger car kilometres per capita decreases by about 260 per year. Fuel taxes, therefore, are clearly effective in reducing the number of car kilometres per person, ceteris paribus.
- Transport policies on climate and air quality are intertwined. Our study has shown that a policy to decarbonise the passenger car fleet may have positive or negative impacts on air emissions, depending on the instruments used and the mechanisms involved. Positive impacts can be expected from policies aimed at (1)

consumers buying lighter cars, as a 10% weight decrease will reduce NO_x emissions by 3% to 4%, and (2) reducing car use, as a 10% reduction in car use will lead to a 10% reduction in polluting emissions. Fuel taxes, commuting subsidies, and, at a local level, congestion charges, parking fees and tolls are the instruments in place that directly affect car use.

- Negative impacts may be expected from policies aimed at consumers switching from petrol to diesel, while either positive or negative impacts may be expected, depending on the technology involved, from policies aimed at improving fuel efficiency by improving technology. Electric vehicles have clear advantages in terms of NO_x reduction.

In the long term, a breakthrough technology is needed to meet European climate ambitions. Electric vehicles represent such a technology. In 2011, 15 EU countries had tax exemptions and/or purchase subsidies for electric vehicles.

A review of studies on the private lifecycle costs of EVs shows that they can be economically attractive from the point of view of their prospective buyers either in particular niches involving high daily mileage, frequent journeys and frequent charging opportunities, such as for taxis, or assuming a favourable development in the costs of EVs and their batteries. In other cases, the additional costs for private car owners may be substantial, which is a barrier to the breakthrough of EVs.

The private lifecycle costs will decrease for EV owners who offer vehicle-to-grid (V2G) services. Studies for Europe show that in some cases net revenues may be generated by providing V2G services. However, the value to EV owners varies widely across power systems. It depends on the type of services that are rendered by the EVs (since this determines the level of the capacity payment and the energy payment), the type of EV fleet (e.g. individual cars versus company fleets) and the saturation of the market. This last aspect will become more important as the number of EVs increases.

Under the typical use scenarios, the CO_2 avoidance costs by implementing EVs turn out to be high compared to those that are associated with other abatement possibilities, which reduces the attractiveness of EVs from the point of view of society. The avoidance cost is low for vehicles with a high mileage, if their usage allows them to be charged frequently. It will also be lower if the costs for EVs and their batteries develop favourably, possibly accompanied by an increase in the costs for ICEVs.

The reviewed studies show that EVs may generate efficiency gains in the electricity sector provided that they are charged in a 'smart' way. By providing V2G services they offer another route to reduce CO_2 emissions and to lower CO_2 abatement costs. Intelligent charging that is adapted to the needs of the power system is an important prerequisite. The net impact on CO_2 emissions depends on the power mix. The higher the share of renewable energy, the larger the net impact. The studies show that a larger share of EVs would allow for integrating larger capacities of renewable energy.

Recommendations for transport climate policy:

- If influencing the share of diesel-fuelled vehicles is one of the objectives of climate policy (or air quality policy), registration taxes are a good instrument to influence that share in new car sales (whereas fuel tax and annual road tax are less suitable).
- Fuel taxes are a suitable instrument to decrease the number of kilometres driven and thus decrease CO_2 and other emissions, as well.

- A car taxation system that favours lighter cars ultimately leads to fewer CO_2 emissions and has substantial co-benefits for NO_x emissions.

Recommendations for further research:

- We have been able to assess the impact of national taxation systems on car use and diesel shares. We did not estimate the effectiveness of incorporating a CO_2 component in those national taxation systems. This would require additional modelling estimates with CO_2 prices derived from the different national taxation systems.
- Our analysis is based on pooled data from private and company cars together. As company cars have a large share in new car sales, have different tax regimes and presumably different reactions to pricing signals, it could be worthwile to make a distinction between those two sub-markets, provided the suitable data are available.
- This study focuses on existing economic instruments for passenger cars. A step further could be to investigate new economic instruments for passenger cars, such as introducing an emission trading system for the passenger car sector.
- The interaction between EVs and the power system should be analysed in order to provide a complete evaluation of electric vehicles. In some cases this may improve the business case for the adoption of EVs. To the best of our knowledge, such an integrated assessment is not yet available.

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Abbreviations

AFV	- Alternatively Fuelled Vehicle
BEV	- Battery Electric Vehicle
CADC	- Common Artemis driving Cycle
EV	- Electric Vehicle
FCEV	- Fuel Cell Electric Vehicle
HEV	- Hybrid Electric VEhicle
ICEV	- Internal Combustion Engine Vehicle
NEDC	- New European Driving Cycle
PHEV	- Plug-in Hybrid Electric Vehicle
V2G	- Vehicle to Grid

Annex 1: Data

The analysis in chapter4 and 5 is based on sales data from ICCT (Campestrini and Mock, 2011), combined with data on national tax regimes from ACEA (2001-2010) and general data on income per capita, corrected for purchasing power, car possession and car use from Eurostat. The countries included in this analysis are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Sweden and the United Kingdom. ICCT data were used instead of EEA-data, as ICCT data contain more detailed information on new car sales over a longer period (including sales prices and NOx emissions per fuel type, essential for the analysis in chapters 4 and 5 respectively). Figure 1 shows a comparison of the ICCT passenger car registration data with two other available datasets: The EEA CO2 monitoring data for 2010, also including data for the years 2000-2009 (EEA, 2011), and a report by the European Automobile Manufacturers' Association (ACEA) (ACEA, 2011). While deviations in recent years are minimal (less than 1%) between the different data sources, the EEA provides different vehicle registration numbers for the years 2001 and 2002, whereas ICCT and ACEA numbers are aligned. It should be noted that the European Commission mentions discontinuities for the pilot phase years 2000 to 2002 in their CO_2 monitoring reports. Furthermore, data of EEA and the European Commission is based on registration data, whereas statistics from ACEA and ICCT (to some extent) draw on vehicle sales data from manufacturers associations. Despite differences between the different datasets, we consider the ICCT sales data to be well in line with other datasets and therefore suitable to be used.

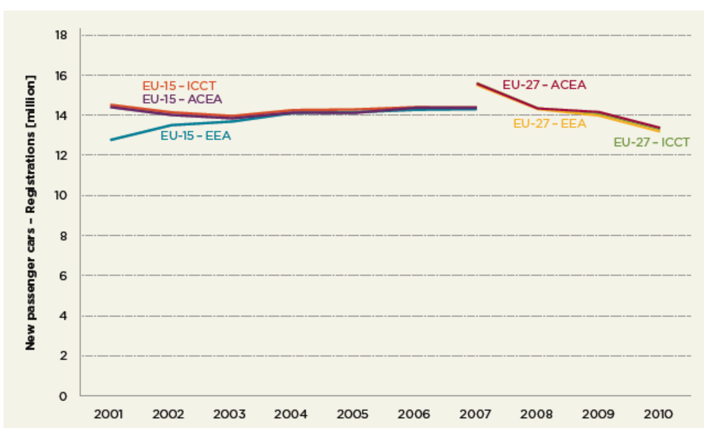

Figure 1: comparison of new passenger car sales data from ICCT, EEA and ACEA (source: Campestrini and Mock, 2011).

Figure 2 shows a comparison of the ICCT passenger car average CO_2 emissions with the official European Commission CO2 monitoring data compiled by EEA and the European Commission (EEA, 2011). The deviation is typically below 1% for most years and was 1.7% in 2010. We therefore consider the ICCT sales data to be well in line with other datasets and fit for use.

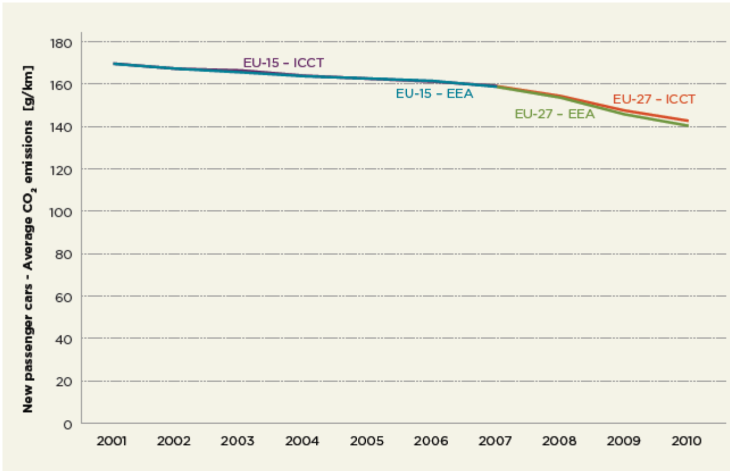

Figure 2: comparison of average new passenger car CO_2 emissions from ICCT, EEA and ACEA (source: Campestrini and Mock, 2011).

Annex 2: Modelling methodology

In order to assess the effects of economic policy instruments on CO2 emissions from passenger transport several analyses were conducted, on car sales and on car use.

In Section 4.2.1 we estimated a discrete choice model on car type categories, either fuel type or combined fuel type and weight categories. The model to be estimated would be different and so would be its output, i.e., effects of different policy measures on the distribution of sales in different car type categories. The model to be estimated requires data on car sales shares for different car categories per year per country. Let us for now assume we only have information on shares per fuel type category per country per year, which is the dependent variable in this model. The model to be estimated is called a multinomial logit model and estimates the effects of explanatory variables, such as a policy measure, on the probability of observing a car sale in a certain car category. The model looks as follows:

$$\text{Prob}\left(Y = j\right) = \frac{\exp\left(V_{itj}\right)}{\sum_{k=1}^{J}\exp\left(V_{itk}\right)}, \quad (0)$$

where Y represents the dependent variable on car sales shares, and V_{itk} represents utility associated with car category k for country i in year t. The model thus states that the probability of observing a car sale in car category j is equal to the utility associated with j as a share of total utility associated with all car categories k=1 …. J. Now, the utility for car category k as a function of policy measures P and explanatory variables X can be written as follows:

$$V_{itk} = \boldsymbol{\delta}_k^1 \mathbf{P}_{itk} + \boldsymbol{\delta}_k^2 \mathbf{X}_{itk} + \vartheta_{itk}, \quad (0)$$

for k=1…J, and where V_{itk} is utility associated with car category k in country i for year t, $\boldsymbol{\delta}_k^1$ is a vector of estimates on a vector of car-, country- and year-specific policy measures $\mathbf{P}_{itk}$, $\boldsymbol{\delta}_k^2$ is a vector of estimates on a vector of car-, country- and year-specific explanatory variables $\mathbf{X}_{itk}$, and ϑ_{it} is a normally distributed error term. Note that this model implies that the coefficients on the explanatory variables vary across car categories. An advantage of this model compared to the regression model in equation (1) is that it estimates effects of policy measures on changes in car sales for specific car categories. This output can subsequently be used to derive an output similar to the output of the regression analysis, i.e., effects on average CO2 emissions per kilometre. Another advantage of the model described in equations (2) and (3) is that policy measures aimed at specific car categories and other car-category specific variables, such as prices, can be included more precisely in the model. A disadvantage is that coefficients per car category are estimated, implying a loss of degrees of freedom and potentially less reliable estimates. At this moment, the use of both models appears to have added value at low cost, since data preparation for both models overlaps to a large extent.

Variations in model specification are of course possible. The most relevant variation is probably the estimation of country-specific parameters for each policy measure, instead of estimating a single parameter per measure. For example, until now we have assumed that a specific policy measure, e.g., a tax incentive, has an identical effect for each country. Letting go of this assumption would allow us to analyse the effects for different countries or sets of countries.

A second analysis is an analysis on car use as performed in section 4.2.2. Especially policies that affect costs per kilometre may have an effect on the number of kilometres driven, and thereby on the total amount of CO_2 emissions. To analyse this effect we require data on kilometres driven per year, preferably per fuel type and weight class. Although kilometres driven per country per year are available, a further distinction in terms of fuel type and weight class most likely is not (see section on data and Appendix A). The model to be estimated then looks as follows:

$$KM_{it} = \gamma^1 \mathbf{P}_{it} + \gamma^2 \mathbf{Z}_{it} + \mu_{it}, \qquad (0)$$

where KM_{it} is the total number of kilometres driven in country i for year t, γ^1 is a vector of estimates on a vector of country- and year-specific policy measures $\mathbf{P}_{it}$, γ^2 is a vector of country-specific estimates on a vector of country- and year-specific explanatory variables $\mathbf{Z}_{it}$, and μ_{it} is a normally distributed error term. Again, unobserved between-country variation is accounted for by estimating fixed and random effects models. Problematic for this model is that the set of variables that may affect the number of kilometres driven is extensive, implying that the probability that we have to leave out potentially relevant variables because of data limitations is substantial. However, for obtaining an unbiased measure of the effects of policy measures this is only problematic when the implementation of such measures is (strongly) correlated with the excluded variables. This is, of course, impossible to check, but we may still be able to derive meaningful insights from this analysis, especially when the number of observations is relatively large (implying that correlations between policy measures and excluded variables are likely small).

The two econometric analyses, i.e., on the effects of different policy measures on the composition of car sales, and on the number of kilometres driven, provide the primary output of the transport sector analysis. They give insight into the effects of policy instruments on transport-related CO_2 emissions, both in terms of car purchasing behaviour and in terms of car use. The results also allow for an approximation of government revenues from taxes and changes therein due to policy measures. Combining changes in revenues with changes in CO_2 emissions for each policy measure gives insight into costs per unit CO_2 reduction, and thereby insight in the cost-effectiveness of the different measures.

Annex 3: Company cars vs. private cars

In finding answers on what economic instruments where effective in decarbonising the European car market, we should look into different categories of the car market, as the economic instruments are designed for specific submarkets and specific submarkets react differently on price incentives

We discern:

- Privately owned cars (around 50 % of new car sales, Copenhagen Economics)
- Company cars (around 50 % of new car sales, Copenhagen Economics)
- Shared cars (total European fleet of 12.000 cars, less than 0,1 %; 400.000 participants, Bundesverband CarSharing, 2009)
- Others

Clearly, privately owned and company cars account for almost 100% of the European passenger car market. As Europe wide data on company car sales are not available within the scope of this project, we focus on the private market. Yet, to illustrate the importance of the company car market, we will shortly dwell on the company car market in the remainder of this paragraph, taking the Netherlands as an example, as reliable data for this country is available.

Company cars, as meant by most tax regimes, can be divided into cars belonging to a lease company, cars belonging to a fleet owner or a rental company and private cars mainly used for business purposes. The share of company cars in new car sales in Europe is about 50 %, with the highest shares in the high-end market (see figure 1).

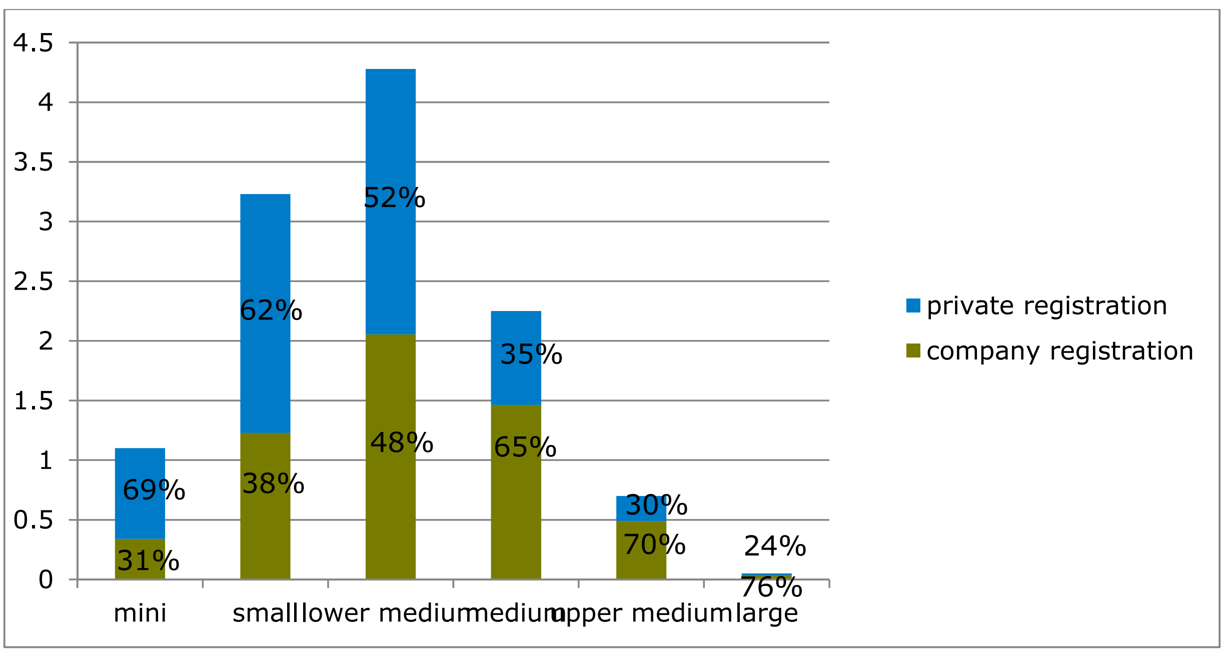

Figure 1: Car sales (in millions) in EU-18 in 2008, private as well as company car sub-markets (source: Copenhagen Economics)

Note: The 18 EU Member States include Austria, Belgium, Czech Republic, Denmark, Finland, Germany, Greece, Hungary, Italy, Luxembourg, the Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, and United Kingdom.
Source: Polk (2009) and Copenhagen Economics

Table 1 gives an overview of the share of company car registrations in 18 European countries. Remarkable is the high share of company cars in Germany the biggest national car market in Europe.

Country	**total registrations (millions)**	**share of company registrations**
Austria	0.29	52%
Belgium	0.54	48%
Czech Republic	0.14	40%
Denmark	0.15	38%
Finland	0.14	44%
Germany	3.06	60%
Greece	0.27	24%
Hungary	0.15	39%
Italy	2.17	32%
Luxembourg	0.05	45%
Netherlands	0.5	54%
Poland	0.29	47%
Portugal	0.16	55%
Slovakia	0.07	34%
Slovenia	0.07	54%
Spain	1.16	46%
Sweden	0.25	60%
United Kingdom	2.13	58%
18 EU countries	**11.59**	**49.50%**

Table 1: Company and total registrations per country in millions, 2008. (Source Polk and Copenhagen Economics)

Besides having different tax regimes and different price elasticities, the company-car market is important to look at, as firstly company cars tend to drive more kilometres than private cars, secondly they are higher CO_2-emitters and thirdly their turn-over rate is high, so a great share of ‘first hand’ company cars ends up on the second hand market for private cars.

In the 19 European countries listed in the table below, tax rules are favourable for company cars, thus subsidising the purchase and use of them[12]. Table 2 shows the level of subsidy[13] to company cars (expressed as percentage relative to their list price) to differ between countries and, within a country, between segments. Greece provides the extreme example of a country where there is no personal income tax on the use of company car. On the other hand, in Poland where personal income taxes are levied on the benefit-in-kind whose value is set at the actual cost of leasing a comparable car we observe the lowest subsidies (Copenhagen Economics, 2010).

	Segment Small	Segment Medium	Segment Large
Group A: Subsidy up to 10%	Finland, Poland	Poland	United Kingdom
Group B: Subsidy 11%-20%	Denmark, Sweden	Denmark, Finland, France, Netherlands, Sweden, United Kingdom	Denmark, Finland, France, Netherlands, Poland, Sweden
Group C: Subsidy 21%-30%	France, Luxembourg, Netherlands, Spain	Austria, Luxembourg, Slovenia, Spain	Czech R., Germany, Italy, Luxembourg, Slovenia, Spain
Group D: Subsidy more than 30%	Austria, Belgium, Czech R., Germany, Greece, Hungary, Italy, Portugal, Slovakia, Slovenia, United Kingdom	Belgium, Czech Republic, Germany, Greece, Hungary, Italy, Portugal, Slovakia	Austria, Belgium, Greece, Hungary, Portugal, Slovakia,

Table 2: level of company car use subsidy in different countries (source: Copenhagen Economics)

High private use is most often encouraged in countries where fuel use or km driven are not taken into account in calculating employee tax base: Austria, Estonia, Denmark, Finland, Germany, Hungary, Luxembourg, Portugal, Romania, Slovakia, Slovenia, and Spain (Copenhagen Economics, 2008, ACEA, 2011). In these countries, a percentage of the purchase price is the basis for calculating the benefit in kind. Though in France and Czech Republic the tax systems do take fuel costs into account, however more intense private use does not have a significant effect on diminishing the level of subsidy. Six of the countries (Austria, Belgium, France, Netherlands, Sweden and UK) have CO_2-components in their taxation on company cars (ACEA, 2011).

Within countries it can be observed that that the level of subsidies is higher for high private mileage. Once again, this is a consequence of the simplified tax rules which typically assume a fixed amount of private travel when valuing the benefit-in-kind. There are only two countries which penalise high private use of company cars – France and Sweden.

Copenhagen Economics (2010) discerns two kinds of market-distortions: First, there are subsidies in place to encourage employees to buy more and more expensive cars than they would have in the absence of the subsidy. Secondly, the widespread non- or low taxed use of fuel for the car means cars are being used more intensively than otherwise. This will, in turn, aggravate adverse environmental effects of the private car use (CO_2 emissions, air pollution, noise and congestion). Based on a study by Puigarnau and van Ommeren (2009), it is estimated that the system of company car subsidies leads to an

[12] We call a taxation system favourable for company cars, if the actual costs incurred by the employer in providing the company car lead to a lower increase in the imputed taxable income for the employee using the car.
[13] We use a broad definition of subsidy, comprising all governmental price support (like tax deductions) to keep prices at a lower level than without the price support .

increase of 4 – 8 % in CO_2 emissions (as part of total European passenger car emission) (Copenhagen Economics, 2010).

On the other hand, as company cars form a large part of the new sales market, and a limited number of lease companies form the majority of that market, company car taxation could be used to drive low-carbon technology deployment, by stimulating companies to buy more fuel efficient, or even very fuel efficient cars like electric ones.

Example Netherlands:

Because company cars usually have a high mileage and running costs for high mileage cars are lower for diesel cars, company cars are more often diesel fueled than private cars. However, petrol and hybrid are getting bigger shares (hybrids had a market share of 3% in 2010, see figure 2).

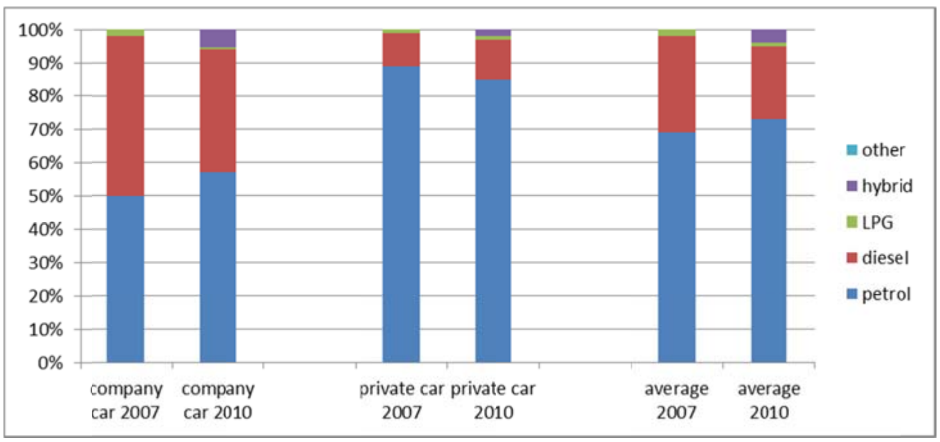

Figure 2: New car sales in the Netherlands 2007 and 2010 divided by fuel type and sub-market (source Ecorys, RDC)

The growth of the petrol share is mainly explained by the sales of small, very fuel efficient petrol cars, which were fiscally attractive. The Dutch tax system is constructed in such a way that it is easier for petrol cars to come in the very fuel efficient category (with associated tax deductions) than it is for diesel cars (see Table 3).

fiscal percentage	*diesel*	*other fuels*
0%	*electric only*	
14% (very fuel efficient)	*< 96 gr/km*	*< 111 gr/km*
20% (fuel efficient)	*96-116 gr/km*	*111-140 gr/km*
25%	*> 116 gr/km*	*>140 gr/km*
35%	*cars > 14 years*	

Table 3: CO2-limits for fiscal percentages of company cars in the Netherlands in 2010

Due to technological progress and fiscal stimuli, the share of (very) fuel efficient cars in the total car sales in the Netherlands (according to the country's fiscal definition presented in table 3) rose strongly in recent years, from 5 % to 25 % of total new sales, both in the private and in the company car market segment (see Figure 3).

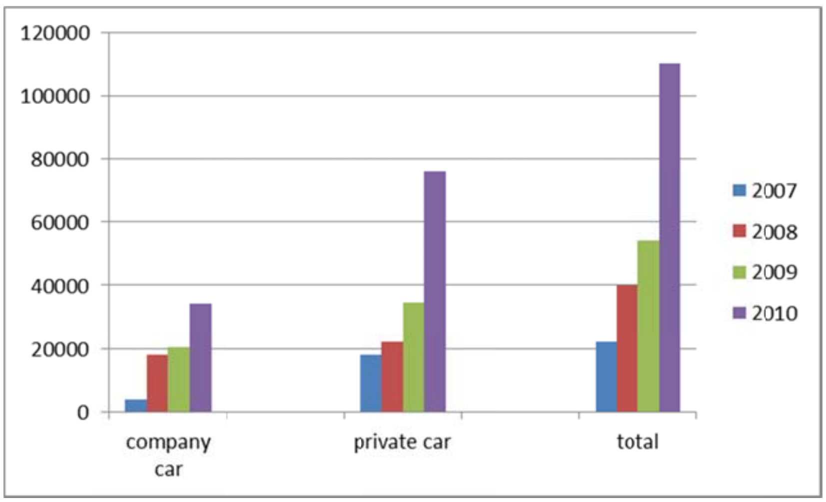

Figure 3: sales figures of efficient and very efficient cars in the Netherlands (Ecorys, RDC)

This rising share of (very) fuel efficient cars will eventually lead to decreasing tax revenues. To prevent this, and to stimulate car manufacturers and consumers to produce and buy even more fuel efficient cars, the limits for fuel efficiency will be tightened according to Table 4 (Dutch Ministry of Finance, 2012). For cars emitting less than 50 gram, a fiscal percentage of 0 – 7 % (depending on date of acquisition) is determined.

	2011	1-7-2012	1-1-2013	1-1-2014	1-1-2015
petrol					
14 %	<111	<103	<96	<89	<83
20 %	111-140	103-132	96-124	89-117	83-110
25 %	>140	>132	>124	>117	>110
diesel					
14%	<96	<92	<89	<86	<83
20%	96-116	92-114	89-112	86-111	83-110
25%	>116	>114	>112	>111	>110

Table 4: fiscal percentage in relation to CO2-emissions (Dutch Ministry of Finance, 2012)

Figure 4 shows that both new private and company cars reduced CO_2 emissions between 2007 and 2010. As company cars are on average heavier than private cars, and as vehicle mass has a strong relation with CO_2 emissions (see chapter 4 for more details), new company cars emit on average more CO_2 than new private cars[14]. As they have a higher mileage as well, they account for a disproportionate share in CO_2 emissions. Whereas company cars constitute about 10 % of total Dutch car fleet, they produce around 17 % of total passenger car CO2 emissions.

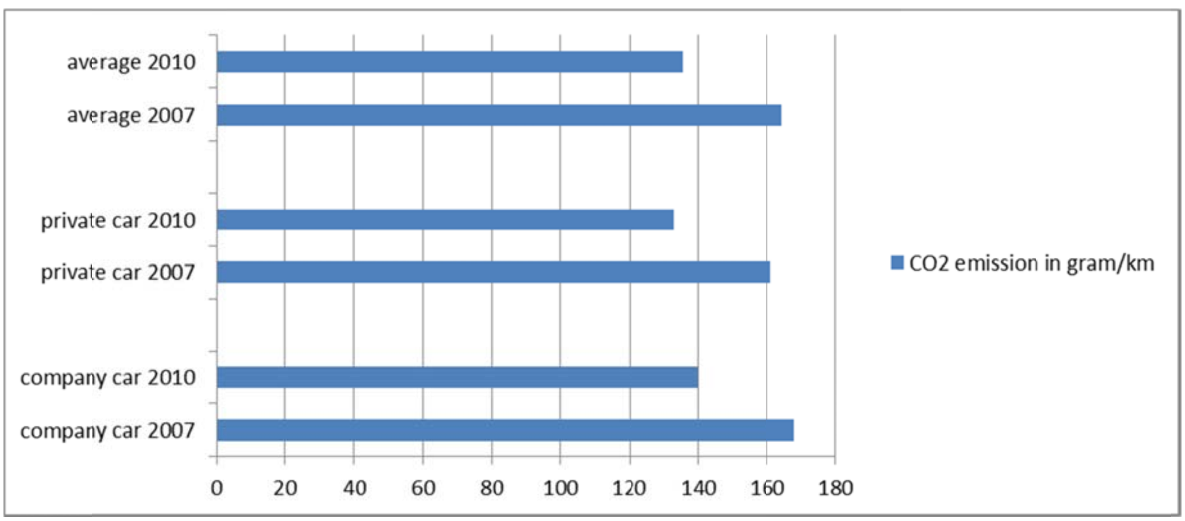

Figure 4: Average CO2 emission Dutch new cars 2007 and 2010 (source: Ecorys, RDW)

[14] The average company car, however, emits less per km. than the average Dutch car, due to the high turn-over rate of company cars and the fast decarbonisation of new cars in general.