CECILIA 2050
OPTIMAL EU CLIMATE POLICY

Choosing Efficient Combinations of Policy Instruments for Low-carbon development and Innovation to Achieve Europe's 2050 climate targets

Climate Policies and the Transport Sector

Analysis of Policy Instruments, their Interactions, Barriers and Constraints, and resulting Effects on Consumer Behaviour

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List of Abbreviations

ACEA	European Car Manufacturers Association
AFV	Alternative Fuel Vehicle
CAA	Clean Air Act (US)
CAFE	Corporate Average Fuel Economy (US)
CAPI	Computer-Assisted Personal Interviewing
CARB	State of California's Air Resources Board
CATI	Computer Assisted Telephone Interviewing
CAWI	Computer-Assisted Web Interviewing
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DETRA	Department for Transport (UK)
EE	Energy Efficiency
EEA	European Environmental Agency
EFTA	European Free Trade Association
EPA	Environmental Protection Agency (US)
EPCA	Energy Policy and Conservation Act (US)
ETS	Emissions Trading Schemes
EU	European Union
EV	Electric Vehicle
FEV	Full Electric Vehicle
GHG	Greenhouse Gases
GPS	Global Positioning System
HDV	Heavy Duty Vehicle
HEV	Hybrid Vehicle
ICAO	International Civil Aviation Organisation
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
LDV	Light Duty Vehicle
LPG	Liquefied Petroleum Gas
MM	Mobility Management
NEDC	New European Driving Cycle
NHTSA	National Highway Traffic Safety Administration (US)
NOx	Nitrogen Oxides
NPV	Net Present Value
NREAP	National Renewable Energy Action Plan
OECD	Organisation for Economic Co-operation and Development
PHEV	Plug-in Hybrid Electric Vehicle
PM_{10}	Particulate Matter (up to 10 micrometres in size)
PT	Public Transport
SCAQMD	South Coast Air Quality Management District (US)
STPM	Soft Transport Policy Measures
SUV	Sport Utility Vehicle

TCO	Total Cost of Ownership
TERM	Transport-Environment Reporting Mechanism
TFP	Travel Feedback Program
VAT	Value Added Tax
VDA	Verband Der Automobilindustrie (Germany)
WBSCD	World Business Council for Sustainable Development
WTP	Willingness To Pay
ZEV	Zero-Emission Vehicles

0. Executive summary

This report was written as part of the CECILIA2050 research project, which looks at policy options to improve European climate policies. A central question of this research is what role economic instruments such as carbon pricing should have in European climate policies. The following discussion takes a closer look at the policy-induced price signals that affect transport in Europe (and abroad) with a focus on road private transport in particular.

It is now well documented that transport sector has a significant greenhouse gases reduction potential and in contrast to common wisdom of high costs of emission reduction, there is a substantial reduction potential at a very low (or even negative) abatement costs. A broad range of transport-related taxes, duties, levies and charges, as well as a number of subsidies, influences any consumption and investment decision related to transport. We review deployment of these instruments in Chapter 1. Many countries have taxes for vehicle purchases, one-off registration or annual circulation taxes for cars; excise duties on fuels; road charges for toll roads or inner-city areas, and parking fees, among other policies. In many cases, these pricing components are adjusted to include an environmental component, e.g. waving registration taxes for very fuel-efficient cars, or levying a penalty tax on cars with a powerful engine. This multitude of taxes has typically grown historically, and serves a number of objectives, which are not always clearly specified. One overriding objective, as with many taxes, is to simply generate revenue for the public budget. Beyond this, a further objective is to internalise the manifold external costs to which transport gives rise: this includes local air pollution, climate change, noise, accidents, and congestion, as well as covering the infrastructure costs.

In theory, carbon pricing is a popular concept with environmental economists, as it addresses the root cause of environmental degradation by internalising the external costs, and since it promises to achieve emission reductions at least cost to society. While the internalisation of external costs is based on a static view, whereby the fuel price should be adjusted to reflect the full external costs at a current point in time, there is also a dynamic perspective: in this view, one function of the taxation of transport fuels is to trigger innovation and adaptation processes. Flanking measures – such as labelling rules, which require manufacturers to identify the fuel efficiency of marketed cars – can support this process, but the price signal would remain the main driver for change.

The available evidence – although limited in scope and methodology – seems to suggest as arguably reasonable to choose instruments targeting fuel economy and fuels as the most effective ones. As discussed in Chapter 2 on U.S. emissions and efficiency regulations it is difficult to calculate their impacts – while the positive impact of these policies on smog-related pollutants is clear and GHG emissions per mile are falling, total miles driven have increased significantly over last 45 years, tempering the emission standards impacts of fuel efficiency. Numerous studies indicate that fuel taxes are a far more cost-effective policy than fuel economy standards because they exploit more options for reducing fuel use. Pricing instruments also tend to act quickly and price elasticities seem to decline over time not as fast as commonly thought. Yet there are some indications that consumers are not very price sensitive to fuel costs and that vehicle utilization choice is rather inelastic. We review the research on elasticities in transport in detail in Chapter 3 with a tentative conclusion that people are more sensitive to road prices, tolls and parking fees than to fuel prices, to quality of public transport services than to a reduction of fares, more so in areas with viable alternatives than in areas without, and more for leisure trips than for business trips and commuting.

Some authors also argue that pricing policies may be more effective if fuel taxation is applied in combination with other types of charges, feebates being one of the most promising – they provide an on-going incentive for improvement which does not diminish with technical advancements (whereas fuel economy standards often stay constant). It has also been pointed out that the point of compliance may be relevant as an implication for cost-effectiveness. Behavioural response to price incentives (such as feebates) may be stronger if the incentives are levied at the consumer rather than the producer level because of information asymmetries[1]. And, not the least, it is needed to ensure that producers and consumers face stable long-term incentives.

The case of fuel tourism discussed in Chapter 4 also serves as an example that consumer decisions are indeed affected by politically induced price changes: as a positive lesson, it shows that consumers do respond to pricing tools. Yet, as argued above, the cases of fuel tourism and second hand vehicle trade also provide examples of how cross-border trade and arbitrage affect the functioning of existing pricing policies at the national level, and the political feasibility of introducing new ones. This suggests a clear need for policy coordination: where markets are linked across borders, and where policies affect domestic markets, there is a need to coordinate policies internationally.

Company car taxation discussed also in Chapter 4 is in its currently dominating setup a flagship example of negative policy overlap. Under the company car tax regimes that are in place in most European countries, the carbon price signal for fuel consumption is effectively muted for company cars – and thus for about half of new car registrations in these countries. This affects driving behaviour as well as purchase decisions, and thereby also the structure of demand for new cars. But the impact does not end there: through trade in second-hand vehicles, the effects of favourable tax treatment for company cars are perpetuated.

A largely underexploited potential is likely with soft measures that are discussed at length in Chapter 5. Teleworking, car sharing, teleconferencing and personalized travel planning are

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[1] This means that customer and dealer are symmetrically informed about incentive(s) targeted to customer, while customer is rarely aware of incentive(s) for dealer.

deemed to promise the largest potential to reduce car travel, although there are gaps is evaluation of their effectiveness.

On the “pull” side reducing the cost of new technology development and deployment e.g. through early investment in low-carbon research and public procurement policies may trigger uptake of new technologies. In Chapter 6 we investigate effects that policy measures promoting the adoption of electric vehicles have on those vehicles’ total cost of ownership (TCO) to find that the implementation of large registration fees for non-EVs and a bonus-malus scheme, which accrue significant consumer savings very early on in the life of the vehicle are particularly effective. To further explore electric vehicle purchasing decisions we review existing studies on (stated) preferences for low carbon vehicles in Chapter 7.

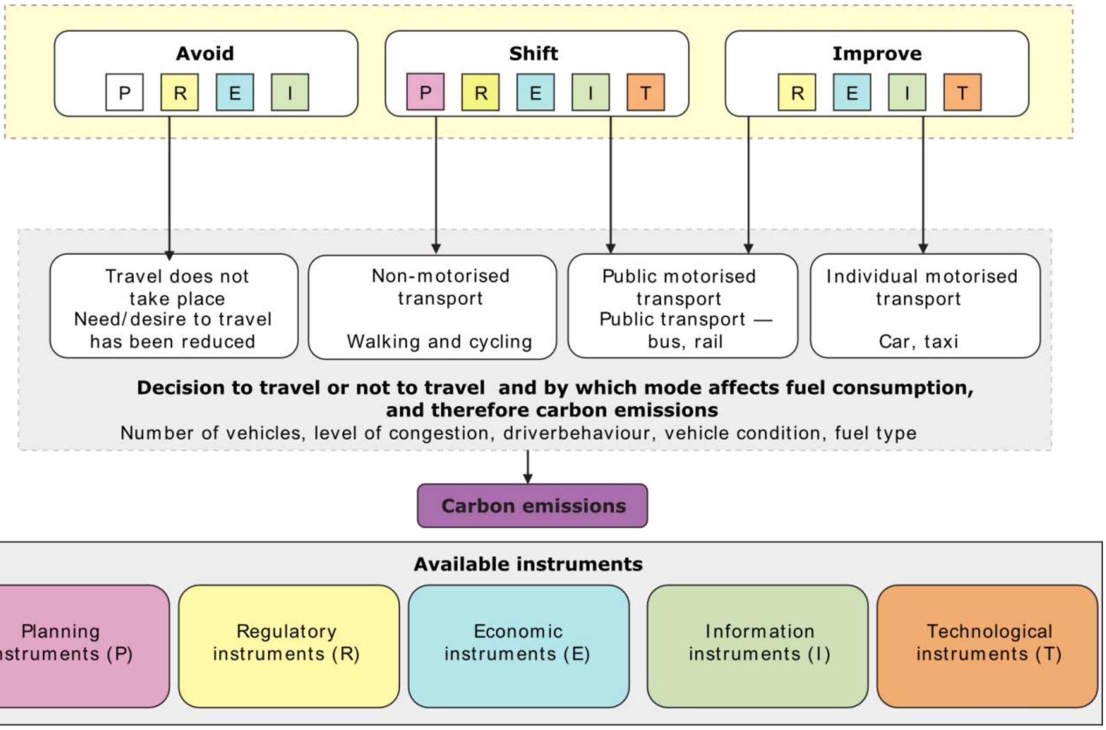
1. Policy instruments in the EU transport sector – an overview

The aim of this chapter is to provide an overview of existing climate policy instruments and mixes in transport sector, their impacts and mutual working in the EU and abroad. The choice of instruments is selective and focuses mainly on price-based instruments, emission/fuel economy standards and mobility management.

The portfolio of climate policy instruments in transport sector is very heterogeneous and various classifications are possible. Transport-environment reporting mechanism (TERM) developed by EEA (EEA, 2010) elaborates on Avoid-Shift-Improve approach (ASI) that distinguishes three key strategies to achieve greenhouse gas (GHG) emission reductions by:

- reduction in journeys number through better urban and regional planning (walkable and bikeable communities), substituting transport with communication (videoconferencing, home office) and behavioural changes (*Avoid*),
- use of alternative modes, i.e. improving the modal split from higher-carbon transport modes (air, road transport) to lower-carbon ones (water, rail, public transport, cycling and walking) (*Shift*), or
- reduction in the carbon intensity of individual transport modes (increasing fuel efficiency, biofuels, electric mobility combined with low-carbon electricity) (*Improve*).

Figure 1 - Potential strategies for reducing GHG emissions



Source: EEA (2010)

Since there is currently no dominant strategy or technology, most EU member countries endorse “all of the above”, i.e., pursuing all the above options in parallel. Various instruments employed in this endeavour can be broadly classified into 5 types – planning, regulatory, economic, information, and technological. Planning instruments can reduce the need to travel and provide opportunities for public transport and non-motorized modes by urban and regional planning. Regulatory instruments may set physical and technological norms and standards, affect production processes or organization of traffic. Economic instruments can harness market forces to discourage use of motor vehicles, encourage use of alternative modes, or improve accessibility. Information instruments aim at increasing public awareness on alternative modes, mobility management or affecting car purchase choices and driving behaviour. Technological instruments focus on cleaner propulsion technologies, fuel improvements and overall vehicle efficiency.

To complicate things further, some of these initiatives are driven by actors at the EU level (in particular fuel efficiency standards, biofuels), others at the national level (electric mobility, modal split), and many others at the regional or municipal level (urban and regional planning, public transport). There is, at best, modest cooperation between these different levels of planning. An illustration of main types of instruments for reducing GHG emissions in transport sector by governance level is shown in the next table.

Table 1 – Policies for transport GHG emission reduction by governance level

Administrative level	Main policies
Global	- Regulation regarding maritime shipping and aviation
EU	- Vehicle and fuel regulation - TEN-T infrastructure policy - Frameworks for fiscal policies (e.g. energy taxation and infrastructure pricing) - Emissions Trading Schemes (ETS)
National	- Spatial policies - Infrastructure policies - Economic instruments: fiscal policies, infrastructure charging - Subsidies and R&D - Fuel and energy regulation and support - Policy for stimulating specific modes, including public transport policy - Traffic management and speed policy on national roads
Local/regional	- Local/regional infrastructure and spatial policies - Local/regional public transport policy - Cycling policy - Traffic management - Local speed policies - Parking policies - Local congestion charging schemes

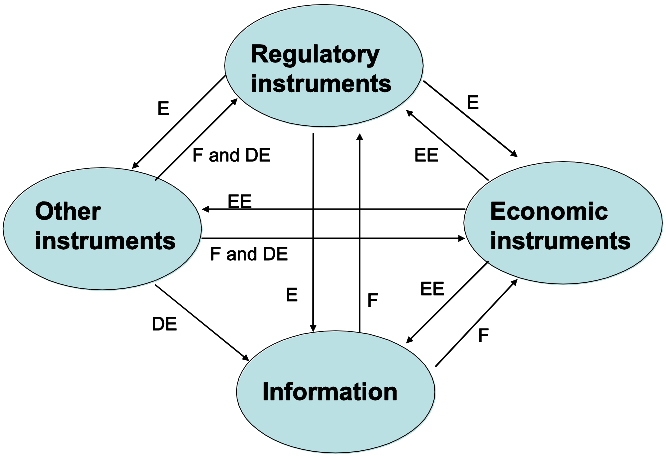
Source: Essen et al. (2012a)

1.1. Interactions and policy mixes

In the following chapter we demonstrate – although in no exhaustive manner – that the level of instruments' deployment is considerably broad and that there is no single instrument that is optimal in all the aspects in pursuing climate goals. Hence, we now turn our attention on instruments' mixes and interactions.

Del Río (2009) looks into interactions of various instrument combinations and suggests a scheme of attractive combinations of instruments (cf. Figure 2).

Figure 2 – Complementarity of instruments



Source: del Río (2009)

Notes: Criteria: E = effectiveness; EE = cost-effectiveness; DE = Dynamic efficiency; F = Political feasibility. The arrows indicate that the origin instrument positively contributes to the final destination instrument regarding the considered criteria.

Limited to pair-based interaction assessment del Río finds the following combinations as particularly promising:

- restrictions to the use of the private vehicle and public transport improvements;
- parking fees (or taxes on fuel or tolls) and public transport improvements;
- economic instruments (taxes and emissions trading) and support for R&D investments (i.e. demand-pull and supply-push);
- public transport improvements and information campaigns;
- restrictions to the use of private vehicles and information campaigns;
- transport and land-use planning and economic/fiscal instruments (i.e. combining long-term and short-term horizons);
- standards, fiscal incentives and user information;

- fuel taxes and eco-driving;
- transport and land-use planning and public transport improvements;
- fuel/CO_2 standards and credit trading (i.e. for vehicle manufacturers);
- subsidies to less polluting vehicles financed with a greater registering tax for the most polluting ones;
- public provision (public purchases) and taxes – i.e. financing public provision (or R&D, public transport etc.) from tax revenues.

EEA (2010) explores three policy packages using the abovementioned ASI approach. ‘Improve’ package considers co-existence of hybrid and electric technologies and low carbon fuels for cars, light commercial vehicles, heavy good vehicles (HGVs), buses and trains; ‘avoid and shift’ package focuses on fuel efficient modes and zero emission travelling through land use planning and regulatory measures; and combined ‘avoid-shift-improve’ package aims at encouraging both technological and behavioural change including improved vehicles and propulsions, low carbon fuels, mixed-use land planning, and avoid and shift measures to steer behavioural change.

At a more quantitative level a preliminary observation is – quoting from Hill et al. (2012) – that identifying the most appropriate combination of regulation and economic instruments is challenging, and depends on, for example, the evolution of the total costs of ownership (TCO) and longer-term behavioural responses.

Yet, as OECD (2008) highlights, there is little consensus as to the relative environmental effectiveness and economic efficiency of alternative policy instruments. Nonetheless it is relatively certain that individual policies targeted on a single aspect of travel behaviour will not be as effective as a package of complementary policies. Measures directed towards increasing the costs of motoring will need to be combined with measures to make public transport more competitive (either by reducing fares or improving service), and with improved infrastructure for cycling and walking. The authors of OECD review also note that there are very few studies of individual behavioural response to regulatory measures, apart from those relating to the CAFE standards in the USA. On the other hand several authors point out at co-existence of transport policies which are not only sub-optimal but contradictory.

1.2. Road transport

It is widely acknowledged that EU and its member countries are de facto *trendsetters* in pursuing climate policy objectives in transport sector. European Council called for adoption of target and strategies for limiting GHG emissions already in June 1990 and later that a "reduction" target of stabilising CO_2 emissions in 2000 at 1990 level was adopted. Subsequently the directive on motor vehicle air pollution[2] in its recitals mandated the Council to decide on measures designed to limit CO_2 emissions from motor vehicles before end of 1992. Motor Vehicle Expert Group set up by the Commission later presented different proposals, including emission standards and fiscal measures.

In between ACEA (European Car Manufacturers Association) started to lobby for voluntary agreement – this idea came from Germany where VDA concluded such a voluntary agreement in 1995. In its 1995 Communication on Community strategy to reduce CO_2 emissions from passenger cars and improve fuel economy[3] the Commission proposed three key measures: (1) voluntary agreement with the car manufacturers to attain CO_2 emission objective) by technological developments and market changes linked to these developments; (2) tax incentives to encourage consumers to buy models which consume less fuel, with tax incentives to promote cars with particularly low fuel consumption to be incorporated in a future global Community initiative on vehicle taxes; and (3) better information for consumers on CO_2 emissions in the form of a suitable labelling system.

1.2.1. Emission performance & fuel economy standards

In the voluntary agreements European, Japan and Korean car manufactures' associations accepted to improve emission performance to fleet-average 140 g CO_2/km by 2008 (ACEA) and by 2009 (JAMA and KAMA). In its 2007 Review of the Community Strategy the Commission voiced concerns regarding the progress made by car industry that has later materialized in voluntary agreements being replaced by Regulation 443/2009 setting binding emission performance standards for new passenger cars. The regulation established a fleet-average CO_2 emission target[4] of 130 g/km to be reached by 2015 (and phased in between 2012-2014) using vehicle technology and additional emission reduction to meet EU 120 g/km target is to be attained by additional measures (such as tyre pressure monitoring and gear shift indicators), and defines a long-term target of 95 g CO_2/km for 2020. Later a similar regulation of emission performance standards for new commercial light vehicles was adopted in 2011[5] setting fleet-average CO_2 emission target for N1 vehicles at 175 g/km to be phased in between 2014 and 2017 and at 147 g/km from 2020. In June 2013 European

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[2] Council directive 91/441/EEC

[3] COM(1995) 689 final

[4] The fleet average (or limit value curve) is set so that manufacturers can make cars with higher emissions provided these are balanced by vehicles below the curve. The manufacturer's specific emission target is set based on the vehicle mass:

Specific Emissions $[CO_2] = 130 + 0.0457 \times (M - M0)$

where M is the mass of the vehicle and M0 is set for 2012-2015 period at 1372 kg.

[5] Regulation (EU) No 510/2011

Parliament, Council and European Commission agreed on 95 g/km target for new passenger cars from 2020, a target for 2025 is to be proposed by Commission by end-2015.[6]

1.2.1.1. *Heavy duty vehicles*

Until recent EC initiative, CO_2 emissions from heavy commercial vehicles have not been directly addressed. In 2011 White Paper on Transport the Commission presented future strategy on HDV CO_2 emissions and fuel consumption and set of actions that will be considered for pursuing.

Also the recent high oil prices are deemed to stimulate manufacturers (and lorry operators) to push ahead with reducing HDV fuel consumption – given the high annual mileage the fuel costs represent by far the biggest single item in the road haulage industry's cost structure with a share of around 30 percent (VDA, 2013).[7]

1.2.1.2. *Non-EU commitments*

Beyond the EU other countries also strive to improve CO_2 emission/fuel economy of new passenger cars. ICCT summarizes the historical performance, enacted and proposed targets for light duty vehicles in USA, Canada, Japan, China, South Korea, Australia and Mexico. China originally imposed fuel economy standards for passenger vehicles in 2004 with two phases – the first starting from 2005 and the second from 2008. New and relatively strict fuel economy standard were passed in March 2013 restricting passenger cars' average fuel consumption to 6.9 litres per 100 km (measured using NEDC) by 2015 and further down to 5.0 litres by 2020.[8]. A detailed overview of U.S. policies of fuel economy is elaborated in Chapter 2.

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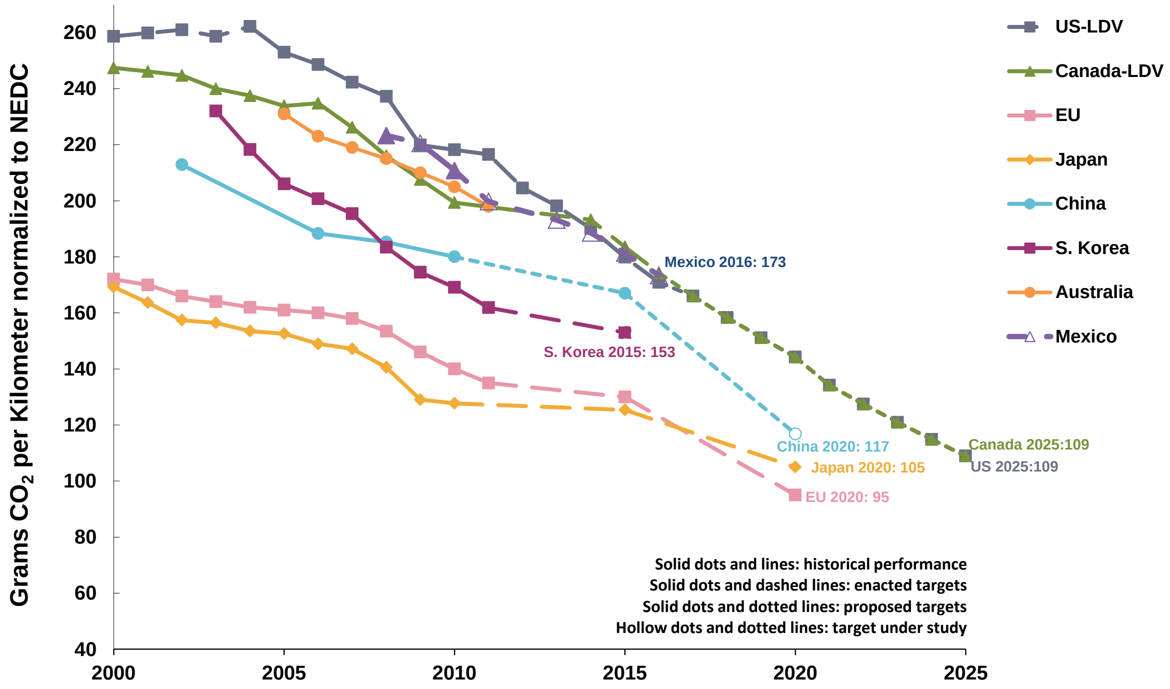
[6] Originally Environment Committee of European Parliament proposed indicative target for post-2020 CO_2 emissions (i.e. from 2025) in the range of 68-78 g/km for passenger cars, and in the range of 105-120 g/km for light commercial vehicles.

[7] According to VDA data a 40 metric ton truck on long-haul trips consumes on average 32 litres per 100 kilometres, i.e. less than 1 litre per 1 ton of payload per 100 km.

[8] The latest data for China in ICCT database shows average fuel consumption of 7.7 l/100 km in 2010.

Figure 3 – Overview of emission performance standards



[1] China's target reflects gasoline vehicles only. The target may be lower after new energy vehicles are considered.
[2] US , Canada, and Mexico light-duty vehicles include light-commercial vehicles.

Source: ICCT (2013)

1.2.1.3. Super-credits in the EU CO_2 emission standards for passenger cars

The EU regulation gives manufacturers additional incentives to produce cars with emissions of 50 g CO_2/km or less (mostly electric or plug-in hybrid cars). These super-credits are meant to help manufacturers reduce further the average emissions of their new car fleet. Each low-emitting vehicle is offset 3.5-fold in 2012 and 2013, 2.5-fold in 2014, 1.5-fold in 2015 and at par from 2016 onward. Political agreement on 2020 target provides for a vehicle emitting less than 50 g/km CO_2 be counted as 2 vehicles in 2020, 1.67 in 2021, 1.33 in 2022 and as one vehicle from 2023 onwards.

From 2012 to the end of 2018, 5 euros will be payable for the first gram of CO_2 that exceeds the limit, 15 euros for the second gram, 25 for the third and from the fourth gram and above, 95 euros. With effect from 2019, there will be a flat rate fine of 95 euros for each gram above the limit. There are exemptions for the smallest manufacturers (production below 10,000 vehicles) and for niche manufactures (production between 10,000 and 300,000 vehicles).

1.2.2. Eco-labelling schemes

In March 1999 a new directive on consumer information on fuel economy and CO_2 emissions[9] was adopted introducing mandatory displaying of fuel economy and CO_2 emission or labels of passenger cars in all means of car marketing.

The Member States have put in place relatively different labelling schemes in terms of format or absolute/relative ratings. Often such labelling system mimics that for electric appliances usually with 7 grades (used e.g. in Denmark, France, Germany, Netherlands, Romania, Spain and UK), alternative scales are used e.g. in Austria or Belgium, other countries use textual information only (e.g. Czech Republic and Hungary). Absolute rating indicates actual CO_2 emissions irrespective of other car characteristic, while in relative rating a comparison within same class (determined e.g. by weight) is given. Absolute rating is used e.g. in Austria, Belgium, Denmark, Finland, France or UK, the latter system e.g. in Germany (weight-related). Duer et al. (2011) also notes differences in categorization – in Finland, band A cars must meet more stringent CO_2 norms than in Denmark and norms in Sweden and Norway range in between Finland and Denmark.

Tyre labelling is mandatory in the EU starting from November 2012[10] for tyres fitted mostly to cars, light- and heavy-duty vehicles. The label describes fuel efficiency or rolling resistance (fuel pump symbol), wet-weather adhesion (rain symbol) and tyre road noise (sound wave symbol) and is divided into classes A to G. The label's focus on just three parameters has been criticised for ignoting other performance characteristics, such as dry braking or tyre life. These characteristics are moreover contradictory – low rolling resistant tyre (fuel efficient and ideal for dry conditions) would perform poorly wet conditions when water evacuation and surface grip is needed. A step up in rolling resistance from A to B equates to increased fuel consumption of 0.1 litres/100 km, a step up in wet-weather adhesion from A to B corresponds to a longer braking distance of between three and six meters.

1.2.3. Price-based instruments

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[9] Directive 1999/94/EC

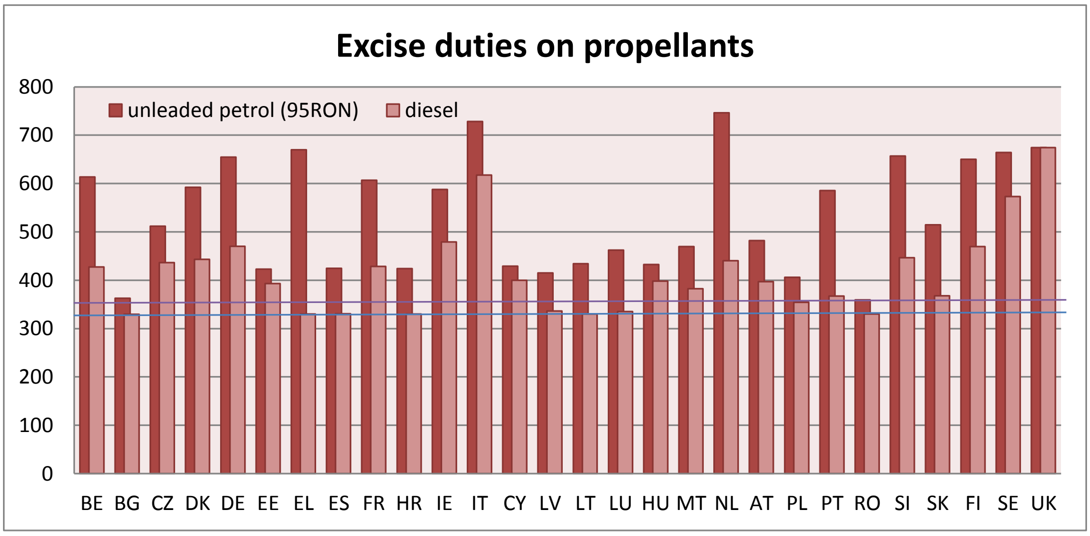
[10] Regulation (EC) No. 1222/2009

Price/fiscal instruments' category encompasses instruments such as taxes on motor fuels (including carbon taxes)[11], purchase/registration and circulation taxes, payments for use of infrastructure, and direct subsidies, e.g. for purchase of cleaner vehicles. The level of deployment of market-based instruments is quite substantial in all the EU member states as documented in an overview table (cf.

Table 4 at the end of this section).

<u>Fuel taxes</u> vary from country to country in the EU with a minimum tax rates set by directive 2003/96/EC at € 359/1000 litres of unleaded petrol and € 330/1000 litres of diesel. There are substantial differences in taxation of diesel across EU. While the UK places equal tax on petrol and diesel, Greece taxes diesel about 50% less than petrol, Netherlands about 40% less and many other countries about 20% less than gasoline. The following table shows comparison of tax rates in member states as of 1.7.2013.

Figure 4 – Excise tax rates on petrol and diesel in EU-28 countries (in EUR_{2013}/1000 l)



Notes: blue and green horizontal lines represent minimum tax rates on diesel and unleaded petrol, respectively, set by the Energy Taxation Directive.

Source: DG TAXUD, 2013

The minimum tax levels of the Energy Taxation Directive correspond to relatively high implicit CO_2 costs, i.e. EUR 126 and 151 per tonne of CO_2 for diesel and petrol, respectively.[12] The discrepancy between implicit CO_2 taxation was addressed in 2011 EU Commission

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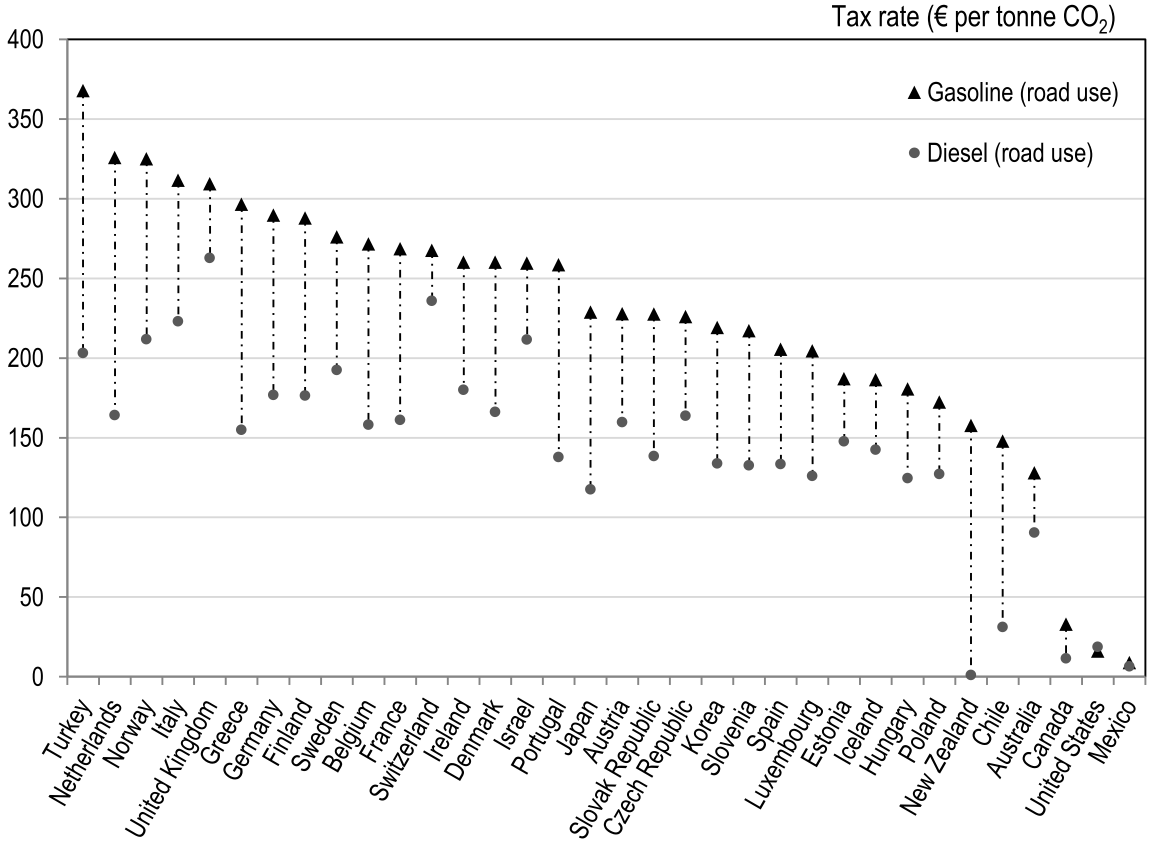
[11] There were also attempts to negotiate EU-wide carbon tax in 1992 and again in 1995 but failed as unanimity vote in the Council is required for tax matters.

[12] A litre of diesel has roughly 10% more combustion energy content than a litre of gasoline, and due to higher carbon content a litre of diesel also roughly 18% more CO_2 emissions (OECD, 2013a). Note also that for cars with the same mass and engine capacity, a diesel vehicle has currently about 23% lower CO_2 emissions (Nijland et al., 2012).

proposal[13] for split-based minimum energy taxation levels to account for CO_2 and energy component, effectively leading to substantial increase of diesel taxation in most countries.

A broader picture beyond EU reflecting also other levies on motor fuels is provided in OECD study on taxation of energy use (OECD, 2013a). Energy used in transport is taxed more heavily than other categories (heating and process use or electricity), and effective tax rates on diesel for road use in terms of both energy and carbon content are typically lower than the comparable rates on gasoline (except for USA). The comparison of effective tax rates on motor fuels (per CO_2 emissions) shows that EU and EFTA countries have generally high tax rates compared to other OECD countries and to Mexico, USA, and Canada in particular.

Figure 5 – Comparison of effective tax rates on motor fuels in OECD countries



Notes: tax rates as of 1 April 2012; local currencies converted by market exchange rates (average over Sept 2011-Aug 2012). Source: OECD (2013a)

Registration taxes in ten Member States (Austria, Croatia, France, Latvia, Malta, the Netherlands, Portugal, Romania, Slovenia and Spain) and in the Flemish region in Belgium use vehicle-specific CO_2 emissions (expressed in g/km) of fuel consumption (lt./km) as a main

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[13] COM(2011) 169 final

parameter in tax calculation. In some countries registration taxes have evolved into mixture of tax benefits and penalties (*feebate systems*), such as in Austria and France.

In Austria fuel consumption tax (Normverbrauchsabsage or NoVA) is levied upon the first registration of a passenger car. The basic rate is set at 2% of the purchase price multiplied by fuel consumption in litres (3 or 2 litres are subtracted for petrol and diesel cars respectively). Under a bonus-malus system, CO_2 (and NOx) emissions (and presence of particles filter) are accounted for. Cars emitting less than 120 g/km receive a bonus of € 300. Cars emitting more than 150 g/km pay a penalty of € 25 for each gram emitted in excess of 150 g/km. Since 1 March 2011, there is an additional penalty of € 25 for each gram emitted in excess of 170 g/km and another penalty of € 25 for each gram emitted in excess of 210 g/km. These penalties are cumulative. Alternative fuel vehicles attract a bonus of maximum € 500. In addition, diesel cars emitting more than 5 mg of particulate matter per km pay a penalty of maximum € 300. Diesel cars emitting less than 5 mg of particulate matter per km and less than 80 g of NOx per km attract a bonus of maximum € 200. The same applies to petrol cars emitting less than 60 g of NOx per km.

France has enacted a feebate system (called “bonus-malus écologique”) in 2008 under which more efficient cars receive a bonus when purchased, while inefficient cars receive a penalty when purchased. A premium is granted for the purchase of a new car when its CO_2 emissions are 105 g/km or less. The maximum premium is € 5,000 (50 g/km or less). An additional bonus of € 200 is granted when a car of at least 15 years old is scrapped and the new car purchased emits maximum 105 g/km. A malus is payable for the purchase of a car when its CO_2 emissions exceed 140 g/km. The maximum tax amounts to € 3,600 (above 250 g/km). In addition to this one-off malus, cars emitting more than 190 g/km pay a yearly tax of € 160.

Ownership (circulation) taxes in twelve EU member states (Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Luxemburg, Malta, Portugal, Sweden and the UK) have a CO_2 (or fuel consumption) component in calculation of. Engine size/power and CO_2 emissions are the most frequently used tax bases for passenger cars, while heavy goods vehicles that are usually taxed according to gross vehicle weight (GVW).

In Denmark the annual circulation tax is based on fuel consumption. For petrol cars the rates vary from 560 Danish Kroner (DKK) for cars driving at least 20 km per litre of fuel to DKK 19,320 for cars driving less than 4.5 km per litre of fuel. For diesel cars the rates vary from DKK 160 for cars driving at least 32.1 km per litre of fuel to DKK 25,920 for cars driving less than 5.1 km per litre of fuel.

The annual circulation tax for cars registered in Germany from 1 July 2009 on is based on cubature and CO_2 emissions. It consists of a base tax and a CO_2 tax. The rates of the base tax are € 2 per 100 cc (petrol) and € 9.50 per 100 cc (diesel) respectively. The CO_2 tax is linear at € 2 per g/km. Cars with CO_2 emissions below 110 g/km are exempt (95 g/km from 2014).

In Sweden the annual circulation tax for cars meeting at least Euro 4 exhaust emission standards is based on CO_2 emissions. The tax consists of a basic rate (360 SEK) and SEK 20 for each g CO_2 emitted above 120 g/km. The sum is multiplied by 2.55 for diesel cars. Diesel cars registered for the first time in 2008 or later pay an additional SEK 250 and those registered earlier an additional SEK 500. For alternative fuel vehicles, the tax is SEK 10 for every gram emitted above 120 g/km. A five-year exemption from annual circulation tax applies for environmentally-friendly cars.

The UK levies annual circulation tax for cars registered after March 2001 based on CO_2 emissions; since the last reform with higher band resolution (10-15 g CO_2 between bands, now A to M). Rates range from zero rate (up to 100 g/km) to GBP 460 (for cars over 255 g/km) (alternative fuels receive a GBP 10 discount were a rate is paid). A first year rate of registration has applied since 1 April 2010. Rates vary from GBP 0 (up to 130 g/km) to GBP 1,000 (more than 255 g/km). Alternative fuelled cars (i.e. not gasoline or diesel) are charged GBP10 less than their conventional counterparts in the same CO_2 band.

Company car taxation in Belgium, Denmark, Netherlands and UK is in part CO_2 emissions or fuel consumption. In the UK the private use of a company car is taxed as a benefit in kind under personal income tax. Tax rates range from 5% of the car price for cars emitting up to 75 g/km, 10% for cars emitting up to 120 g/km, 15% for cars emitting up to 125 g/km; and then a 1% increase for each additional 5g/km band up to a maximum of 35%. Diesel cars pay a 3% surcharge, up to the 35% top rate. Cars emitting 0g/km are exempt until April 2015.

1.2.3.1. Road pricing

Time-based road pricing (vignette) provide virtually no incentive to reduce car use as there is no relationship between vignette ownership and infrastructure use. On the contrary, this may even increase the use of the infrastructure if the users opt for ‘getting the most out of their money’.

Infrastructure use is the core feature of distance-based road pricing that is widely used for charging use of motorways (or entire network such as in Switzerland) or to limit entrance to congested urban areas. An overview of road charging schemes for use of highways (and in some cases of other main roads) in EU member countries is show in Table 2.

Table 2 – Road charges in EU countries

country	**cars**	**HGVs**
Austria	vignette	road toll
Belgium	-*	Eurovignette
Bulgaria	vignette	vignette
Croatia	road toll	road toll

Czech Republic	vignette	road toll
Denmark	-*	Eurovignette
Estonia	-	-
Finland	-	-
France	road toll	road toll
Germany	-	road toll
Greece	road toll	road toll
Hungary	vignette	vignette
Ireland	road toll	road toll
Italy	road toll	road toll
Latvia	-*	-
Lithuania	-*	vignette
Luxembourg	-	Eurovignette
Netherlands	-*	Eurovignette
Poland	road toll	road toll
Portugal	road toll	road toll
Romania	vignette	vignette
Slovakia	vignette	road toll
Slovenia	vignette	road toll
Spain	road toll	road toll
Sweden	-*	Eurovignette
United Kingdom	road toll	road toll

* except for special tolls for tunnels, bridges etc.
Source: van Essen et al. (2012b), Hylén et al. (2013)

Urban electronic road pricing schemes were introduced in London (2003), Stockholm (2007), Milan (2008), Durham (UK) and Valletta (Malta).[14] While main reasons for introducing these charges were to improve accessibility and air quality, reduction in car traffic is also observed.

Variety of different parking schemes exists in most European cities, such as with or without free parking for electric vehicles, and reduced tariffs for inhabitants or handicapped. For example Sweden has a significant program on clean vehicles and as part of that provides free parking for EVs and other clean vehicles.

1.2.3.2. Subsidies / purchase and tax incentives

Recently popular scrappage (buyback) schemes fall typically fall into one of two broad categories (Brand, Anable, & Tran, 2013): (1) cash-for-scrappage, a payment to consumers regardless of how the consumer replaces the scrapped vehicle, and (2) cash-for-replacement, a payment conditional upon the consumer replacing the scrapped vehicle with a specific type of vehicle (typically a new car). A number of schemes were introduced in EU countries following economic downturn, including Germany, France, Italy, Spain and UK.

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[14] Singapore was the first to implement electronic road (congestion) pricing system in 1998.

The Scrappage Incentive Scheme in the UK was not explicitly addressed on any efficiency or environmental goal but provided a GBP 1000 incentive (matched funding from vehicle manufacturers) for consumers to replace their 10 year old or older vehicle (8 years in the case of vans) with a brand new vehicle. The UK scheme lasted for nearly a year during 2009/2010, reportedly having generated nearly 400,000 new car registrations over the period, or about 20% of all new cars registered in the UK.

A majority of EU member countries provide certain incentives for the purchase and use of electric (EV), hybrid electric (HEV), plug-in hybrid (PHEV), or alternative fuel vehicles (AFV). An overview of various measures is provided in the following table based on ACEA data.

Table 3 - Overview of purchase and use incentives for electric, hybrid and alternative fuel vehicles

country	**purchase incentives**	**use incentives**
Austria	(P/H)EV+AFV - bonus under fuel consumption tax (NoVA)	EV - exempted from vehicle tax
Belgium	EV - exempted from registration tax (Flanders) - Eco-bonus (Wallonia)	EV - lowest annual circulation tax - preferential tax treatment of company cars
Czech Republic	-	(P/H)EV+AFV - exempted from road tax (only business cars are taxed)
Germany	-	EV - exempted from annual circulation tax (10 years from registration)
Denmark	EV - exempted from registration tax (below 2000 kg)	
Spain	(P/H)EV+AFV - premiums from regional governments (EUR 2-7000)	
Finland	EV - lowest rate of registration tax (5%)	
France	(P/H)EV+AFV - premium under bonus-malus system up to EUR 7000	EV - exempted from company car tax (HEV with CO_2 emissions below 110g/km for the first two years)
Greece	(H)EV - exempted from registration tax	
Ireland	(P/H)EV - exemption/partial relief from vehicle registration tax	
Italy		EV - exempted from annual circulation tax (5 years from registration, then reduced rates)
Luxembourg	EV - premium (EUR 5000, limited to agreed supply of green electricity)	
Latvia	EV - exempted from registration tax	
The Netherlands	(P/H)EV+AFV - exempted from registration tax (up to set emission threshold)	EV - exempted from annual circulation tax
Portugal	EV - exempted from registration tax HEV - 50% reduction of registration tax	EV - exempted from annual circulation tax
Romania	(H)EV - exempted from registration tax	

Sweden	Super green car premium - SEK 40,000 for cars with CO_2 emissions below 50 g/km	(P/H)EV - exemption from annual circulation tax (for 5 years from the first registration; only cars meeting new green car definition)
United Kingdom	premiums for low carbon vehicles (PHEV, EV, CO_2 emissions below 75 g/km) up to GBP 8,000	EV - exempted from annual circulation tax - exemption from company car tax (until April 2015)

Source: ACEA (2013)

Subsidies for commuting are provided as in-kind benefit in many countries. As such they tend to enhance transport demand and therefore CO_2 emissions. According to Dutch study abolishment of commuting subsidy leads to 2% to 4% decrease in demand measured as passenger kilometres driven by car (Hibers et al., 2012, cited in Nijland et al., 2012).

1.2.3.3. Biofuel policies

The 2009 Renewable Energy Directive[15] sets an overall 10% target for the share of energy from renewable sources in 2020 in transport sector. Member states were obliged to submit national renewable energy action plans (NREAPs) specifying their plans to meet this target. The policy measures enlisted in NREAPs can be divided in the following subcategories:

- mandates;
- tax exemptions and reductions;
- subsidies;
- dedicated marketing strategies (i.e. aimed at use of blends beyond current blending limits).

The overview of deployment of these instruments in EU-27 as summarized in EC funded study by Kampman et al. (2013) is shown in

Table 5 below. Vast majority of member states oblige suppliers of motor fuels to ensure that a specific percentage of fuel sales is represented by biofuels (mostly based on volume content). Currently, most mandates are within current blending limits for diesel and petrol (i.e. mostly B7 and E5, E10 is now common e.g. in Germany).

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[15] Directive 2009/28/EC

Table 4– Overview of price-based instruments in road transport in EU member countries

	Registration/purchase taxes		EV/AFV incentives	Circulation/ownership taxes		insurance taxes	fuel taxes		
country	**registration tax**	**VAT**		**Passenger Cars**	**Commercial Vehicles**		**petrol (€/1000 lt.)**	**diesel (€/1000 lt.)**	**CO_2 tax**
Austria	Based on fuel consumption Maximum 16% + bonus/malus	20%	maximum € 500 bonus for alternative fuel vehicles	Kilowatt	weight	x	482	397	
Belgium	Based on cc + age + CO_2 emissions (Wallonia) CO_2 + Euro standards + fuel + age (Flanders)	21%	Electric vehicles are exempt from registration tax in Flanders. They benefit from the Eco-bonus (up to €2,500) in Wallonia.	Cylinder capacity	weight, axles	10% (vehicle insurance) +7.56% (risk insurance)	613.57	427.69	
Bulgaria	-	20%		Kilowatt	Weight, axles		363.02	329.79	
Croatia	based on price and CO_2 emissions (differentiated for diesel and for other fuels)	25%	tax reduction for PHEV	Cylinder capacity	-		424.35	330	
Cyprus	Based on cc + CO_2	17%		Cylinder capacity, CO_2 emissions	-		429	400	
Czech Republic	-	21%	Electric, hybrid and other alternative fuel vehicles are exempt from the road tax	-	Weight, axles		511.96	436.6	
Germany	-	19%	Electric vehicles are exempt from the annual circulation tax for a period of ten years from the date of their first registration	CO_2 emissions	Weight, exhaust emissions, noise	x	654.5	470.4	
Denmark	105% up to DKK 79,000 + 180% on the remainder	25%	Electric vehicles weighing less than 2,000kg are exempt from the registration tax	Fuel consumption, weight	Fuel consumption, weight	42.9+1.1% of the insurance premium (34.4% for tourist buses)	592.21	443.29	x
Estonia	-	20%		-	Weight, axles suspension		422.77	392.92	
Spain	Based on CO_2 emissions -from 4.75% (121-159g/km) to 14.75% (200g/km or more)	21%	incentives of €2,000 to €7,000 for the purchase of electric, hybrid, fuel cell, CNG and LPG vehicles	Horsepower	Payload	x	424.69	331	
Finland	Based on price + CO_2 emissions: Min. 5%, max. 50 %	24%	Electric vehicles pay the minimum rate (5%) of the CO_2 based registration tax	CO_2 emissions/ Weight x days	Weight x days	x	650.4	469.5	x

France	Based on CO_2 emissions - from € 100 (136 to 140g/km) to € 6,000 (above 200g/km)	20%	Electric hybrid vehicles emitting 110g/km or less of CO_2 benefit from a premium of up to €3,300	-	Weight, axles, suspension	x	606.9	428.4	
Greece	Based on cc + emissions 5% - 50% Luxury tax up to 40%	23%	Electric and hybrid vehicles are exempt from the registration tax	CO_2 emissions/ cylinder capacity	Weight	10% of the insurance premium	670	330	
Hungary	Based on cc + emissions	27%	lower rates of registration tax for electric and hybrids vehicles (also for CNG/LPG)	Kilowatt	Weight		432.43	398.26	
Ireland	Based on CO_2 emissions: 14 to 36%	23%	Electric vehicles are exempt from the registration tax VRT up to a maximum of €5,000	CO_2 emissions/ cylinder capacity	Weight		587.71	479.02	x
Italy	Based on kilowatt /weight/seats	21%	Electric vehicles are exempt from the annual circulation tax for a period of five years from the date of their first registration. After this five-year period, they benefit from a 75% reduction	Kilowatt, exhaust emissions	Weight, axles, suspension	basic rate 12.5% (provinces may increase/decrease by up to 3.5%)	728.4	617.4	
Lithuania	LTL 50	21%		-	Weight, axles, suspension		434.43	330.17	
Luxembourg	-	15%	electric vehicles (or other vehicles emitting 60g/km or less of CO_2) receive a premium of €5,000	CO_2 emissions	Weight, axles		462.09	335	
Latvia	Based on CO_2 emissions	21%	Electric vehicles are exempt from the registration tax	Weight	Weight		415.11	336.11	
Malta	Based on price, CO_2 emissions, vehicle length	18%	Electric and hybrid vehicles have a zero tax rate	Cylinder capacity	-		469.39	382.4	
The Netherlands	Based on price + CO_2 emissions	21%	Electric vehicles are exempt from registration tax and annual circulation tax Cars emitting less than 95 g/km are exempt from registration tax	CO_2 emissions, weight	Weight		746.55	440.28	
Poland	Based on cc 3.1% - 18.6%	23%		-	Weight, axles		406.3	354.61	
Portugal	Based on cc + CO_2 emissions	23%	Electric vehicles are exempt from registration tax annual circulation tax (hybrids 50% reduction of registration tax)	Cylinder capacity, CO_2 emissions	Weight, axles, suspension		585.27	367.53	
Romania	Based on cc + emissions + CO_2	24%	Electric and hybrid vehicles are exempt from the registration tax	Cylinder capacity	Weight, axles		359.59	330.395	

Sweden	-	25%	Super green car premium of SEK 40,000 for the purchase of a new cars with CO_2 emissions of maximum 50 g/km exemption of EV & EV from circulation tax for 5 years	CO_2 emissions/ weight	Weight, axles, exhaust emissions	x	664.46	572.99	x
Slovenia	Based on price + CO_2 emissions	20%		-	-		656.95	446.32	x
Slovakia	-	20%		-	Weight, axles		514.5	368	
United Kingdom	-	20%	Electric vehicles are exempt from the annual circulation tax EV&PHEV receive a premium of £ 5,000 (maximum)	CO_2 emissions/ cylinder capacity	Weight, axles, exhaust emissions		674.15	674.15	

Sources: ACEA Tax Guide 2013, Taxes in Europe (TEDB), van Essen et al. (2012), DG TAXUD Excise duty tables, July 2013

Table 5 – Overview of biofuel policy instruments in EU-27

	AT	BE	BG	CY	CZ	DK	EE	FI	FR	DE	EL	HU	IE	IT	LV	LT	LU	MT	NL	PL	PT	RO	SK	SI	ES	SE	UK
mandates																											
Overall	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X	X	X	X		X
Petrol	X	X			X					X		X							X			X	X		X		
Diesel	X	X			X					X		X							X			X	X		X		
tax exemptions/reductions																											
Vehicle registration	X												X								X			X			
Circulation taxes	X										X																
Fuel taxes	X	X	X		X		X	X	X	X		X	X	X	X	X		X	X	X	X		X	X	X		X
CO_2 tax						X	X	X	X																	X	
Road charging		X																		X							
Other									X											X							
subsidies																											
Vehicles				X		X							X					X	X								X
Infrastructure																											
R&D/pilot plants						X		X											X								
Biofuel production				X				X							X		X									X	
Biomass production			X													X											
dedicated marketing strategies																											
Low blends	X				X																						
High blends					X		X		X			X		X	X	X			X						X	X	
Pure biofuels			X		X					X									X								
Biogas																										X	
Other/n.a.		X		X		X		X			X		X				X	X		X	X	X	X	X			X

Source: Kampman et al. (2013)

1.3. Non-road modes

1.3.1. Rail transport

The rail transport is commonly considered as climate friendlier means of transport compared to road and air transport. This may be the reason that there are only two pricing instruments used that are to some extent related to climate policies – taxation of energy products (fuels and electricity) and infrastructure access charges. Infrastructure access charges are however of minor importance as they are primarily intended to cover costs of infrastructure provision and maintenance and only rarely reflect environmental effects other than noise.[16]

Taxation of energy products used by rail, most importantly diesel and electricity including preferential treatments is harmonized through Energy Taxation Directive that allows for partial or total exemption of energy products used for carriage of passengers and goods by railways. EU member countries widely differ in using these concessions – while 16 MS set tax rate for electricity used by railway at standard rate, only 12 MS levy energy taxes on diesel in at standard rate.[17]

Table 6 - Exemptions/reductions applied in energy (excise) taxes

Country	Diesel	Electricity
Austria	Standard rate	Standard rate
Belgium	Exemption	Exemption
Bulgaria	Standard rate	Standard rate
Croatia	Standard rate	Standard rate
Czech Republic	Standard rate	Exemption
Denmark	Reduction	Reduction
Estonia	Reduction	Standard rate
Finland	Reduction	Standard rate
France	Reduction	Standard rate
Germany	Standard rate	Reduction
Greece	Standard rate	Standard rate
Hungary	Exemption (via tax refund)	Standard rate
Ireland	Reduction	Standard rate
Italy	Reduction	Exemption
Latvia	Standard rate	Exemption
Lithuania	Standard rate	Standard rate
Luxembourg	Exemption	Standard rate
Netherlands	Standard rate	Standard rate

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[16] One such example is the Czech Republic where access charge is increased for use of electrified line by diesel-motored vehicles.

[17] Although the share of energy taxes in price of electricity is usually much smaller compared to share of energy taxation in price of diesel.

Poland	Standard rate	Standard rate
Portugal	Reduction	Standard rate
Romania	Standard rate	Standard rate
Slovakia	Standard rate	Exemption
Slovenia	Reduction	Standard rate
Spain	Exemption	Standard rate
Sweden	Exemption	Exemption
United Kingdom	Standard rate	Standard rate

Note: Malta and Cyprus are not reported as there is currently no railway in operation.
Source: DG TAXUD

1.3.2. Aviation

Aviation has seen a dramatic increase in CO_2 emission in last decades with on-going globalization, liberalization and rise of low-cost air carriers. The portfolio of climate policy instruments in aviation comprises emission trading, fuel taxes and aviation taxes. Airport charges and air navigation service charges are not very relevant as there shall as a principle be based on cost-recovery principle (although airport charges, especially noise charges, are sometimes differentiated to encourage use of least noisy aircrafts).

The 2008 amendment to ETS Directive 2003/87/EC[18] extended emission trading scheme to include CO_2 emissions from international aviation starting from 2012. Originally all the aircraft operators operating civil commercial flights to and from any airport in the EU or EFTA were obliged to surrender an amount of allowances corresponding to CO_2 emissions from these flights. Following a huge pressure from USA, China and Russia during 2012, EU announced a “freeze” on enforcing application of emission trading to non-EU flights and let ICAO to act on a global mechanism for tackling CO_2 emissions from aviation. In October 2013 the Commission proposed amending the EU ETS so that only emissions for the part of flights that takes place in European Economic Area will be covered, i.e. about 35% of aviation emissions originally included in ETS. The ICAO global mechanism is to be agreed by 2016 and start in 2020.[19]

The possibility for <u>aircraft fuel taxation</u> is very limited – the Convention on International Civil Aviation (1944) exempts from custom duty and local duties and charges fuel and lubricating oils on board of aircrafts, while aircraft fuel loaded in host country is usually exempted pursuant to bilateral air service agreements. Energy Taxation Directive concedes to this in Art. 14 (1) (b) that exempts energy products supplied for use as fuel for air navigation (other than private pleasure-flying).

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[18] Directive 2008/101/EC.

[19] In recent ICAO assembly the EU failed to find sufficient support for “airspace approach” that would allow to impose ETS on emissions over EU airspace, and the assembly restated its position (not mandatory) that any measure to reduce emissions from aircrafts could only happen under bilateral agreements.

Although the possibility of levying CO_2 emission charges was repeatedly discussed in ICAO, the consensus among member states has not been reached and such charging is therefore only possible by bilateral agreements (or mutual agreement among member states of a regional economic integration organization such as EU).

Several EU countries have a specific fuel tax rate for aviation gasoline used in intra-country flights: Ireland (tax rate € 587.71/1,000 litres including CO_2 charge), Finland (€ 641.2/1,000 litres, incl. energy content and CO_2 tax and stock pile fee), United Kingdom (€ 438.57/litres), France (€ 359/1,000 litres), and Sweden (€ 427.98/1,000 litres, including CO_2 tax).

UK was one of the first countries to introduce air passenger tax in 1994 and the rates were increased several times (in 2007, 2009, 2010, and 2012). Tax rate depends on the final destination (4 bands) and the travel class (2 classes).

Denmark introduced air passenger tax in 2005, but halved the rates in 2006 and the tax was abolished in 2007 mostly because many passengers evaded to Malmö and Gothenburg airports in Sweden.

France introduced air passenger tax in 2007 as a charity charge whose proceeds support UNITAID with rates differentiated for flights within and outside EU and for first/business and other classes.

Netherlands imposed air passenger tax in July 2008 but after protests from aviation and tourism sectors set the rate to zero a year later and finally abolished the tax in January 2010. Gordijn and Kolkman (2011) observe a decline in demand, increasing use of low-cost airlines and defection of passengers to foreign airports (Düsseldorf, Weeze and Brussels).

Ireland imposed air travel tax in 2009 with two rates for short- and long-haul flights that were changed to single rate of €3 per departing passenger in 2011.

Germany introduced air traffic tax (Luftverkehrsteuer) from January 2011, but its future is not clear as it faces fierce opposition from aviation industry and Bavaria. The rates are differentiated according to flight length to 3 categories (EU, EU-candidate and EFTA countries; other countries less than 6000 km away, other countries beyond 6000 km). An assessment by Intraplan (2012) attributes to the tax introduction a loss of 2.5% of air traffic demand, 2/3 of it as decreased demand and 1/3 as defection to foreign airports.

In Austria a system similar to the German one was introduced in April 2011 with differentiated rates for short-, medium-, and long-distance flights (€8, €20, €35 per passenger).

1.3.3. Water navigation

Water navigation and maritime shipping in particular is a large source of GHGs with strong increase in the past and forecasted growth in the future. Yet there has only little been done what is especially true about international maritime emissions. While the European Commission strives for a legally binding reduction commitment the progress in IMO is relatively meagre – a Resolution on technology cooperation that was effectively barring setting of energy efficiency standards was only adopted in May 2013. In June 2013 the Commission put forward a proposal for monitoring, reporting and verifying annual CO_2 emissions from large ships using EU ports.[20]

There are several pricing instruments used in varying extent in water navigation – fuel taxes, port dues, fairway dues and waste (water) discharges. According to van Essen et al. (2012b) majority of EU member states exempt fuels for freight and passenger inland navigation (unlike France and Italy) and only levy fuels used for recreation and pleasure boats.

Table 7 – Fuel taxes for inland navigation

Tax imposed	Freight	Passenger	Recreation / Pleasure
Austria	No	No	Yes
Belgium	No	No	No (diesel)
Bulgaria	No	No	Yes
Czech Rep.	No	No	Yes
Estonia	No	No	Yes
Finland	No	No	Yes
France	No	Yes	Yes
Germany	No	No	Yes
Hungary	No	No	Yes
Italy	No	Yes	Yes
Latvia	No	No	Yes
Lithuania	No	No	Yes
Netherlands	No	No	Yes
Poland	No	No	Yes
Romania	No	No	Yes
Slovak Rep.	No (on Danube)	No (on Danube)	Yes
Spain	No	No	Yes
UK	No	No	Yes

Source: van Essen et al. (2012b)

The scope for use of pricing instruments (fuel taxes etc.) in international maritime navigation is quite similar to that for aviation. According to UN Convention on Law on Sea the right of innocent passage in the territorial sea is guaranteed for foreign-flag vessels without being

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[20] COM(2013) 480 final

subject to any charges, except for services received. Consequently, in all the EU member states, energy products supplied for the use commercial navigation are exempted from the excise duty.[21]

1.4. Effectiveness of instruments

As OECD (2006) underlines any policy instrument used to achieve environmental targets should cause changes in consumption and/or production patterns to be considered effective. If an instrument fails to cause such changes, it cannot deliver any environmental improvements. The relevant issue here is who is to change their behaviour, by how much and within which timeframe.

A usual measure of the demand response to changes in price (e.g. from tax increase) is referred to as elasticity (own-price/cross-price) and is described in detail in section 3 of this report. We only briefly summarize findings from studies already cited here that specifically reflect pricing instruments' effectiveness in this section.

As suggested by Nijland et al. (2012) there are two main mechanisms that can explain observed improvements in efficiency. First, through technological change, all car types may have become more fuel-efficient. Second, consumers may have changed their behaviour by moving towards more fuel-efficient types (AFV, diesel, fuel-efficient car). Nijland and colleagues analysed new car sales data for 14 EU countries in the 2001-2010 period and found – for the technology improvement part – that a large part of variation between countries in diesel and petrol efficiency improvements can be explained by differences between countries and years in the cars' features, such as weight, engine size, and horse power. With respect to consumer choice and fuel shift in particular they note that 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. On the other hand diesel cars are on average heavier than petrol cars meaning that an increase in weight may counteract decarbonisation efforts. The first effect, i.e. reduction of CO_2 emissions due to a market shift towards diesel vehicle sales, has been significant explanatory variable in a study by Fontaras and Samaras (2007) who analysed car manufacturers' voluntary agreements using experimental emission data from ARTEMIS database.

Frondel et al. (2011) in their frontier analysis argue that reliance on targets based on per-kilometre emissions (i.e. fuel efficiency/CO_2 emissions) not only obscures true compliance costs but is also less cost-effective that alternatives such as emission trading. Yet another evidence of compromised efficiency of fuel economy standards is presented in Ajanovic and

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[21] See also Energy Taxation Directive 2003/96/EC Art. 14 (1) c.

Haas (2012) who find a high rebound effect with 44% more km driven if fuel intensity is improved. Their conclusions are clearly pointing out that technical standards as the only policy instrument will have limited success and that fuel taxes accompanied to fuel intensity standards may compensate the rebound effect.

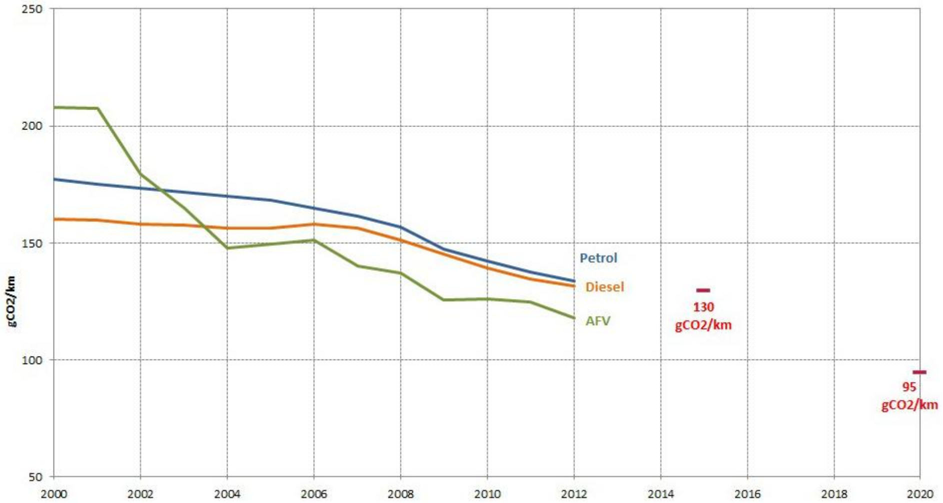
Klier and Linn (2013) estimated the effect of fuel prices on average new vehicle fuel economy in 8 largest EU countries based on detailed data from 2002-2007 period and find a statistically significant effect on average new vehicle fuel economy, but this effect is much smaller than such estimates for the US. Schipper (2011) also observes rising fuel economy in Europe since mid-1990 and also points to confounding effects – plateau in per capita vehicle use and upward spiral of car weight and power that effectively slows or negates improvement in fuel economy. He also notes that the promise of savings from dieselization has not materialized on a large scale mostly since diesel cars are driven much more than gasoline cars.

1.4.1. Fuel economy/CO_2 emission standards

In the following paragraphs we briefly review effectiveness of fuel economy/CO_2 emission standards focusing on studies in the EU. A large economic literature analysing the U.S. CAFE standards is summarily discussed in Chapter 2 below.

The effects of Regulation (EC) 443/2009 can be witnessed in the marked reductions in fuel consumption per km, and hence the fall in CO_2 emissions per km, for new cars sold across the EU that could be observed in recent years. Between 2000 and 2007, there was only a fairly modest decrease in fuel consumption and hence emissions: The average for new cars declined from 172 g CO_2/km in 2000 to 159 g CO_2/km in 2007, which represents an average reduction of 1.2% per year. Since 2007, the speed of reduction has increased perceivably: in 2007 – 2011, average emissions of new cars have declined by 3.8% per year, from 159 to 136 g CO_2/km, suggesting that the target of 130 g CO_2/km, set for 2015, will be achieved well ahead of time.

Figure 6 - Average emissions for new cars sold in EU versus 2015 and 2020 targets



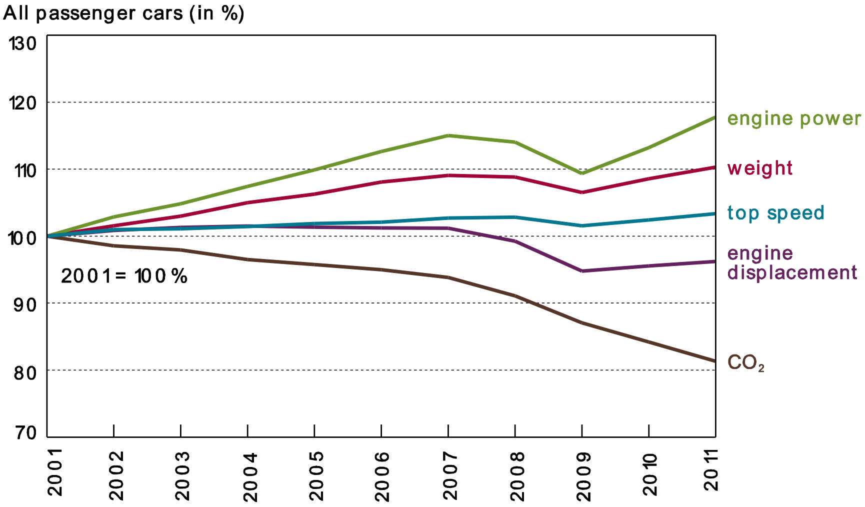
Note: AFV – alternative fuel vehicles
Source: EEA (2013)

The effectiveness of CO_2 emission standard set by the said Regulation is however substantially distorted by the weight-based nature of specific emissions calculation. This is because car makers who reduce their vehicle's weight would face a stricter CO_2 standard hence it exerts only weak incentive to vehicle weight reduction. Indeed, as **Error! Reference source not found.** documents the vehicle weight of European new vehicle fleet has grown by 10% between 2001 and 2011, while CO_2 emissions were reduced by almost 20%.

In this respect Nijland and colleagues (2012) found in their study that a 10 % increase in weight accounts for about 8.4 % increase in CO_2 emissions, whereas a 10 % increase in engine displacement accounts for an increase in CO_2 emissions of a 0.8 %. Furthermore, due to weight increase alone, diesel and petrol cars have become less fuel efficient by 6 % and 2 % respectively, but corrected for fuel type, weight, engine capacity and engine power cars have become some 23 % more fuel efficient over that period. They also observe that increase in engine power does not significantly increase CO_2 emissions.

A similar claim with respect to "decoupling" of engine power and CO_2 emissions was made by VDA (2013) that reports that engine power of German-branded passenger cars on the German market in the past 6 years has increased by 8 percent to 106 kW but at the same time average CO_2 emissions have been cut by 10 percent to 141.4 grams/km. These findings are also reflected in European vehicle market statistics by ICCT that *inter alia* reports relative evolvement of CO_2 emissions and technical parameters over the period 2001-2011.

Figure 7 – Passenger cars CO_2 emissions and technical parameters (2001=100%)



Source: ICCT (2012)

Recent ICCT study (Mock et al. 2013) conducted on a sample of almost half a million private and company cars from Europe also found a gap of around 25% between so called type-approval and real-world fuel-efficiency (and consequently CO_2 emissions). They also observed a temporal increase in average type-approval and on-road discrepancy – from below 10% in 2001 to about 25% ten years later. The authors suggest that rather than substantial change in driving behaviour the gap is likely due combination of various factors including increased application of technologies showing higher benefits in type-approval tests than on-road, use of permitted variances in type approval and changes in external factors (e.g. increased use of air-conditioning). Previous study on Dutch vehicle fleet (Ligterink and Bos, 2010, cited in Nijland et al., 2012) reported that gap between real world and test-cycle emissions was also more pronounced for the lowest emitting cars.

The choice of weight-based calculation (as opposed to single CO_2 standard or footprint-based calculation[22]) was pushed through by Germany, the home country to luxury car manufacturers (such as Daimler and BMW), who would likely be hit harder by the emission standard if the fleet average emissions calculation does not account for weight (as luxury cars tend to be heavier and consume more fuel per kilometre) or a single CO_2 standard is mandated.

Furthermore from a broader perspective the fuel/CO_2 emission standards – at least as nowadays used – are relatively incompatible with other instruments and interplay with other instruments (mostly adopted at EU member states level) is often rendering the latter

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[22] Track width multiplied by wheelbase; the revised U.S. CAFE standard now uses this approach. For review of responses to attribute-based regulation see e.g. Ito and Sallee (2013).

ineffective.[23] This holds in particular for policy measures addressing purchase of electric, hybrid and other AFVs such as tax credits or other subsidies, because in the presence of binding fuel economy regulations greater penetration of hybrid vehicles will simply allow carmakers to cut back on fuel-saving technologies for conventional petrol (or diesel) vehicles. Similarly, taxes on vehicles with low fuel economy or high CO_2 emissions may increase demand for smaller, more efficient vehicles, but this will allow carmakers to install fewer fuel-saving technologies than would otherwise be needed to meet the standard (Anderson et al. 2011, McConnell and Turrentine 2010).

1.4.2. Labelling schemes

A study on implementation of car labelling directive (AEA, 2012) claims that absolute labelling (i.e. showing actual CO_2 emissions) outperforms relative labelling (i.e. showing comparison within same class) in terms of intelligibility for consumers. The authors note that its main disadvantage – erosion in differences between ratings assigned to similar cars – can be overcame by showing best (and possibly also worst) ones in class. In a recent study for DG Climate Action Codagnone et al. (2013) analysed effectiveness of possible new eco-label variants and of related promotional materials using internet surveys and laboratory experiments in three member states. They find that absolute classification system works better than others, and that fuel economy nudges (information on lost savings on fuel, running costs/electricity consumption) work better than emission related nudges. Also graphical illustration of CO_2 emissions and indication of running costs over several years are examples of effective nudges.

While a representative survey by Deutsche Energie Agentur (quoted in VDA, 2013) reports that the label was either important or very important factor for about 63% respondents in their purchase decision, Codagnone et al. (op. cit.) found that respondents are only moderately familiar with existing labels, and more importantly that there is an attitudes-action gap between attitudes and actual behaviours (i.e. consumers first selecting vehicle class and seem to take eco-friendliness into account only when selecting a model).

1.4.3. Fuel taxes

Nijland et al. (2012) in their analysis show that increase in fuel prices (via fuel taxes) 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. They suggest that fuel taxes are effective in reducing the number of car kilometres per person but not effective in influencing prospective car buyers in the decision whether to buy

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[23] Note that this raises issues similar to those about interactions between the EU Emission Trading Scheme and member states' climate & energy policies.

diesel or petrol fuelled car. This finding is however not fully consistent with findings by Burguillo-Cuesta et al. (2011), who studied effects of dieselisation in EU-15 using simultaneous equation model. They conclude that diesel car choice in EU-15 is mainly a consequence of technological improvements reinforced by institutional factors (favourable diesel fiscal treatment, emission standard policies etc.). They also found that habit, income and economic efficiency are significant explanatory variables in purchase decision (while neither relative price of diesel nor relative price of diesel car is significant) and habit, real income per capita, diesel car registrations and real excise duties on motor fuels are significant variables explaining diesel demand. According to authors the dieselisation process is to continue, in part reinforced by habit in diesel car demand.

1.4.4. Vehicle taxation

The evidence on effectiveness of purchase/registration taxes is rather mixed. A study by COWI (2002) estimated that CO_2-related restructuring of registration tax would reduce CO_2 emissions by 5% per year over 20 years. Rogan et al. (2011) reports that the Irish car tax changes in July 2008 from engine size based to CO_2 emission performance were estimated to reduce average specific emissions of new cars by 13% (i.e. to 145 g/km) in the first year of the scheme; and this effect translated into a 33% reduction in tax revenue. Nijland et al. (2012) using random effects panel estimator analysis estimated that a registration tax that will increase the sales price of a diesel car relative to its petrol counterpart by 1000 euros, will decrease the share of diesel cars in new car sales by 3%. Meerkerk et al. (2013) analysed vehicle purchase decisions among Dutch households to find that differentiation of the purchase tax seems to be rather effective, leading to a predicted increase in probability of purchasing a small gasoline and small diesel car of approximately 11% and 20% respectively.

An econometric modelling by Ryan et al. (2009) using data for EU-15 from 1995 to 2004 suggested that registration taxes in place in that period did not have an important impact on the CO_2 emissions intensity of the new passenger car fleet over and above the effects of circulation and fuel taxes.

In a life cycle-based assessment of environmental effects of French bonus-malus system D'Haultfœuille et al. (2013) found a short- and long-run increase in CO_2 emissions (169 kt and 1Mt CO_2 per quarter, respectively). The positive effect of the change in new car sales composition (-80.5 kt) is overturned by CO_2 emissions from new car manufacturing (232 kt). In the long-run a lifetime change effect also comes into play (decrease in vehicle life-time in small cars' class B and substantial increase in life-time of large cars' class G), and emissions from travels due to the increase in the fleet size prevails.

Kok (2011) explores effects of CO_2-differentiated vehicle taxation on car choice, CO_2 emissions and tax revenues. He finds that Dutch consumers are responsive to price incentives for low carbon cars in that cars exempted from registration tax (i.e. below 95 g/km) in the small and compact segment reached 50% market share on new car sales in 2010 and fleet average CO_2 emissions from new cars have fallen to 136 g/km (instead of 142 g/km without tax changes).

Duer et al. (2011) assessed car taxation in Nordic countries and found that the size of the car fleet depends inter alia on the consumer prices for cars and inherently on the registration tax. Further, car fleet composition depends on numerous factors, and the model for Denmark foresees only minor change in average CO_2 efficiency of new cars if the registration tax is abolished (but the total mileage and CO_2 emissions will increase because the car fleet will increase and include both more new small and large cars, and the growing number of cars will result in higher mileage and total CO_2 emissions). If the registration and circulation taxes are differentiated according to CO_2 emissions the composition of new car fleet will converge to more CO_2 efficient cars.

Zimmermannová (2012) analysed impact of second-hand registration fees for passenger cars on fleet composition in the Czech Republic. She finds a strong positive linear correlation between the car registration fee and new registrations of new passenger cars, and a strong negative linear correlation between the car registration fee and new registrations of used passenger cars.

1.4.5. Road pricing

A review by Anas and Lindsey (2011) indicates that potential congestion relief benefits of road pricing dominate any environmental benefits and that schemes designed for congestion pricing can yield appreciable environmental benefits if designed to minimize traffic displacement. Li and Hensher (2012) give an overview of the effects of the congestion charging schemes in four cities (London, Stockholm, Milan and Singapore), with a prevailing evidence of car traffic reduction by about 15% to 20%.

Table 8 - Effects of congestion charging schemes

Impact	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	Observed peak traffic after charging hours in the first year, normalised in	Observed peak traffic after charging hours	+23%

	coming years	the coming years		
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%

Source: Li and Hensher (2012)

Börjesson (2012) analyse congestion charging in Stockholm and show that the traffic reduction caused by the charges has increased slightly over time and that exemption of alternative fuel vehicles from the charge (until the end of 2008) has led to substantial increase in their sales. Several studies also investigated effects of congestion charging on air quality. While no consistent evidence of improved air quality resulting from the congestion charging scheme in London was found (Kelly et al., 2011), Carnovale and Gibson (2012) in evaluation of Milan's congestion charging found that temporary suspension of the charge led to increase in average daily concentration of PM_{10} and CO by 15% and by 25% in case of total suspended particles (even more hourly results for particles peaked with 40% increase in late afternoons). Another assessment of Milan's congestion charging by Rotatis et al. (2010) found that the scheme has been effective in curbing not only pollution emissions, but also congestion. Also interestingly, the authors note that the result has been achieved with low implementation costs and without major political opposition.

1.4.6. Purchase and tax incentives

The effects of the scrappage policies on CO_2 emissions are not clear and are highly dependent on the detailed design of the scheme, possible rebound effects and on the fact that they had been introduced primarily to stimulate the car market rather than to meet any explicit environmental objectives. The effects reported consist in either a slight decrease or increase in CO_2 emissions (Van Wee, De Jong, & Nijland, 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).

Nemry et al. (2009) emphasize that 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. Furthermore, the effects tend to be temporary (unless the policy is permanent) - car sales increase only during the period the policy is maintained and afterwards car sales drop. The observed emission reductions during the policy implementation period rapidly disappear after it is no longer in place. The age limit (usually set as a qualifying criterion) is likely to induce delay in envisaged scrappage (and drop in car sales) before the start of the scrappage program. With the purchase of a new car people may be attracted to travel more (e.g. due to enhanced reliability and higher energy efficiency) leading to a substantial rebound effect. Also in ex-ante modelling by Brand et al. (2013) scrappage schemes are found relatively inefficient in reducing CO_2 emissions and on life-cycle basis they may even increase CO_2 emissions.

1.5. Cost-effectiveness

Cost-effectiveness is traditionally used to determine the least costs option to achieve a policy goal, i.e. GHG emission reduction target. The costs of reaching the specified target are estimated by using a cost (abatement) curves or another modelling approach. Consequently, the choice of policy instruments affects the efficiency at which a given target it reached and also affect the rate of new technology developments, which can be of importance for the cost to society of reaching policy targets in the longer term.

Smokers et al. (2009) examined a popular hypothesis that greenhouse gas abatement costs of measures in the transport sector are higher than for measures in other sectors to find that studies claiming high costs in the transport sector tend to focus on a limited number of expensive options (mainly hybrid passenger cars and biofuels), and that various studies show that compared to other sectors the transport sector has a significant reduction potential available at negative abatement costs.

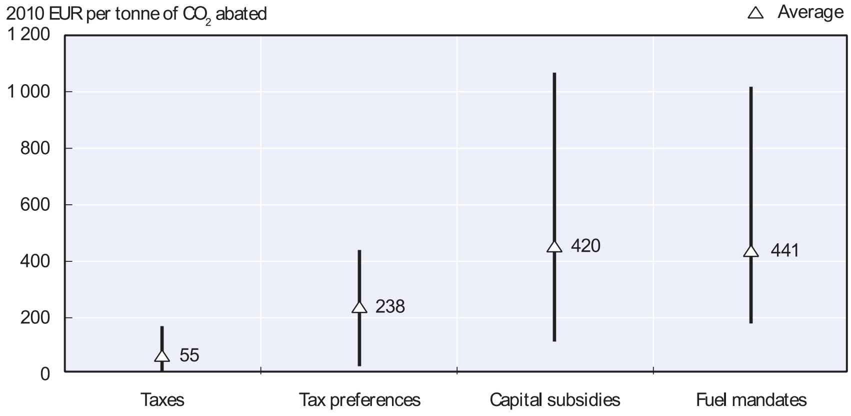
Cost-effectiveness estimates for various measures in transport were summarized in EU Transport GHG: Routes to 2050 project (Hill et al., 2012). The authors summarize that technical measures (engine, transmission, hybridisation, driving resistance reductions, auxiliary systems often have relatively low or even negative abatement costs (mostly in form of reduction in fuel consumption) but have not been exploited due to various barriers (principal-agent problems, ownership transfer problems, pricing distortions, technical standards, consumer habits, lack of awareness etc.). Negative cost-effectiveness figures are also reported for fuel efficient driving (between -100 and -10 euro per tonne CO_2), fuel taxes (-592 to -150 euro per tonne CO_2), passenger car road charging (-99 to -38 euro per tonne CO_2), and reduction of tax-free compensation for commuter and business travel (-84 to -338 euro per tonne CO_2). In contrast, lowering speed limits on motorways seem to be relatively ineffective – carbon costs of lowering limits from 120 to 100 km/h were estimated to about 250 euro per tonne CO_2 and also from 100 to 80 km/h to about 420 euro per tonne CO_2.

Carbon costs of attaining 130 g/km vehicle standards were estimated to 6 to 54 euro per tonne CO_2. Cost curves of 95 g/km target for 2020 were estimated in a study by TNO led consortium (Smokers et al., 2011), with average marginal costs (for every manufacturer) amounting to EUR 91 g/km. Hill et al. (2012) claims that strong indications exist that the costs for meeting the 2020 target could be lower that estimated using the main cost curves from the TNO's study, as the scenarios in their study suggest that payback times might be equal to or shorter than what was estimated for the 130 g/km target.

Van Wee et al. (2011) noted that cost-effectiveness of car scrappage schemes is often quite poor, but their review suggests that scope of emissions accounted for in the assessments matters. Nemry et al. (2009) estimated the average cost of GHG emissions reduction at USD 600/ton, while Li et al. (2010) at USD 91-294/ton or USD 106334/ton with and without taking into account the co-benefit of reducing air pollutants respectively.

Recent study by OECD (OECD, 2013b) estimated CO_2 reduction costs in 15 countries for a broad range of instruments *inter alia* in road transport sector to find that energy taxes are by far the most cost-effective way of emission reduction.

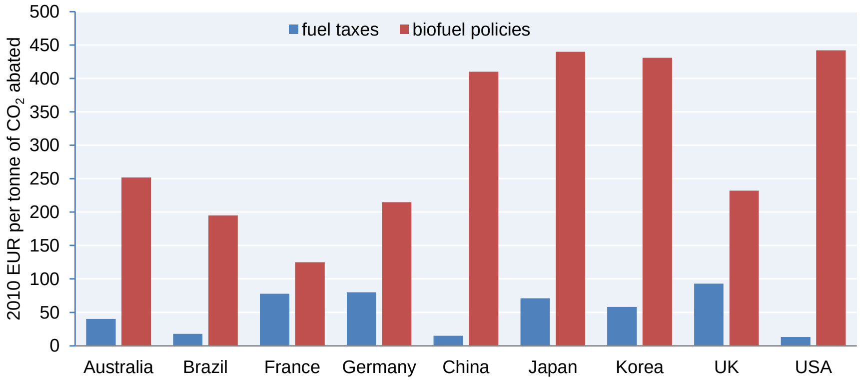
Figure 8 - Estimated effective carbon prices in the road transport sector



Source: OECD (OECD, 2013b)

A comparison of effective carbon prices of fuel taxes and biofuel policies (tax preferences, grants and mandates) in 9 countries from OECD study is shown in Figure 9. This well illustrates that biofuel policies tend to be costly option for curbing carbon emissions and also that costs of biofuel policies substantially differ across countries.

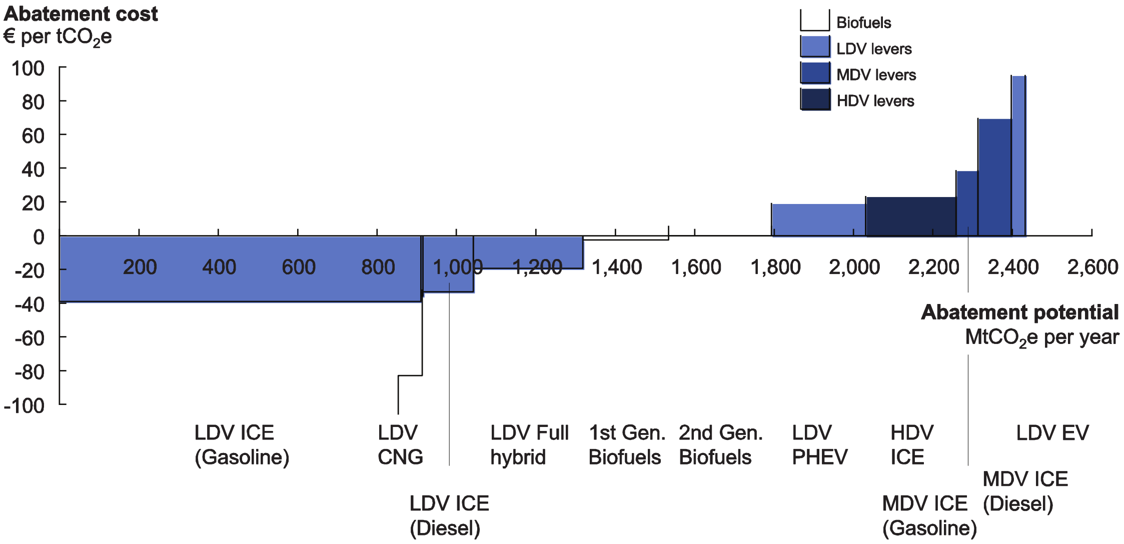
Figure 9 - Effective carbon prices of fuel taxes and biofuel policies



Source: data from OECD (OECD, 2013b); carbon prices reported as intervals are shown as arithmetic average.

Yet another illustration of cost-effectiveness estimates for various measures are GHG abatement costs curves such as those developed by McKinsey&Company that combine abatement costs and abatement potential in a single graph. Its global 2.0 version shows that in road transport sector there is a substantial potential for abatement at negative costs mainly from efficiency improvements in internal combustion engine technology of light duty vehicles and that average costs of the reductions under consideration are negative.

Figure 10 - Global GHG abatement cost curve for road sector (mix technology scenario 2030; societal perspective)



Source: McKinsey&Company (2009)

Note however that McKinsey&Co. abatement cost curves have been repeatedly criticised for substantial shortcomings, including comparability and consistency of the data used and ignoring existing taxes, subsidies and incurred transaction costs of abatement measures.

1.6. Concluding notes

This overview has demonstrated in a non-exhaustive manner the breadth of deployment of policy instruments aiming at curbing GHG emissions from transport. Albeit the review is selective in focusing dominantly on road passenger transport – where the level of instruments' deployment is by far the largest – most of the notes apply sector-wide.

Importantly, it is now well documented that transport sector has a significant GHG reduction potential and in contrast to common wisdom of high costs of emission reduction, there is a substantial reduction potential at a very low (or even negative) abatement costs.

When it comes to choosing the most effective policy instruments targeting fuel economy and fuels seem arguably reasonable. Numerous studies indicate that fuel taxes are a far more cost-effective policy than fuel economy standards because they exploit more options for reducing fuel use.[24] In addition, pricing instruments tend to be additive – i.e. hybrid vehicle subsidies and CO_2 related vehicle taxes can improve fuel economy and reduce fuel use, regardless of any pre-existing fuel taxes. Some argue here that pricing policies may be more effective if fuel taxation is applied in combination with other types of charges, feebates being one of the most promising – they provide on-going incentives for improvement and does not diminish with technical advancements (whereas fuel economy standards often stay constant).

Hence, it is needed to ensure that manufacturers and consumers face stable long-term incentives to increase fuel efficiency – be it through fuel and differentiated vehicle taxes and/or feebates or through fuel carbon pricing where fuel excise duty is currently below the shadow price of carbon. It has been also pointed out that point of compliance may be relevant as an implication for cost-effectiveness. Behavioural response to price incentives (such as feebates) may be stronger if the incentives are levied at the consumer rather than the producer level because of information asymmetries (Busse, Silva-Risso, & Zettelmeyer, 2006). Brand et al. (2013) also highlighted the role of CO_2 grading in acceleration of low carbon technology uptake. On the "pull" side reducing the cost of new technology development and deployment e.g. through early investment in low-carbon research and public procurement policies may trigger uptake of new technologies.

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[24] Austin and Dinan (2005) and Jacobsen (2013) estimate that for a given long-run reduction in fuel consumption, fuel economy standards (U.S. CAFE in this case) are about two to three times more costly than a tax on petrol.

It is also important to note that instruments aiming to reduce CO_2 emissions by increasing the cost of transport all have the potential for adverse social and distributional impacts.[25] In particular, such policies would impact on the affordability and thus the mobility of low income groups and those living in rural areas in particular.

In addition, to allow for more accurate evaluation of instruments of diverse nature it is necessary to adapt GHG “accounting scope” to take better account of entire well-to-wheel emissions for alternative options, to account also for emissions emitted in the course of extraction, production and transmission, and embedded energy in vehicles (i.e. emitted in the course of the vehicle‘s production).

Design of policy instruments is of particular importance in order to avoid making unwanted perverse incentives. As documented by Anderson et al. (2011) separate standards for cars and light trucks, the taxes on inefficient vehicles and subsidies of efficient vehicles operate separately within these two fleets, meaning that large cars are taxed while potentially less efficient small trucks are subsidized. This creates a perverse incentive to redesign large cars as trucks (i.e. SUVs, pickups etc.). Similarly, “tax notches” - pivotal points where a marginal change in fuel economy can create a large discrete change in tax treatment – are often present in vehicle taxation schemes. Manufacturers’ response to such notches by slightly modifying vehicles close to cut-off points in the tax system, resulting in some loss of efficiency, has been found by e.g. Sallee and Slemrod (2012).

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[25] Note that fuel economy standards may also be regressive, cf. Jacobsen (2013).

2. American vehicle emission regulation schemes

In the United States (US), rules governing motor vehicle emissions and fuel efficiency are promulgated through three separate regulatory systems. The Environmental Protection Agency (EPA), the National Highway Traffic Safety Administration (NHTSA), and the State of California’s Air Resources Board (CARB) each have the authority to create rules and regulations regarding emissions or fuel efficiency standards in motor vehicles sold in the US. These systems were established independently, at different times, and with different regulatory objectives in mind. However, since 2009 these three systems have been working in cooperation with each other to harmonize their standards, effectively creating a single “National Program” for emissions and efficiency regulations. Prior to that year, the existence of multiple regulators led to the US containing two groupings of states with markedly different standards for vehicles. This feature made US fuel efficiency and emissions policy extremely complex and caused industry leaders to call for uniting the standards into a single, national one (Union of Concerned Scientists, 2011; Yacobucci, Canis, & Lattanzio, 2012). While harmonization between the three regulatory agencies has begun, it is not yet entirely complete, nor are there any legal assurances that they ever will be (ibid.).

California Air Resources Board (CARB)

The first of these systems was created by the State of California in 1967, when legislation was enacted, resulting in the creation of the California Air Resources Board (CARB, 2012). This new organization was born out of concern for maintaining air quality, particularly in the Los Angeles area, which was and remains the smoggiest region of the United States (South Coast Air Quality Management District, 1997, 2013). As early as the 1950s, it was known that smog posed a significant threat to human health and that motor vehicle exhaust was one major cause of it (ibid.). CARB was established with the goal of, among other things, creating regulations on permissible levels of specific chemicals in motor vehicle exhaust to prevent or lessen the occurrence of smog in California (ibid.).

Environmental Protection Agency (EPA)

Federal authority to regulate motor vehicle emissions was established by the Clean Air Act (CAA) beginning in 1968 (McCarthy, Copeland, Parker, & Schierow, 2011). The US Environmental Protection Agency (EPA), an independent federal agency, has administered these regulations since its founding in 1970 (California Air Resources Board, 2012). Initially, as in the case of CARB, CAA standards were focused on reducing smog-forming pollution. While federal legislation typically has supremacy over state and local laws, the CAA acknowledged that California not only had a particular interest in reducing air pollution, but that it also had a regulatory regime already in place. Due to that, CAA was designed to allow California to continue its own regulatory system as long as CARB's standards were at least as stringent as the EPA's. Technically speaking, California must apply to the EPA for a waiver from CAA regulations in order to make any changes to their standards and the EPA must determine that the proposed standards are necessary for the protection of clean air; however, in practice these requests are almost always granted (Yacobucci et al., 2012).[26]

Under CAA, only the state of California may set standards that would replace those written by EPA. However, other states are allowed by Section 177 of CAA to adopt California's stricter regulations on any or all classes of vehicles they may choose (Legal Information Institute, undat.; Simon, 2011; Union of Concerned Scientists, 2012; Yacobucci et al., 2012). This means that there are effectively two standards for vehicle air pollution regulation within the United States existing side-by-side: one promulgated by the EPA and enforced as a national minimum, and another, stricter one established CARB and adhered to in so-called "Section 177 states." There are currently 14 states enforcing CARB standards under Section 177, together constituting 40% of the US new car market (ibid.).

National Highway Traffic Safety Administration (NHTSA)

The third US regulatory system which impacts vehicle emissions was established by Congress in 1975 in response to the Arab oil embargo of 1973-74, which had broad social and economic consequences stemming from a shortage of oil and petroleum products in the United States. Rather than attempting to curb pollution like the previous two regimes, the Energy Policy and Conservation Act (EPCA) was intended to decrease American economic dependence on imported oil. To that end, it empowered the National Highway Traffic Safety Administration (NHTSA), a division of the Department of Transportation, to enforce standards for increasing fuel efficiency in cars and light trucks (Union of Concerned Scientists, 2012; Yacobucci & Bamberger, 2007). Dubbed "Corporate Average Fuel Economy" (CAFE) standards, these new regulations went into effect beginning in model year (MY) 1978. As they were intended to make the US economy run on less oil, CAFE standards set limits on the amount of fuel that an average vehicle can use in travelling a given distance. The phrase "corporate average" is a reference to the fact that these regulations apply only to automakers, not to consumers. CAFE standards define the average fuel efficiency that must be achieved by the fleet of vehicles sold by a given manufacturer in a given MY. Non-compliance is punishable by fines calculated by taking into account the degree of non-compliance and the size of the fleet sold by that manufacturer in that MY. EPCA required the average fuel efficiency of new cars to approximately double to 27.5 miles per gallon (mpg) (8.6 litres per 100 kilometres) by MY1985 (Union of Concerned Scientists, 2012; Yacobucci &

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[26] An exception to this occurred in 2008 when the Bush Administration denied one of CARB's proposals, though the request was later granted by the EPA in 2009 after President Obama took office(cf. Zabarenko, 2009)

Bamberger, 2007). It also set a CAFE standard for light trucks at 20.7 mpg (11.4 litres per 100 kilometres). The light truck standard was later increased between MY2005 and MY2011 to 24.0 mpg (9.8 litres per 100 kilometres) (Union of Concerned Scientists, 2012; Yacobucci & Bamberger, 2007).

2.1. Recent Developments

In 1990, CARB began encouraging a market for "zero-emission vehicles" (ZEV), including hydrogen fuel cell, full electric, and plug-in hybrid electric vehicles, seeing their adoption as an opportunity to decrease pollution from motor vehicles even further. ZEV support policies have included funding for research and infrastructure investments, as both hydrogen- and electrically-powered vehicles require a different type of refuelling/recharging infrastructure than do traditional vehicles (California Air Resources Board, 2012, 2013a; Governor's Interagency Working Group on Zero-emission Vehicles, 2013; Union of Concerned Scientists, undat.). CARB has also attempted to establish ZEV sales quotas for manufacturers doing business within the state. These have however been stalled due to litigation (ibid.). In 2003, CARB created a new system whereby manufacturers were assigned ZEV quotas that could either be met by the sale of ZEVs, by the purchasing of credits from manufacturers who produced more ZEVs than their quota required, or by a combination of the two (ibid.). The resulting system, with targets and tradable credits, resembles the electricity industry's Renewable Portfolio Standards, used by many US states to require that utilities purchase and distribute a certain percentage of electricity from renewable sources. Due in part to CARB's ZEV program, California is now home to nearly 40% of US plug-in electric vehicles (Governor's Interagency Working Group on Zero-emission Vehicles, 2013). Recently it has been announced that a total of eight states have joined California's ZEV program, and will all require that in 2025 at least 15% of vehicles sold in each of their states be ZEV vehicles (CARB, 2013b: 3; Cobb, 2013). These states are also cooperating in the development of necessary infrastructure, the adoption of ZEVs into their government-owned fleets, and creation of consumer incentives to spur ZEV adoption, among other initiatives. It is expected that these combined efforts will yield sales of at least 3.3 million ZEVs by 2025 and that they will be more effective in causing the uptake of ZEVs than federal programs will be (ibid.).

As climate change has become a more publicized and better understood phenomenon, vehicle emissions standards have been altered or reinterpreted to be ways of controlling not just smog or oil imports, but the release of greenhouse gasses (GHG) as well. In 2004, California began its efforts to curb GHG emissions across the state, which inevitably led to

CARB regulations on GHG emitted by motor vehicles (CARB, 2012).[27] On the federal level, 2007 brought a decision from the Supreme Court regarding the case Massachusetts v. EPA, a decision which effectively required the EPA to acknowledge that GHG constitute "air pollution" under CAA. This ultimately led to the EPA regulating GHG, including from motor vehicles, under the authority of CAA (*Massachusetts v. Environmental Protection Agency*, 2007; Union of Concerned Scientists, 2012; Yacobucci & Bamberger, 2007). Finally, the Energy Independence and Security Act of 2007 (EISA) greatly expanded NHTSA's authority, requiring the NHTSA to set CAFE standards at the "maximum feasible" level for any given MY, based on the vehicle's "footprint," measured by its length and width (Union of Concerned Scientists, 2012; Yacobucci et al., 2012). EISA additionally stipulates that NHTSA may only publish rules that are applicable to five MYs or fewer (ibid.).

Since taking office, the Obama Administration has sought to harmonize regulations on emissions from motor vehicles, so as to avoid the creation of a "patchwork" of standards regulating fuel efficiency and GHG emissions from cars and light trucks. In 2009 EPA and NHTSA announced the creation of their first joint GHG and CAFE standards, which laid out regulations for MY2012 through MY2016. These rules required that fleets meet emissions levels of 250 g CO_2-equivalent (CO_2e) per mile (155.3 g CO_2e/km) and fuel efficiency levels of 34.1 mpg (6.9 L/100km) by MY2016 (ibid.) Subsequently, California announced that they would allow vehicles meeting these standards to be sold as if they were CARB-compliant, even though federal standards during these MYs are below CARB's published standards (ibid.)

Working together, the EPA, NHTSA, CARB, and automakers came to an agreement in 2012 that lays out incremental improvements in vehicle emissions and fuel efficiency through MY2025 (Yacobucci et al., 2012). Due to the requirement that NHTSA can only establish CAFE standards applicable to a maximum of five MYs at a time, the final fuel efficiency rules through MY2025 have not been officially set, rather a rule has been made for MY2017 to MY2021 and a preliminary rule has been published that would apply from MY2022 through MY2025 (EPA & NHTSA, 2010; Yacobucci et al., 2012). Meanwhile, GHG standards, which are not limited in the way CAFE standards are, have been finalized and will rise to 163 g CO_2e/mi (101.3 g CO_2e/km) by MY2025. This requirement, after taking into account expected improvements in non-fuel related GHG emissions (e.g. improved air conditioning systems), is expected to correspond to a CAFE standard of approximately 49.7 mpg (4.7 L/100km). CARB has agreed to implement these standards simultaneously (ibid.).

In addition to the above three programs, the Energy Tax Act of 1978 (ETA) gave the EPA the authority to administer a "Gas Guzzler Tax," which would be collected from vehicle manufacturers for each car sold that was less fuel efficient than a predetermined level. Since

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[27] EPA granted CARB a CAA waiver for this purpose, which allowed California's GHG regulations to take effect on MY2009 vehicles (cf. Center for Climate and Energy Solutions, undat.)

1991, this level has been 22.5 mpg (10.45 L/100km). The tax begins at $1,000 for cars that get below 22.5 mpg and becomes progressively larger until it reaches $7,700 for cars with under 12.5 mpg (EPA, 2012a). When the law was written and passed, larger vehicles like minivans, sport utility vehicles, and pick-up trucks were relatively small portions of the national motor vehicle fleet and were generally purchased for business purposes, therefore they were exempted from the tax. However, in subsequent decades, these types of vehicles have become more popular among average consumers, something which the ETA did not foresee (ibid.). EPA and NHTSA have also begun to regulate emissions and efficiency with regards to medium- and heavy-duty vehicles, starting with MY2014. These standards differentiate obligations for the various types of medium- and heavy-duty vehicles and their usages, setting regulations for cargo transport vehicles in terms of gCO_2/ton-mile, while busses and other non-cargo vehicles are evaluated on their emissions as gCO_2/mil. It is expected that these new regulations on medium- and heavy-duty vehicles will prevent 270 million tonnes CO_2e from entering the atmosphere over the lifetime of MY2014-2018 vehicles and that they will have a net financial benefit for individual operators and for society as a whole. (EPA, 2011)

For a short time in the summer of 2009, the US Department of Transportation (DOT) also offered nearly $3 billion (€2.1 billion) in financial subsidies for consumers who traded in old, fuel inefficient vehicles, for newer, more efficient ones (Bunkley, 2009; NHTSA, 2009). This program, officially dubbed the "Car Allowance Rebate System (CARS), but more colloquially known as "Cash for Clunkers," was designed to simultaneously protect the environment and spur the economy. Regulations were very strict about how inefficient the old vehicle had to be and how efficient the replacement had to be in order to qualify for the subsidy. When taking part in this program, the engine of the older vehicle had to be destroyed in order to ensure that the subsidy was actually removing an inefficient motor from the roads, rather than just passing it on to the used car market. Over the course of barely over a month, CARS accepted 700,000 vehicles for trade-in and replaced them with new vehicles that were on average 58% more fuel efficient (ibid.) However, there is still an ongoing debate around the real environmental impact of the Cash for Clunkers program. It has been estimated that the overall fuel savings were equal to only a few days' national consumption, that GHG reductions were small and much more expensive than alternative strategies, and that the expedited scrapping procedures required by the program created an unnecessarily large amount of environmentally hazardous waste (Gayer & Parker, 2013; Santisi, 2013).

On top of these efforts to regulate or financially support fuel efficiency and low emission vehicles, the EPA and the NHTSA have enacted, beginning with MY2013, new labelling requirements for new vehicles sold in the US that make clearer the environmental and financial benefits of choosing cleaner-running vehicles. These new labels also make it much easier to compare the energy efficiency of electric vehicles (both full electrics and plug-in hybrids) with gasoline, diesel and "flex fuel" (running on gasoline, ethanol, or any mixture thereof) vehicles (EPA, 2012b).

2.2. Policy Assessment

The impact of US emissions and efficiency regulations are difficult to calculate and there is much debate among academics, in particular regarding how best to measure the effect of increased fuel efficiency. While there are still numerous regions of the country experiencing higher than acceptable levels of smog, these levels have been, in general, decreasing since the beginning of CARB and EPA regulation in the late 1960s and early 1970s. This is in spite of the fact that both population and the total number of vehicle miles driven have been increasing over that time period (Bloomer, Vinnikov, & Dickerson, 2010; Dickerson & Vinnikov, 2009; He et al., 2013; Pollack et al., 2013; SCAQMD, 1997).

A National Research Council study concluded that fuel use at the beginning of the 21st century would have been one-third higher if CAFE standards had never been implemented. The study goes on to state that the effective reduction in national GHG emissions amounted to 7% (TRB, 2002; Linn, 2013). Yet, calculating the total impact is extremely difficult, as there has been significant research to suggest the existence of a rebound effect within fuel consumption and efficiency – i.e., fuel saved through efficiency measures could actually be used to drive more, rather than to reduce fuel use and emissions. The idea generally follows that more efficient vehicles make it cheaper to drive a given number of miles (both by using less fuel per mile and by reducing market demand for fuel and therefore lowering the price per unit of fuel), therefore in some circumstances, fuel efficiency measures could be incentives for greater amounts of driving (TRB, 2002; Linn, 2013). However, a number of recent studies, mostly relying upon data from the US DOT, have shown that since 2008 the total number of vehicle-miles driven annually has levelled off, if not decreased. Furthermore, taking into consideration population growth, the number of vehicle-miles per capita has almost certainly been decreasing over the last five years, likely due to demographic shifts and changes in consumer choice, as more people move to the cities and younger people choose alternative modes of transportation (Dutzik & Baxandall, 2013; FHA, 2013; TRI, 2011)

Over the last four and a half decades, US policies concerning vehicle emissions and fuel efficiency have matured greatly from regional reactions to visible pollution, to a coordinated national effort to protect human health and the environment. The positive impact of these policies on smog-related pollutants is clear, if not complete. Smog remains a problem in many metropolitan areas, but its severity has decreased, even as the number of cars on the road has increased. Similarly, while GHG emissions per mile are falling, over this 45 year period total miles driven have increased significantly, tempering the emissions impacts of fuel efficiency. However, increased support for and adoption of electric vehicles, as well as recent trends showing a decrease in annual vehicle-miles per capita, bode well for future efforts to reduce the GHG impact of the US motor vehicle fleet.

3. Review of transport elasticities

Transportation GHG emissions are considered to be the result of the interaction of four factors: vehicle fuel efficiency, the carbon content of the fuel burned, the number of miles that vehicle travel, and the operational efficiency experiences during travel (Cambridge Systematics, Inc. 2009: 1).

We analyse policies that may lead to a reduction in the amount of travels by cars, by inducing people to use less fuel-intensive means of transport (such as walking, cycling, riding public transport or carpooling), or by reducing travel in terms of the amount of fuel consumed during the travel or the amount of kilometres driven.

Policies addressing a change in demand for individual travel modes will mainly be considered in this review. The following text refers to selected problems of transport elasticities and the implications they have on effectiveness of policy measures. The structure of this chapter is as follows: i) introduction of the measurement of transport demand; ii) patterns in elasticity values; iii) selected individual elasticities; iv) current trends in elasticities and v) policy implications.

3.1. Transport demand and elasticity

When assessing various strategies to reduce greenhouse gas emissions transport/travel demand and its analysis stands in the focus. Travel demand refers to the amount and type of travel that people would choose in particular situations (Litman, 2013c: 2). Travel demand can be affected by various economic, social or geographic factors. Models reflecting relations between travel demand and these factors can predict how various trends, policies or strategies will affect travel activity in the future.

Since prices are the direct and perceived costs of using a good, they affect where to and how often people travel, which route and means of transport they choose and a plenty of connected issues. However, in the transportation sector, prices include besides direct monetary costs also opportunity costs of travel time, discomfort of risk.

The effect of price changes on travel demand is commonly measured using elasticities. Elasticity (E) is a percentage change in consumption (Q) that results from each one per cent change in price or another variable x_i:

$$E = \frac{\Delta \mathrm{Q}/\mathrm{Q}}{\Delta \mathrm{x_i}\ /\mathrm{x_i}}$$

The point elasticity (refers to a specific point on the demand function) is interpreted as the per cent change in demand due to a one per cent change in the *x* variable. It is important to remember that this elasticity differs for different points on the demand function. The demand in transportation sector is mostly measured in litres of fuel, number of kilometres driven or number of trips. Elasticities are estimated for short (ranging from 4 months to 1 year), medium or long-run (1 year to 5-10 years) periods of time.

Elasticities may be estimated with respect to e.g.: (i) price (purchase and/or maintenance); (ii) vehicle kilometres; (iii) income; (iv) fuel price, or (v) the rate of car ownership. Various studies aim at estimation of elasticities of different types of transport prices: fuel taxes, road pricing and tolls, mileage and emission charges, parking prices, taxi services, distance-based vehicle insurance or registration fees etc. (cf. Litman, 2013c.)

3.1.1. Materials and methods

The number of individual studies providing multiple estimates of transport related elasticities is enormous. Still, most primary studies cover only car use and ownership for private purposes, while very little evidence is related to commercial freight traffic or sector (Goodwin et al., 2004).

To be able to draw a robust conclusion relevant to the analysis of behavioural response to policies aiming at CO_2 emission reduction, mostly reviews and meta-analyses are considered in this study.[28] Also recent individual studies on selected policy instruments such as road pricing or congestion charging are included. We aim to cover estimates generally acknowledged for the second half of the 20th century, as well as general trends and the development in the last decade.

3.2. Patterns in the observed elasticity values

Litman's (2013c) extensive overview of factors affecting transport demand in personal transportation sector is the basis for this review. He argues that although the impact of price changes for various modes, user groups and travel conditions, it is possible to identify certain patterns which allow related relationship to be modelled. He summarizes the patterns as follows:

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[28] The main advantage of meta-analytical studies compare to narrative reviews is that it integrates a large collection of findings from individual studies using a statistical method. It is a method enabling to draw general conclusion (more van den Bergh et al., 1997) from results that differ in magnitude and sometimes in the direction. The meta-analysis also helps to systematize various effects – factual as well as methodological – on the respective estimates.

- Transport pricing impacts may vary, including changes in trip generation, mode, destination, route, vehicle type and parking location. Pricing of one transport mode or service can affect the demand for others.
- Pricing impacts tend to increase over time, and typically triple over the long-run.
- Higher value travel, such as business and commute travel, tend to be less price sensitive than lower value travel.
- Wealthy people tend to be less sensitive to pricing and more sensitive to service quality than lower-income people.
- Travel tends to be more price-sensitive if travellers have better travel options.
- Motorists tend to be particularly sensitive to road tolls and parking fees.
- The way of promotion, collection and the structure of fees may affect their impacts on travel behaviour.
- Motorists are more likely to accept vehicle price increases if presented as part of an integrated program that is considered fair and provides dispersed benefits.

Numerous studies investigating transport elasticities are available (e.g. Glaister and Graham 2002; Graham and Gleister, 2004, Goodwin, Dargay and Hanly 2004; Pratt 2004, Small van Dender, 2005 and Wardman and Shires 2011, Holmgren, 2007, Odeck, Bråthen, 2008). Various methods were applied in these studies and the results correspond to different countries, travel modes, travel purposes and segments of population. Still, many studies refer to the short and long term price and income elasticity of the same/comparable magnitude. Selected estimates from recent overview studies are displayed below:

Graham and Glaister (2002) have surveyed the international literature on elasticities of demand for road traffic. They have reported results based on thousands of elasticity estimates from all over the world associated with car travel, car ownership, fuel demand and freight traffic. They report short and long-run car mileage response to fuel price changes with elasticity -0.15 and -0.31 respectively. In the long-run a greater response to fuel price arises in number of kms driven than in car trips, supposedly due to adaptation in some combination of mode choice, destination choice, relocation of population, retail and service activities (Graham, Glaister, 2002: 94).

Estimates of the long run income elasticity of demand for car ownership fall within the range from 0.3 to 1.1 with a mean value 0.74. The short run income elasticity is much smaller, taking a mean value of 0.28. Glaister and Graham (op. cit.) further suggest that the long run price elasticity of demand for fuel is between -0.6 and -0.8 and the short run elasticity between -0.2 and -0.3. The income elasticity of fuel demand is between 0.3 and 0.5 in the short run and between 0.5 and 1.5 in the long run. Variation in income demand estimates is large.

Goodwin, Dargay and Hanley (2004) summarize elasticity estimates from American, European, OECD and other studies. Various measures of demand with respect to fuel price are estimated (see Table 9 below) using dynamic estimation and time series data.

Table 9 - Elasticity of measure of demand with respect to fuel price (per litre)

Dependent variable	Short-term	Long-term
Fuel consumption (total)		
Mean elasticity (Standard deviation)	–0.25 (0.15)	–0.64 (0.44)
Range	–0.01, –0.57	0, –1.81
Number of estimates	46	51
Fuel consumption (per vehicle)		
Mean elasticity (Standard deviation)	–0.08 (n/a)	–1.1 (n/a)
Range	–0.08, –0.08	–1.1, –1.1
Number of estimates	1	1
Vehicle-km (total)		
Mean elasticity (Standard deviation)	–0.10 (0.06)	–0.29 (0.29)
Range	–0.17, –0.05	–0.63, –0.10
Number of estimates	3	3
Vehicle-km (per vehicle)		
Mean elasticity (Standard deviation)	–0.10 (0.06)	–0.30 (0.23)
Range	–0.14, –0.06	–0.55, –0.11
Number of estimates	2	3
Vehicle stock		
Mean elasticity (Standard deviation)	–0.08 (0.06)	–0.25 (0.17)
Range	–0.21, –0.02	–0.63, –0.10
Number of estimates	8	8

Notes: Estimates produced by dynamic estimation using time series data.
n/a = Not available
Source: Goodwin, Dargay and Hanley (2004)

The results are broadly consistent with several earlier reviews, though not always with current practice. Goodwin, Dargay and Hanly (2004) infer from the single estimates the following picture of the price and income effects: "If the real price of fuel rises by 10% and stays at that level, the result is a dynamic process of adjustment such that the following occur:

a) volume of traffic will fall by roundly 1% within about a year, building up to a reduction of about 3% in the longer run (about 5 years or so),
b) volume of fuel consumed will fall by about 2.5% within a year, building up to a reduction of over 6% in the longer run."

They presume that the reason why fuel consumed falls by more than the volume of traffic is because the price increases trigger a more efficient use of fuel (by a combination of technical improvements to vehicles, more fuel-conserving driving styles and driving in easier traffic conditions). A further probable differential effect is between high- and low-consumption vehicles, since with high prices, gas-guzzlers are more likely to be the vehicles left at home or scrapped.

Therefore, further consequences of the same price increase are as follows (Ibid.):

c) efficiency of the use of fuel rises by about 1.5% within a year, and around 4% in the longer run,
d) total number of vehicles owned falls by less than 1% in the short run, and by 2.5% in the longer run.

If real income goes up by 10%, the following occurs:

- Number of vehicles, and the total amount of fuel they consume, will both rise by nearly 4% within about a year, and by over 10% in the longer run.
- However, the volume of traffic does not grow in proportion: 2% within a year and about 5% in the longer run.

The above described picture of the price and income effect on transport demand is supported by several other studies. For example Litman (2013b) estimates that about a third of fuel saving that result from fuel price increase consist of reduced vehicle travel. Further results indicate that the long-term elasticity of vehicle travel with respect to fuel price typically averages about -0.3 (INFRAS, 2000; Johansson and Schipper, 1997, Schimek, 1997, Small and Van Dender, 2005). Long-run travel elasticities in these studies are typically 3.4-9.4 times short-run elasticities.

Most recently **Litman (2013b)** has conducted a review of meta-analytical studies providing price elasticity estimates with respect to geography, time span, model design and other factors. The studies considered by Litman (2013b) vary significantly in scope and methodology. Whereas many older studies used relatively simple models, more recent studies tend to account for more demographic, economic and geographical factors. Summary of Litman´s findings on the available values of fuel price elasticities (on fuel consumption and vehicle travel) are reproduced in the two following tables:

Table 10 - Summary of transport fuel price elasticity studies

Study	Study Type	Scope	Major results
Goodwin et al. (2004)	Summarized various fuel price and income elasticity studies	1929–1991. Mostly North America and Europe	−0.25 short run
			−0.6 long run
Espey (1996)	Review of 101 gasoline price elasticity studies	1936–1986, US	−0.26 short run
			−0.58 long run
Glaister and Graham (2002)	Review of various fuel price and income elasticity studies	Second half of the Twentieth Century. Mostly North America and Europe	−0.2 to −0.3 short run
			−0.6 to −0.8 long run
Lipow (2008)	Review of selected energy price elasticity studies	Second half of the Twentieth Century. Mostly North America and Europe	−0.17 short run
			−0.4 long run

Small and Van Dender (2005)	State-level cross-sectional time series of gasoline price elasticities. Comprehensive model	US State Data, 1966–2001	1966–2001
			−0.09 short run
			−0.41% long run
			1997–2001
			−0.07 short run
			−0.34% long run
Hymel et al. (2010)	State-level cross-sectional time series of gasoline price elasticities. Comprehensive model	1966–2004, US	−0.055 short run
			−0.285 long run
Agras and Chapman (1999)	Gasoline price elasticity	1982–1995, US 88	−0.25 short run
			−0.92 long run
Li et al. (2011)	Fuel price elasticities with tax increases and price fluctuations analyzed separately. Comprehensive model	1968–2008, US 88	−0.235
Hughes et al. (2006)	Gasoline price elasticities. Comprehensive model	1975–2006, US	1975–1980
			−0.21 to −0.34 short run
			2001–2006
			−0.034 to −0.077 short run
Boilard (2010)	Fuel price elasticities. Comprehensive model	1970–2009, Canada	1970–1989
			−0.093 to −0.193 short run
			−0.762 to −0.45 long run
			1990–2009
			−0.046 to −0.091 short run
			−0.085 to −0.256 long run
Komanoff (2008–2011)	Short-run fuel price elasticity. Simple model	2004–2011 US data	−0.04 in 2004
			−0.08 in 2005
			−0.12 in 2006
			−0.16 in 2007
			−0.29 in 2011

Source: Litman, 2013b

Table 11 - Summary of vehicle travel price sensitivity studies

Study	Study type	Scope	Major results
Johansson and Schipper (1997)	Summary of various previous studies	International	−0.2 long run
Goodwin et al. (2004)	Summarized results of various fuel price and income elasticity studies	1929–1991, mostly North America and Europe	−0.1 short run
			−0.3 long run
Schimek (1997)	Elasticity of vehicle travel with respect to fuel price	1950–1994 time-series and 1988–1992 pooled data, US	−0.26
Small and Van Dender (2005)	Vehicle travel elasticity with respect to fuel price. Comprehensive model	1966–2001, US	1966–2001
			−0.047 short run
			−0.22 Long run
			1997–2001
			−0.026 short run
			−0.121% long run

Hymel et al. (2010)	State-level cross-sectional time series gasoline price elasticities. Comprehensive model	1966–2004, US	−0.026 short run
			−0.131 long run
Li et al. (2011)	Vehicle travel with respect to fuel price. Comprehensive model	1968–2008, US	−0.24 to −0.34
Brand (2009)	Gasoline price elasticities	2007–2008, US	−0.12 to −0.17 short run
			−0.21 to −0.3 long run
Gillingham (2010)	Odometer and fuel consumption data. Comprehensive model	2005–2008, California	−0.15 to −0.20 medium run, varies by vehicle type and location

Source: Litman (2013b)

3.3. Selected individual elasticities

Since the purpose of this study is to support the evidence basis usable for recommendation of effective transport policies, selected specific elasticities deserve particular attention. Following text presents elasticities related to road pricing, mileage and emission charges, parking prices and public transport. The differentiation among these is especially important for drawing conclusions concerning the effect of specific policy measures on the transport behaviour.

3.3.1. Road Pricing and toll

Road pricing means that drivers pay a toll for using a particular road or driving in a particular area. Congestion pricing refers to tolls that are higher during peak compared to off-peak periods of time, since they are used to reduce traffic congestion.

Several experts argue that drivers tend to be relatively sensitive to road pricing compared to other types of price changes (e.g. Litman 2013c). Spears, Boarnet and Handy (2010) summarize recent road pricing experience. They conclude that the elasticity of traffic volumes to toll is typically -0.1 to -0.45, depending on conditions. Roads with fewer essential trips, more viable alternatives or lower congestion levels tend to have higher elasticities. They find that *cordon tolls* have reduced traffic volumes 12 % to 22 % in five major European cities, and Singapore, indicating a -0.2 to -0.3 elasticity.

Parsons and Brinckerhoff (2012) indicate significant aversion against paying tolls, regardless of the amount. They argue that this reluctance to pay road tolls has reduced traffic volumes and revenues below what was predicted for many toll road projects (Litman, 2013).

Odeck and Bråthen (2008) investigated the change of demand at 19 Norwegian toll roads. They found that elasticities average around -0.56 in short run and -0.82 in long run. These estimates are somehow higher than the averages that have been derived elsewhere, but supposedly not too high to raise any particular concern as to why they are higher. The authors specify that the magnitudes of elasticities tend to vary with project characteristics, i.e. road types, locality, etc., which in turn implies that elasticities vary with type of traffic served. Toll price elasticities are significantly and positively correlated to the level of toll fees. Similarly to other types of elasticity, long-run toll elasticities are higher than the short-run ones. However, the results of the study indicate a lower ratio at 1.05–1.60 than the ratio of 2-3 provided e.g. by Goodwin et al. (2004). Odeck and Bråthen (2008) also found that people's attitudes towards tolls become more favourable when people understand how revenues will be used.

Arentze, Hofman and Timmermans (2004) found that for commute trips, route and departure time changes are most likely to occur, with smaller shift to public transport and to working at home. For non-commute trips shifts to cycling also occur. They conclude that the price elasticity of traffic on a particular road is -0.35 to -0.39, including shifts in route and time, and -0.13 to -0.19 for total vehicle travel on a corridor.

Guo et al. (2011) argue that given financial incentives, household in denser, mixed use, PT-accessible neighbourhoods reduce their peak-hour and overall vehicle travel significantly more than comparable households in automobile dependent suburbs.

Impacts and benefits of road pricing are affected by the price structure. Litman (2013c) indicate that congestion pricing fee (initially £5 in 2003 and £8 in 2005) charged for driving in downtown London during weekends, reduced private automobile traffic in the area by 38% and total vehicle traffic by 18%. Ubbels and Verhoef (2006) predict reduction of car trips by 6 or 15% if road pricing were introduced in the Netherlands. However, flat kilometre charge (with levels on 3, 6 and 12 € cents and different use of revenues) primarily affects social trips and tends to cause decline of total trips and shift to non-motorized modes.

A peak-period fee primarily affects commute trips, and tends to cause a shift in time (cf. Parsons Brinckerhoff, 2012, or Adler, Ristau and Falzarano, 1999) and mode, as well as working at home. May and Milne (2000) compare the impacts of cordon tolls, distance pricing, time pricing and congestion pricing using a steady-state equilibrium assignment model. They assess the performance of the four charging systems across a wider range of charging levels and output indicators in both the fixed and variable demand cases. Cordon toll based on charges for travel in a fixed area was set on 21, 45 and 90 pence per crossing. Time based pricing is based on time spent travelling and was set on 5, 11 and 19 pence per minute. Congestion pricing was set on 60, 200 and 500 pence per minute spent in congestion and distance pricing was set on 10, 20 or 37 pence per kilometre travelled. The following indicators of the performance of the four pricing systems were considered: travel time and distance within the charge area, reduction in delayed time, average network speed and total travel demand.. They conclude that time-based pricing provides the greatest overall benefit, followed by distance-based pricing, congestion pricing and cordon pricing.

3.3.2. Mileage and Emission Charges

Various pricing policies impose distance-based vehicle fees. These include per- kilometre road use and emission fees, and distance-based vehicle insurance and registration fees. INFRAS (2000) estimates elasticities of –0.1 to –0.8 for kilometre fees depending on the trip purpose, mode and price level.

Harvey and Deakin (1998) distinguish impacts of two types of emission fees: a charge per-mile based on each vehicle model-year average emissions, and a fee based on actual emissions measured when a vehicle is operating. Emission charges based on the distance average about 0.5¢ per mile. Reduction in vehicle miles travelled by 1-7% and emissions by 14-35% is indicated. The authors argue that the fee based on actual emissions has much greater emission reducing impacts, since it discourages driving of high-emitting vehicles.

3.3.3. Parking Price

Motorists tend to be particularly sensitive to parking price because it is a direct charge. Parking fees are found to have a greater effect on vehicle trips compare to other out-of-pocket expenses, typically by a factor of 1.5 to 2.0 (USEPA, 1998). Litman (2013c) summarizes that a $1.00 per trip parking charge is likely to cause the same reduction in vehicle travel as a fuel price increase averaging $1.50 to $2.00 per trip.

Some overviews of parking price impacts on travel behaviour take into account demographic factors and travel conditions and type of trip, including changes in the magnitude and structure of prices, removal of parking subsidies for employees, parking discounts and park-and-ride facility pricing. Results presented by Concas and Nayak (2012), Spears, Boarnet and Handy (2010a), or Vaca and Kuzmyak (2005) indicate that the elasticity of vehicle trips with regard to parking prices is typically –0.1 to –0.3, with significant variation depending on demographic and geographic factors, travel choice and trip characteristics. A study of downtown parking meter price increases by Clinch and Kelly (2003) finds that the elasticity of parking frequency is smaller (–0.11) than the elasticity of vehicle duration (-0.20), which indicates that some motorists respond to higher fees by reducing how long they stay.

Hensher and King (2001) model the price elasticity of CBD parking in central business district. They predict how an increase in parking prices in one location will shift cars to park at other locations and drivers to public transit. The main results of their analysis are displayed in the

Table 12 below.

Table 12 - Parking Elasticities

	Preferred CBD	Less Preferred CBD	CBD Fringe
Car Trip, Preferred CBD	-0.541	0.205	0.035
Car Trip, Less Preferred CBD	0.837	-0.015	0.043
Car Trip, CBD Fringe	0.965	0.286	-0.476
Park & Ride	0.363	0.136	0.029
Ride Public Transit	0.291	0.104	0.023
Forego CBD Trip	0.469	0.150	0.029

Note: Elasticities and cross-elasticities for changes in parking prices at various Central Business District (CBD) locations.
Source: Hensher and King 2001 in Litman, 2013u

Litman (2013c) summarizes the above displayed results and points out that the parking fees affect trip destinations as well as vehicle use. An increase in parking prices can reduce use of parking facilities at a particular location, but this may simply shift vehicle travel to other locations. Thus, increased parking prices may result in spill-over parking problems, as motorists find nearby places to park for free illegally ("Parking Management," VTPI, 2005, in Litman, 2013c). However, total vehicle travel can be reduced by higher parking prices if parking prices increase throughout an area and there are good travel alternatives. For some types of trips, pricing can affect parking duration, such as how long shoppers stay at a shop (Clinch and Kelly, 2003). Litman (2013c) asserted that shifting from free to priced parking typically reduces drive alone commuting by 10-30%, particularly if implemented with improvements in public transport and car-sharing programs and other travel management strategies.

3.3.4. Public transport (Transit) elasticities

Several estimates of public transport elasticities may be found in literature. Dargay and Hanly (1999) studied the effects of public transport fares and their changes in UK. Their estimates of the elasticity of bus demand and car ownership with respect to transit fares are higher than in previous studies (e.g. Goodwin 1992). They also found that demand is slightly more sensitive to rising fares (-0.4 in the short run and –0.7 in the long run) than falling fares (-0.3 in the short run and –0.6 in the long run), and tends to be more price sensitive at higher fare levels. Interestingly, the cross-elasticity of bus patronage to automobile operating costs was found negligible in the short run, although it increases to 0.3 to 0.4 over the long run. The long run elasticity of car ownership with respect to transit fares is 0.4, while the elasticity of car use with respect to transit fares is 0.3. The differences in bus fare elasticities for urban and non-urban travel are displayed in the table below.

Table 13 - Bus fare elasticities

Elasticity Type	Short-Run	Long-Run
Non-urban	-0.2 to –0.3	-0.8 to –1.0
Urban	-0.2 to –0.3	-0.4 to –0.6

Source: Dargay and Hanly 1999, p. viii

Transport Research Laboratory (TRL, 2004) calculates that bus fare elasticities average approximately to –0.4 in the short-run, -0.56 in the medium run and -1.0 over the long run. Metro rail fare elasticities are –0.3 in the short run and –0.6 in the long run. Bus fare elasticities are lower (-0.24) during peak than at off-peak (-0.51).

Holmgren (2007) used meta-analysis to explain the variation in elasticities estimated in previous demand studies for the US. He calculated short-run elasticities with respect to fare price (−0.59), level of service represented by supply of vehicle kilometres (1.05), income (-0.62), price of petrol (0.4) and car ownership (−1.48). His analysis also indicates that commonly used elasticity estimates treat transit service quality as an exogenous variable. To improve accuracy of the analysis he recommends treating service variable as endogenous.

Mattson (2008) analysed the effect of rising fuel prices on the use of public transport in US cities of different size. He found longer-run elasticities of transit ridership with respect to fuel price to be 0.12 for large cities, 0.13 for medium-large cities, 0.16 for medium-small cities, and 0.08 for small cities. Unlike the conclusions by Litman (2013c, see further in the text) Mattson’s results indicate that for large and medium-large cities, the response is fairly quick, mostly occurring within one or two months after the price change. For medium and small cities, the effects take five to seven months.

Taylor et al. (2009) found a relatively high aggregate (all types of public transport) fare elasticity of -0.51, and a public transport service level elasticities measured as total vehicle hours of 1.1 to 1.2.

Service elasticity of public transport refers to how changes in the mileage of public transport service, service-hours, frequency, and service quality affect public transport ridership. Public transport ridership tends to be more responsive to service improvements than to reduction of fares. Pratt (2004; 10-12) concludes that “ridership tends to be one-third to two-thirds as responsive to a fare change as it is to an equivalent percentage change in service”. This holds particularly for transport behaviour of people who can drive. Evans (2004) provides various estimates of public transport service elasticities. The elasticity of public transport use to service expansion (measured as bus miles or bus miles/kms per capita) is typically 0.6 to 1.0. The elasticity of use of public transport with respect to the frequency of service averages 0.5. Litman (2013) points out that there is a wide variation in these factors, depending on specific conditions. Higher service elasticities often occur with new express public transport, in university towns, and in suburbs with rail transit stations to feed. It usually takes 1 to 3 years for ridership on new routes to reach its full potential.

Litman summarizes several factors that affect public transit elasticities (Litman 2013c):

- *User Type.* Transit dependent riders are generally less price sensitive than discretionary (also called choice) riders, people who could drive for that trip. People with low incomes, disabilities, young and old age tend to be more transit dependent. In most communities transit dependent people are a relatively small portion of the total population but a large portion of transit users, while discretionary riders are a potentially large but more price sensitive market segment.

- *Trip Type.* Non-commute trips tend to be more price sensitive than commute trips. Elasticities for off-peak transit travel are typically 1.5-2 times higher than peak period elasticities, because peak-period travel largely consists of commute trips.

- *Mode and route.* Rail and bus elasticities often differ. In major cities, rail transit fare elasticities tend to be relatively low, typically in the –0.18 range due to users relatively high incomes. For example, the Chicago Transportation Authority found peak bus riders have an elasticity of -0.30, and off-peak riders -0.46, while rail riders have peak and off-peak elasticities of -0.10 and -0.46, respectively. Fare elasticities tend to be lower on routes that serve more people who are transit dependent and higher on routes where travellers have viable alternatives, such as for suburban rail systems.

- *Geography.* Large cities tend to have lower price elasticities than smaller cities and suburbs, probably reflecting differences in the portion of transit-dependent residents.

- *Type of Price Change.* Transit fares, service quality (service speed, frequency, coverage and comfort) and parking pricing tend to have the greatest impact on transit ridership. Fuel price tends to have relatively little impact. Elasticities appear to be somewhat higher for higher fare levels (i.e., when the starting point of a fare increase is relatively high).

- *Direction of Price Change*. Transportation demand models often apply the same elasticity value to both price increases and reductions, but there is evidence that some changes are non-symmetric. Fare increases tend to cause a greater reduction in ridership than the same size fare reduction will increase ridership. A price increase or transit strike that induces households to purchase an automobile may be irreversible, since once people become accustomed to driving, they often continue using that option.

- *Time Period.* Price impacts are often categorized as short-term (typically, within one year), medium-term (within five years) and long-term (more than five years). Elasticities increase over time, as consumers take price changes into account in more decisions (such as where to live or work). Long-term transit elasticities tend to be two or three times as large as short-term elasticities.

- *Transit Type.* Bus and rail often have different elasticities because they serve different markets. Although car ownership has a negative impact on rail demand, it is of lower magnitude than for bus demand and, although there are quite large variations between market segments and across distance bands, the overall effect of income on rail demand is often positive.

3.4. Specific estimates and modelling process

Obviously, the elasticity differs significantly also between trips for with various purposes and duration of the trip. De Jong and Gunn (2001) summarize individual values for commuting, business trips, education and other (see the following table). Whereas business travel is generally price insensitive, travel demand for education appears to be elastic. Generally higher elasticities of private car travel demand were estimated with respect to travel time changes (see columns 4 and 5 in the following table).

Table 14 - European travel elasticities

Term/ Purpose	Car-Trips WRT Fuel Price	Car-Kms WRT Fuel Price	Car-Trips WRT Travel Time	Car-Kms WRT Travel Time
Short Term				
Commuting	-0.2	-0.12	-0.62	
HB business	-0.06	-0.02		
NHB business	-0.06	-0.02		
Education	-0.22	-0.09		
Other	-0.2	-0.2	-0.52	
Total	-0.16	-0.16	-0.6	-0.2
Long Term				
Commuting	-0.14	-0.23	-0.41	-0.63
HB business	-0.07	-0.2	-0.3	-0.61
NHB business	-0.17	-0.26	-0.12	-0.53
Education	-0.4	-0.41	-0.57	-0.76
Other	-0.15	-0.29	-0.52	-0.85
Total	-0.19	-0.26	-0.29	-0.74

Notes: WRT – with respect to; HB – home based; NHB – not home based
Source: de Jong and Gunn 2001 in Litman 2013c

Gillingham (2013) found that for urban and suburban residents, higher fuel economy cars have a lower elasticity than SUVs and pickups, suggesting that multi-vehicle households respond to price increases by shifting travel to more fuel-efficient vehicles. Rural, low-income residents driving pickups and SUV's appear to have lower elasticities than medium- and high-income residents and most clusters of urban and suburban dwellers, possibly because they use larger vehicles for work purposes.

Several authors point out that modelling process significantly affects estimates obtained. For example, Graham and Glaister (2002a) show the differences in the magnitude of the estimated elasticities and they present the main results of their meta-analysis in the following way:

- For short run elasticities, the use of time series or cross-section time series data produces less elastic price elasticity estimates than the analysis based on cross sectional data (i.e. cross-section data reflect the intermediate run rather than short run).
- Non-dynamic modelling structures tend to produce more elastic short run estimates, but do not affect long run results.
- The specification of the demand function is the most consistently important factor. The inclusion of vehicle-related and exogenous variables produces less elastic estimates for both price and income, because it removes the effects of changes in the vehicle stock, in the characteristics of that stock, or in local socio-economic and price conditions. Thus, the use of restricted demand specification may lead to biased elasticity estimates. The inclusion of vehicle-related variables leads to less elastic estimates for both price and income, because it removes the effects of changes in the vehicle stock or in the characteristics of that stock.
- Geographical coverage can make a difference to the magnitude of estimates, and thus, results for one particular empirical context may not hold good for any other.

3.5. Trends in price and income elasticities

Regarding geographical differences, several studies (e.g. Goodwin et al., 2004; Litman, 2013b) show that USA has lower fuel consumption elasticities than Europe with respect to both price and income; also OECD countries have higher elasticities (Goodwin et al., 2004). Goodwin et al. (2004: 289) argue that there is no evidence that price elasticity is related to price level, which is much lower in US than in most developed countries.

Litman (2013a) states that the studies he reviewed indicate that North American fuel price elasticities declined during the last quarter of the twentieth century to less than -0.1 short run and less than -0.4 long run fuel price elasticity. According to Litman (ibid.) several specific factors may help explain the decline in fuel and vehicle travel price elasticities during the last decades of the 20th century. The real (inflation adjusted) median per capita income rose by 88%. Between 1960 and 2000, real fuel prices declined, but since then have again increased. In addition, manufactures and consumers responded to high fuel prices and fuel economy standards in the 1970s and 80s by increasing fuel economy, meaning increasing number of kms per litre. Total vehicle fleet fuel economy thus increased by 38% between 1960 and

2000. These trend significantly reduced fuel and vehicle travel costs relative to income during the last quarter of the 20th century. Further factors hypothesized to contribute to low price elasticities in the respective periods are extensive roadway expansion and more dispersed, automobile-oriented land use developments.

Goodwin et al. (2004) considered also time aspect of the demand measures and provide moderate estimates of its future development. They distinguish three time periods: i) before 1974; ii) 1974-81; and iii) after 1981. Several results show that the middle period has higher price elasticities and lower income elasticities than early or late periods. There is no evident systematic decline except, perhaps, for long run income effect on fuel consumption. The dynamic results for fuel price, at -0.1 for short-run and at -0.29 for long-run effects on traffic volume, show a slightly lower short-run elasticity but virtually the same long-term elasticity as reported 10 years ago in, for example Goodwin (1992), whose own results seemed similar to comparable results 10 years earlier. Dividing the period into three indicated that price elasticity has increased over time, not reduced as the generalized cost hypothesis (as defined by the UK Department for Transport) would suggest. The authors conclude that “the most important figure for forecasting, -0.29 for the price elasticity in the latest period, is as high as has ever been estimated. There is no obvious trend effect for income elasticities.” (Goodwin et al., 2004: 288).

Regarding the last decade, even though recent studies indicate that vehicle travel has become more price sensitive since 2005, there are no unequivocal conclusions. Small and van Dender (2007) found both the short- and long-run price elasticities of fuel consumption lower by a third to a quarter when estimated for a 1997–2001 panel of US states than when estimated from their full sample that spanned 1966–2001. Hughes et al. (2008) found that the short-run price elasticity of petrol demand were considerably less elastic in the beginning of 21st century than in previous decades. When estimated from US monthly data, it fell from a range of −0.21 to −0.34 over 1975–1980 to a range of −0.034 to −0.077 over 2001–2006. Liddle (2009) using US annual data found that the short-run price elasticity of petrol was statistically significantly lower by a factor of more than three over 1991–2006 than over 1978–1990. Also, Pock (2010), who focused on Europe, found petrol was highly price inelastic in both the short-run and the long-run.

Lastly, Bonilla and Foxon (2009) determined that the demand for fuel economy was price inelastic for both petrol and diesel in the UK. Komanoff’s analyses (2008-2011) indicate a steady increase in fuel price elasticities between 2004 and 2011 (Litman, 2013b). Also Litman (2013b) argues that since 2005, price elasticities have increased to -0.1 to -0.2 for the short run, and to -0.2 to -0.3 for the medium run. Brand (2009) found that the 20% US fuel price increase between 2007 and 2008 caused a 3.5% vehicle travel reduction, indicating a short-run price elasticity of -0.17 (for four months in 2007), and about -0.12 (for ten month in 2007). Gillingham (2013) calculated 2005-2008 travel elasticities for California. His study indicates statistically significant medium-run (two-year) elasticities of vehicle travel with respect to petrol price ranging from -0.15 to -0.20. In addition, these price effects appear to increase over time.

4. Limits to carbon pricing in the road transport sector: barriers, constraints and path-dependencies

The following discussion takes a closer look at the policy-induced price signals that affect transport in Europe. There are a number of constraints and barriers at work that limit the effectiveness and the efficiency of pricing tools when it comes to private transport.[29] Of these different barriers and constraints, this subchapter investigates three selected examples: fuel tourism, tax benefits for company cars, and the intra-European trading patterns of second-hand vehicles. This selection is not based on an estimation of the relative importance of these three factors. Rather, it is based on the fact that they provide three very illustrative, and often overlooked, examples of how the political, institutional and legal framework conditions in the EU affect the functioning of pricing tools, and prevent them from achieving their theoretically derived potential.

The bottom line is that, in each of these three cases, consumers are behaving rational, given the incentives and constraints they are facing. Yet in each of these cases, the carbon price signal that has been created through climate policies is effectively muted, and does not have much (or not any) impact on actual consumption and investment decisions. As the case of trading patterns for second-hand vehicles in particular shows, this is not necessarily a case of a market failure. In fact, it is rather a feature of the internal market in Europe, which needs to be considered when designing policy instruments or when anticipating their potential effects.

The fact that the carbon price signal is muted – in some cases for a considerable share of the market – means that carbon pricing as the alleged first-best-policy is rendered partly ineffective. Therefore, second-best options are justifiably part of the policy instrument mix. In particular, this means that the transmission from high fuel prices to demand for fuel-efficient cars to improved fuel efficiency may not function as smoothly as theory would assume, which provides a justification for binding fuel efficiency standards as part of the policy mix.

4.1. Fuel tourism

Most European countries are relatively small in terms of area, but fairly densely populated. There is generally a well-developed and fairly dense road network, so that many Europeans are only a 1-2 hour drive away from the next border to a neighbouring European country. At

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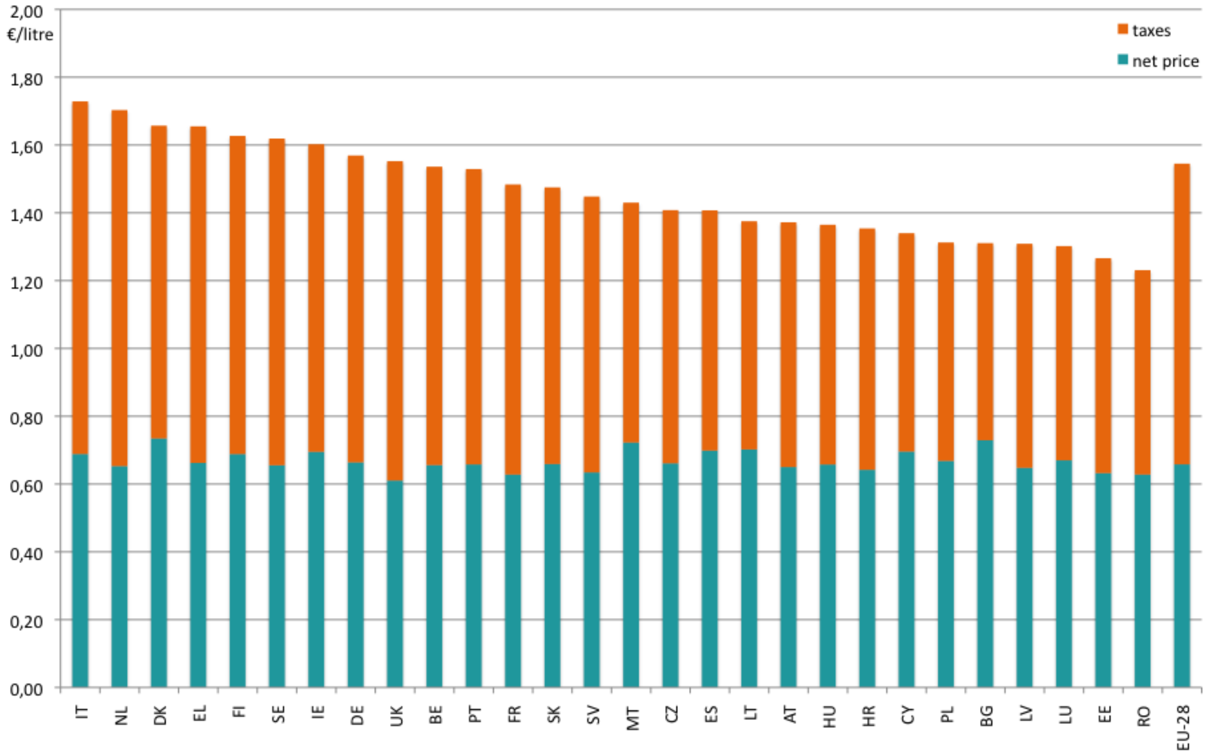
[29] This builds on a much broader body of literature investigating the responsiveness (or lack thereof) of private consumers to price signals, and the various real-life constraints that could explain the observed deviations of actual consumer behaviour from the predictions of economic rationality, see for instance Jaffe and Stavins (1994).

the same time, there is a wide discrepancy in excise duties on road fuels across Europe. As the EU energy taxation Directive merely sets minimum levels for the taxation of fossil fuels, which many countries exceed, fuel prices at the pump differ considerably across EU countries, with fuel prices in the most expensive country (currently Italy) more than 40% higher than in the cheapest country (currently Romania).

Figure 11: Fuel prices (Super 95) across EU countries, October 2013



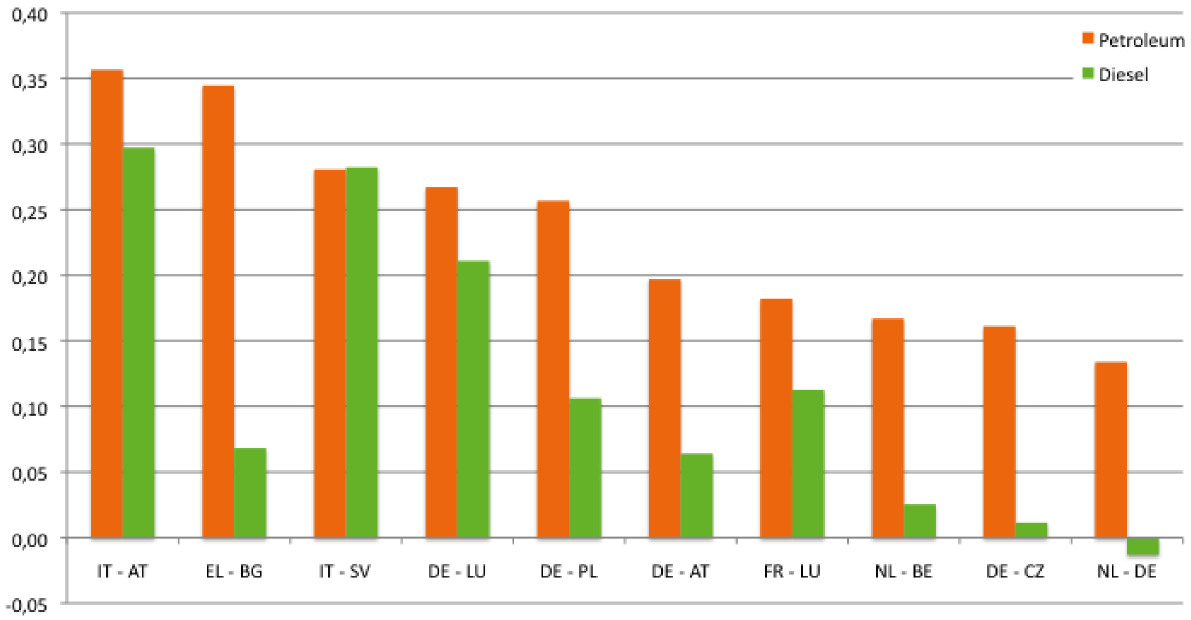
Source: DG Energy Oil Bulletin

This situation gives rise to a behaviour that is known in economics as arbitrage, or more colloquially fuel tourism. Car owners take advantage of the differences in fuel prices at the pump by filling up their cars where it is cheapest. If the price difference, and hence the cost saving of refuelling abroad, is large enough to offset the additional cost (in terms of time and fuel) of refuelling abroad, fuel tourism may induce additional traffic, which is purely motivated by the tax differentials between countries.

There are different reasons why fuel tourism can be seen as problematic. First, fuel tourism can induce additional traffic, and hence additional emissions. This is the case if drivers travel across the border to a neighbouring country only for the purpose of filling up there. In this case, the additional traffic would only be motivated by the tax differential, and would serve no other purpose than to exploit this tax differential. Second, apart from the cases where fuel tourism induces additional traffic, it is also problematic where cross-country traffic is taking place anyway, and where drivers adapt their refuelling strategies to exploit price differences.

This can be the case for international freight transport, especially in typical transit countries such as Luxemburg or Austria, but also for transboundary commuting. The problem, in this case, is one of tax competition between countries: the threat of fuel tourism and the fear of losing revenue limits governments' freedom to introduce welfare-maximising prices for road fuels, which reflect the full external costs of transport, and which may be in line with the preferences of the national electorate. Third, fuel tourism affects the distribution of tax revenues – to the point where a small country can increase its revenue by lowering fuel taxes, if the fall in revenue from domestic consumers is offset by the increase in consumption from foreign consumers. And fourth, the incidence of fuel tourism makes the attribution of emissions more difficult. Under the established accounting rules for CO_2 emissions, the emissions associated with the combustion of transport fuels are attributed to the country where the fuel is sold. In the case of (outbound) fuel tourism, however, the actual emissions occur in another country, and are caused by foreigners. This does not change the physical accounting rules, nor the fact that the domestic government is legally accountable for these emissions. But it may suggest that the domestic government does not assume the political responsibility for these emissions, and therefore feels less compelled to address emissions from fuel tourism than emissions from stationary sources within its boundaries.

Figure 12: Top twelve fuel price differentials at inner-EU borders, October 2013



Source: DG Energy Oil Bulletin

The incidence of fuel tourism across Europe is determined by the differences in fuel prices, and the geographic location of a country. Countries like Luxemburg, Austria or Switzerland, which are located at major European thoroughfares and which have significantly lower fuel prices than neighbouring countries, experience a substantial amount of fuel tourism. Figure 12 presents the top 12 of fuel price differentials at inner-EU borders. For petrol, the highest differentials can be observed at the Italian-Austrian and Italian-Slovenian border, the border between Greece and Bulgaria, and the German-Luxembourg and German-Polish borders, with differences ranging up to 35 cents per litre. For diesel, the differences tend to be markedly lower, with only two cases where the price differential exceeds that for petrol.[30]

For **Luxemburg**, the existence of fuel tourism has long been established. Already in 1994, it was observed that the consumption of transport fuels per capita – and especially diesel – in Luxemburg was three times higher than in Germany and France, which led to the conclusion that two thirds of the transport fuel sold in Luxemburg is in fact consumed by foreigners (Bleijenberg, 1994).[31] In **Austria**, fuel prices are also considerably lower than in the neighbouring Italy and Germany, and even lower than in Slovenia, Slovakia and the Czech Republic. Consequently, a 2012 study concluded that between 25% to 30% of all transport fuels sold in Austria were due to fuel tourism. Of this, more than 80% is in the form of diesel, of which two thirds went into freight transport. German drivers accounted for most of the fuel tourism, aided by the high population density in the border region and the relatively high number of border crossings (Austrian Energy Agency 2012). **Switzerland** is a third European country in a central location where price differentials with neighbouring countries have led to the emergence of fuel tourism. To study the occurrence of fuel tourism, Banfi et al. (2003) have looked at the density of fuel stations in border regions, comparing this data to the average data for the respective country examined. They found a substantially higher density of fuel stations in the border regions, particularly in the City of Basle (bordering Germany and France) and the Ticino canton bordering Italy, where the density of fuel stations was about twice as high as the national average (5.6 and 6.4 stations per 10,000 vehicles compared to a national average of 3.1). But fuel tourism can also be observed in more peripheral regions: for the case of **Ireland**, Fitz-Gerald et al. (2008) estimated based on model simulations that in 2005 5-9% of total petrol sales in the Republic of Ireland were actually consumed in Northern Ireland, where fuel prices are higher. For diesel, this share even came to 15-20% of all diesel sold (Fitz Gerald et al. 2008).

In terms of the amount of additional traffic that is induced in order to take advantage of fuel price differences, different authors arrive at different conclusions. For instance, Rietveld et al. (2001) estimate that the average Dutch driver living near the German border requires a price difference of 0.5 €-cents/l per extra km travelled. Along the same lines, Michaelis (2003) found that Germans are willing to drive 2 to 4 additional kilometres into a neighbouring nation per 1 €-cent per litre (Michaelis 2003), which converts into 0.25 – 0.5 cents/l per km. In addition to these empirical findings, the experience with measures taken to combat fuel tourism have also underlined the fact that drivers are highly responsive to price differences. Thus, the Northern Italian province of Lombardy had introduced price rebates at fuel stations

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[30] Note that the calculation is based on the average fuel prices reported per country: since fuel prices also differ within a country, the actual differences at the border are likely to be lower (but can also be higher).

[31] Bleijenberg A. N. (1994) Internaliser les coûts sociaux des transports, Conférence européenne des Ministres des Transports (CEMT), L'art de l'internalisation, OECD

for inhabitants of the regions near the border. After only six months, Swiss border regions reported a drop in demand of 20 to 40%, whereas sales increased substantially at Italian fuel stations (Banfi, Filippini, and Hunt 2003).

Finally, some research from Spain points to the fact that fuel tourism can also occur within a country, if there are differences in fuel taxation between independent regions. Thus, Romero-Jordána, et al (2011) analysed the case of Spain, where Autonomous Communities have the authority to levy regional sales retail taxes. This led to variations in the diesel prices of up to 5 cents per litre, or 4% on average. In a case study for the neighbouring Autonomous Communities of Galicia and Castile-Leon, the authors estimated that fuel stations in the border regions of Galicia (where a regional tax is levied) experienced lower fluctuations than in the bordering regions in Castile-Leon: for a 1% increase in the diesel price in the region without tax, the diesel price in the region with tax increased only by 0.8%. This shows that fuel stations use the available leeway to limit price increases, in order to avoid a loss in market shares. In a similar fashion, Leal et al. (2009) studied the behaviour of diesel prices and demand in the three neighbouring Communities of Catalonia, Madrid and Aragon between 2001 and 2007. The authors found that a 1% increase in the price of diesel in Catalonia and Madrid, respectively, lead to an increase in diesel sales in Aragon by 1.6 and 0.6% (Leal, López-Laborda, and Rodrigo 2009).

The bottom line is that the published evidence on the incidence of fuel tourism is too isolated to provide a complete picture of the phenomenon. The available studies underline that the extent of fuel tourism can be considerable in the region where it occurs, but that only occurs under particular circumstances. Thus, fuel tourism is problematic above all in small countries in central locations, especially if these are located at major thoroughfares or in cases where there is a high population density in the border region, combined with a sufficiently high discrepancy in fuel prices. Thus, in October 2013, there were two cases where the fuel price difference between countries exceeded 30 cents, and three more where this difference exceeded 25 cents, which would suggest that consumers could travel as far as 100 km to exploit the price difference. At most inner-EU borders, however, the price difference would be too small to induce much additional traffic. Thus, at least for private vehicle use, and depending on the assumptions on the cost of commuting, fuel tourism would largely be confined to international commuters, transit traffic, and to those living in a 10-15 km radius from the border. The larger the share of the population that lives within this area, the more relevant the issue becomes.

The case is even less clear, however, for freight transport. On the one hand, it is very plausible (and supported by anecdotal evidence) that road hauliers plan their refuelling stops to take advantage of fuel price differentials. The larger fuel tanks of heavy-goods vehicles mean that the geographical extent of fuel tourism is potentially much larger. This suggests that the incentive effect of rising fuel prices on commercial transport, especially longer-distance transboundary transport, will be limited because of fuel tourism. On the other hand, the question is whether this refuelling strategy merely results in a relocation of fuel purchases and revenues between countries, or if it indeed creates additional traffic (i.e. when hauliers plan a detour to take advantage of fuel price differentials). Yet, in comparison to private vehicle use, the opportunity cost of spending time on the road is both much higher and also much harder to ignore for commercial transport, which would impose a limit on the extent of fuel tourism.

A further, potentially larger impact of fuel tourism is its impact on the pricing policies and the level of ambition in different countries. However, this effect largely escapes quantification. In a would-be frontrunner country, the existence of fuel tourism may stifle the ambition to raise fuel taxes – even as the factual impacts may be limited, the issue may nonetheless attract political attention and media coverage. And yet, even in countries with relatively high fuel taxes, and despite the fact that transport fuels for road transport tend to be taxed more heavily than other transport modes and other energy carriers, taxes on transport fuels do not cover all the external costs of (passenger) road transport (van Essen et al. 2011, 2012; Schreyer et al. 2004). This means that the threat of fuel tourism may prevent the implementation of welfare-maximising taxation, and thus perpetuate welfare losses.

At the same time, there can be situations where the laggard country has a fiscal disincentive to increase its transport fuel taxes, in order to reduce the price differential. Raising the fuel price means increasing the revenue from domestic consumers, but it also entails a loss of revenue from fuel tourists. Thus, for a small country a central geographic location and much transit, raising the tax rate may (paradoxically) lead to lower revenue, if the foregone revenue from former fuel tourists exceeds the revenue gain from domestic consumers.

In conclusion, the incidence of fuel tourism affects the effectiveness and the efficiency of pricing tools in transport. But, at least for private vehicle use, it does so only in a confined area, and is therefore above all a regional phenomenon. It therefore mostly affects smaller Member States bordering on countries with significantly lower transport fuel taxes. The effects on political feasibility are therefore potentially more serious than the actual impacts on efficiency and effectiveness.

4.2. Company car tax policies

Economic approaches such as the ‘total cost of ownership’ assume that new cars are purchased by individuals, and that the individuals will consider all cost components in their purchase decisions: the purchase price of the new car, the cumulative costs of fuel consumption, insurance, taxes and maintenance over the time horizon in which the car is used, and the resale value of the car at the end of the time horizon. Pricing policies can influence these components in different ways: through differentiated taxes for the purchase of a new car, by increasing the fuel price, or through differentiated registration or circulation taxes. In any case, the different price components would become part of the total cost of ownership, and would therefore play a role in the purchase decision of a rational consumer. Yet the reality is that, in most European countries, this assumption of a rational end-user, reflecting the full costs in the purchase decision, only holds for about half of the private car market in Europe – and in several countries even only for a minority of all cars purchases. Instead, a large share of new cars is sold as company cars.[32] For this part of the market, the price signal imposed by policies are muted at least partly, if not entirely.

The fiscal treatment of company cars differs between European countries. However, the commonality is that, in all countries, the car is bought (or leased) and registered by the employer, and used by the employee. The employee has to declare the in-kind benefit of using the company car as part of the taxable income. How the value of this in-kind benefit is calculated – whether it is based on the catalogue price of the car, the actual purchase price, or the resale value, and what proportion of this value needs to be declared as taxable income – differs from country to country. Most countries apply the catalogue price of the actual purchase price, and consider between 10-30% of this value as taxable income. Often, this is not a single rate per country, but a range of values, depending on the absolute business mileage, the distribution of private and business use, the age of the car, or its CO_2 emission performance. A minority of countries use standard rates to calculate the in-kind benefit, irrespective of the value of the car (for an overview, see Copenhagen Economics 2010). In general, it can be concluded that the taxation rules impose a cost burden on the employee that is much less than the lease price of a comparable vehicle (Tschampa 2013). Costs related to insurance, taxes, maintenance and repair are covered by the employer, but are typically not considered explicitly in the calculation of the taxable in-kind benefit. By assumption, these would be seen as covered by the taxable share of the car's value. Finally, for the fuel use, the fiscal treatment again differs. It is common practice that companies that provide a company car also cover the cost of the fuel, e.g. by providing a fuel card to the employee. Only a minority of countries have taxation rules for the value of the fuel received, in the majority this cost escapes taxation. Hence, the employer absorbs the entire fuel cost; the employee has no incentive to reduce (or to even consider) the fuel consumption (Macharis and De Witte 2012). Where taxation rules exist, they typically operate on the basis of the kilometres travelled, and hence require the employee to keep a logbook (Copenhagen Economics 2010).

At the same time, there has been a growing recognition of the problematic, distorting effect of company car taxation rules, and some countries – such as the UK or Belgium – have reformed the fiscal treatment of company cars. Thus, in both cases, the taxable share of the car's value varies depending on the CO_2 emission performance of the car: for higher-emitting cars, a higher share of the car's value will be considered as taxable income (Copenhagen Economics 2010, also FÖS 2012). Also, in both cases, employees have to declare at least part

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[32] Corporate purchases of cars are understood to include those in the manufacturing, rental, and car dealership sectors. One part of this are "company cars" (as in corporate-sponsored personal vehicles for employees) which serve as attractive perks for employees.

of the fuel received free of charge as taxable income. These reforms seem to be having an effect: for instance, in the UK, the average CO_2 emissions of the UK company car fleet have decreased quicker than the average CO_2 emissions of cars sold to private consumers. Since 2003, average emissions of the company car fleet have been lower than the average of all passenger cars, suggesting that the company car tax succeeded in discouraging the purchase of higher-carbon vehicles (Veitch and Underdown 2007). It also suggests that the company car market may respond to market conditions faster than the private car market would.

On the whole though, and despite changes in some countries, the various rules for company car taxation continue to lead to a situation where both the company and the employee benefit financially. In particular, in most countries there still is no incentive to reduce the fuel consumption, be it by changing the driving behaviour, or by choosing a more efficient car.

The fiscal attractiveness of company car explains their high share in the car fleet. Thus, Copenhagen Economics (2010) provide evidence from 18 EU countries, according to which company registrations accounted for just below half of the 12 million cars registered in these countries in 2008. This is in line with country-level evidence from other sources: for instance, in the UK, companies contribute to over half of new car sales (Veitch and Underdown 2007). In Belgium, corporate purchases cover half of new car registrations, and company cars proper comprise of 10% of the auto fleet (Macharis and De Witte 2012). In Germany, nearly 70% of new car sales are registered to companies (Federal Motor Transport Authority 2013). This means that private consumer behaviour, and the demand profile of private consumers, by and large does not drive the German personal vehicle market (Tschampa 2013).

The influence of the taxation rules for company cars becomes even more pronounced when studying the effects on the composition of the vehicle fleet. There is a clear bias in that company cars tend to be mostly in the more upmarket segments: of 12 million cars registered in 18 EU countries in 2008, company cars accounted for 31% of registrations in the mini segment, 48% in the lower medium segment, and 70% in the upper medium segment (Copenhagen Economics 2010). For the high-end segment, the situation is even more extreme: in Germany, the Federal Motor Transport Authority reports that over 85% of high-end cars sold are registered to companies. Indeed certain luxury car models are exclusively registered as company cars (Federal Motor Transport Authority 2013).[33]

This means that the company car policy is changing the incentives that a prospective car buyer is facing; and in particular, it is muting the incentive effect of fuel prices to stimulate demand for more fuel-efficient vehicles. The prospective buyer of a company car, in this case the employee at a European company taking advantage of the corporate car benefit, will not behave the same way a private consumer would.

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[33] For instance, 96% of the Audi A8 series, and more than 90% of the BMW 7 series were registered to companies in 2013 (January to November) (Federal Motor Transport Authority 2013).

As a consequence, the company car fleet in a country will differ from the overall car fleet. As Graus and Worrell (2008) point out for the Netherlands, company cars tend to be newer than the average, and the share of diesel cars is higher, both of which speaks prima facie for a better fuel efficiency. Yet company cars are also larger, heavier and more powerfully motorised. Therefore, on the whole, the average fuel efficiency of company cars is worse than the average of cars that are privately purchased (Graus and Worrell 2008). Diekmann et al. (2011) confirm this finding for the case of Germany: they report that, in 2008, all company cars registered in Germany had average emissions of 167 g CO_2 / km, compared to 162 g / km for cars registered to private owners. Company cars also dominate the bracket of particularly emission-intensive cars (emissions in excess of 200 g / km), where they account for 77% of new registrations.

Further to such immediate impacts, company car tax policies also affect the composition of the vehicle fleet in a country: like rental cars, company cars are typically driven only for a few years, and then are sold on as second-hand vehicles for the remainder of the vehicle lifetime (Scott, et al. 2012, see also Diekmann et al. 2011). The combination of the high turn-over rate for company cars and their high share in new vehicle registrations means that the market for second-hand cars in many countries is dominated by former company cars. As argued in the following chapter, this effect extends beyond the borders of the country where the vehicle was originally purchased.

The distorting effect of the company car taxation rules, however, is not limited to the purchase decisions. It also extends to the driving behaviour, as company car users in most European countries do not face any monetary incentive to reduce (or even to monitor) their fuel consumption. An immediate effect of this type of policy is therefore to incentivise more driving, and lessen the concern for efficiency. For the Netherlands, Graus and Worrell (2008) estimate that the company car phenomenon might lead to a net fuel use increase of 1–7% (Graus and Worrell 2008). They point out that company cars make up 11% of all passenger cars in the Netherlands, but at the same time account for 21% of the energy consumption of passenger cars, as the annual mileage of company cars is twice as high as for private cars. Only part of this difference is attributed to the actual business travel for which company cars are intended; a comparable share of the difference is due to the fact that company car users, on average, commute much longer distances to work. The finding that company car tax policies induce additional transport is supported by a study from Israel, which concluded that such policies result in use of the vehicle by the employee’s entire household, as well as driving considerable extra mileage (Shiftan, Albert, and Keinan 2012).

Yet, the fiscal benefit of company cars does not accrue to the employee only: the company itself also benefits in different ways. For instance, the company will be able to deduct VAT paid for the purchase of the car, for fuel purchase and for maintenance and repair. Also, the employee receives the use of the company car as a benefit-in-kind that is part of the salary (and as such liable to income tax), but in contrast to the monetary wage is not subject to social security contributions, which would otherwise be paid for by the company and the employee jointly.

As both companies and employees benefit, the public budget loses: indeed, the preferential fiscal treatment of company cars amounts to a significant subsidy. This subsidy is an implicit one in the sense that the support consists in taxes that are lower than in a reference scenario that is oriented at tax neutrality (e.g. all cars privately owned and operated), and not in an explicit payment. The value of this subsidy can therefore only be estimated, though, as the difference between current tax revenues (income tax, VAT) and the tax revenues under a reformed scenario approximating tax neutrality. In this way, Diekmann et al. (2011) estimate the annual value of tax revenue losses due to the preferential treatment for company cars in Germany alone at between 2.9 and 4.6 billion Euro. For 18 EU countries, Copenhagen Economics (2010) estimate that the annual tax revenue loss at 54 billion Euro, or 0.5% of the GDP of the countries considered. In addition to the total volume of the subsidy, the authors also point out that it is a highly regressive subsidy: first, because company cars tend to be available to higher-earning employees, and secondly, because the value of the reduced income tax depends on the income tax rate that would otherwise apply, so that higher-earning individuals, facing a higher income tax rate, benefit more if their taxable income is reduced by a given amount.

As an aside, the effects of company car tax policies could be particularly detrimental to electric vehicles. Current electric vehicle retail prices are much higher than comparable vehicles with an internal combustion engine, therefore the main economic incentive to purchase an EV are fuel costs savings, i.e. the much lower cost of electricity compared to petrol or diesel (Gilmore and Lave 2013). However, when employers have to declare the value of their company car as taxable income, but do not have to pay for their fuel, that means the benefit of an EV does not apply for a company car. Worse still, with EVs, employees may fear having to actually pay for ”fuel,” since they would be charging the vehicles at home and paying for electricity out of pocket (although new schemes of reimbursement may be introduced to counter this).

Regarding the role carbon pricing for road transport, this means that the effects of carbon taxation on vehicle purchases and driving behaviour are effectively muted for a large segment of the market. If corporations have no obligations to lower the carbon emissions of their vehicle fleet, and employees do not pay for fuel, increasing fuel taxes would do little to encourage a change in behaviour or spark demand for fuel-efficient cars.

Because company car tax policies affect a sizeable share of the market, they interfere significantly with carbon pricing tools. Carbon pricing would theoretically offer the optimal approach to tackling the climate impact of transport. Yet, since company car tax policies render carbon pricing ineffective for a large part of the car fleet the first-best solution would be to remove company car preferential treatment, or to design it in such a way that the incentive effect of higher fuel prices is preserved. If this is not considered politically feasible, second-best options would then come into play. This may include binding standards for fuel efficiency, as applied in EU and US legislation. In the current context, the advantage of such standards is that they apply irrespective of vehicle ownership: they impose an obligation on car manufacturers irrespective of whether the car will be bought and driven as a company car, or as a normal privately owned car.

A third-best option, which could conceivably also serve as a complementary policy measure, would be voluntary commitments by companies to green their vehicle fleet. In the current policy debate, the companies do not figure as prominent players. However, by adjusting their purchase policies or setting standards for the maximum allowable emissions of company cars, they have a potentially very effective – albeit controversial – tool at their disposal.

4.3. Second hand car markets

In order to understand how transport-related environmental policies in general, and pricing tools in particular, affect the demand for cars, it is important to consider the entire lifecycle of cars. One of the key instruments that the EU employs to tackle greenhouse gas emissions from road transport are the fuel efficiency standards that are mandatory for new cars.[34] But by their nature, such standards only affect the newly produced cars that enter the car fleet. Whether or not they succeed in reducing overall fuel consumption, and therefore also CO_2 emissions from passenger cars, depends on the speed at which the car fleet is renewed.

A closer look at the European market for passenger cars soon reveals that very different dynamics are at work in the different parts of Europe. Central and East European Member States started with comparatively low motorisation rates (i.e. levels of car ownership) after the fall of the wall. In Romania, Poland, Bulgaria, Hungary and the Baltic Countries, there were less than 200 cars per 1,000 inhabitant, compared to an EU-27 average of 334 in 1991. During the last 20 years, levels of car ownership have increased massively in all of the new Member States (and some older ones): the motorisation rate has more than doubled in Bulgaria, Latvia and Estonia, it has almost tripled in Poland and more than tripled in Romania, and quadrupled in Lithuania. Over the same period, growth trends have been more modest in most old Member States, typically between 10 and 40% over 20 years. As a result, there is now convergence in terms of car ownership patterns across Europe, with motorisation rates of 400 – 550 vehicles per 1,000 inhabitants in the majority of Member States (old and new).

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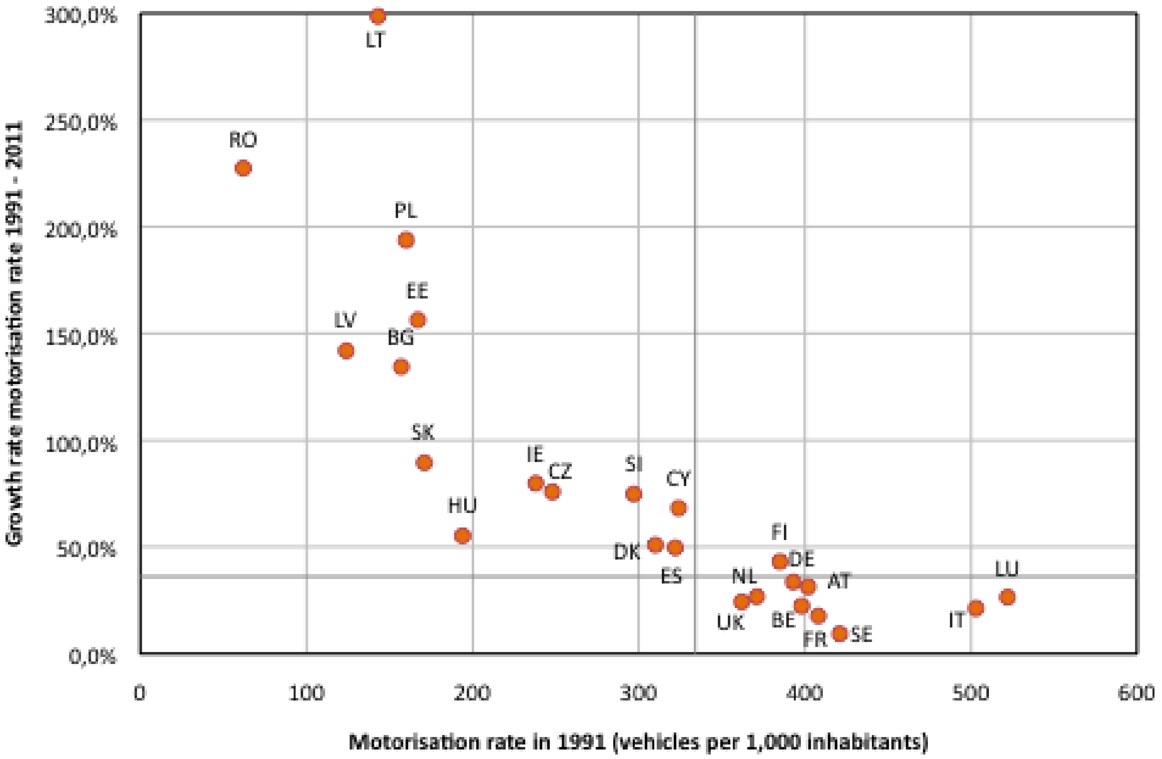
[34] See Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles. A review of the regulation, setting standards for 2020, is pending at the time of writing (October 2013).

Figure 13: Motorisation rate in 1991 vs. motorisation growth rate 1991 - 2011



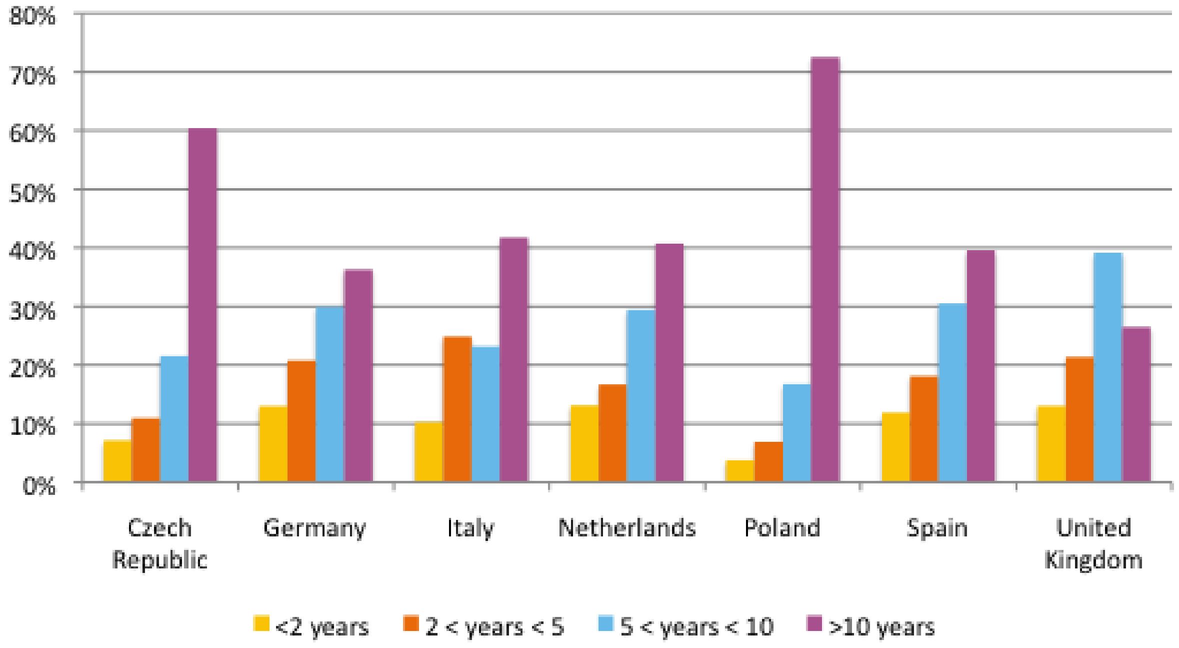
Source: Eurostat

The catching-up process that has taken place in the new Member States over the last 20 years was driven both by the addition of new vehicles to the vehicle fleet, but also to a considerable degree by shipments of second hand cars from Western European countries. While the data on intra-European trade in second hand vehicles is not always reliable, it is evident from the available data that there is a well-developed market for second hand markets, in which some countries (which tend to be richer countries and older Member States) are net exporters, and other countries (which tend to be poorer and more recent Member States) are net importers.

Thus, Mehlhart et al. (2011) estimate that, in 2008, there were six countries in Europe where the number of imported second hand vehicles exceeded the number of newly manufactured cars that were registered in the same year: this was the case in Poland, Bulgaria, Latvia, Greece, Slovakia and the Czech Republic. In another four Member States (Cyprus, Malta, Romania and Estonia), imported cars represented more than a third of the annual increase in the country’s car fleet. At the same time, the authors identified five countries with high export shares: in Luxemburg, Belgium, Slovenia, the Netherlands and Germany all had large export shares, in all cases markedly higher than the corresponding import shares. In Germany, Luxemburg and the Netherlands, the vast majority of exports went to other EU countries; in Slovenia, the majority was extra-EU trade, in particular to Balkan countries.

As would be expected, the trading patterns have resulted in a skewed distribution of the vehicle fleet across Europe in terms of age. Most second hand vehicles traded in Europe have been on the road for several years. Mehlhart et al. (2011) provide figures for Poland, where the majority of imported vehicles in 2008 and 2009 were older than ten years. As a result, while the average age of the car fleet in Europe is just above 8 years, it is markedly higher in many of the new Member States. According to ACEA, the average age of cars in Latvia was almost 16 years (2008), and more than 11 years in Estonia and Slovakia (2010 data). This discrepancy also becomes apparent when considering the distribution of cars across different age brackets. In the following graph, which presents the age distribution of the car fleet for seven EU countries in 2011, the Czech Republic and Poland stand out with a share of 60 – 70%, respectively, for the share of cars older than 10 years. By contrast, the corresponding share is between 26 and 42% in the five older Member States covered in the sample.

Figure 14: Age distribution of the passenger car fleet in selected EU countries, 2011



Source: UNECE Transport Statistics

The observation that different dynamics are at work in the European market for passenger cars may not be particularly surprising, given the discrepancies in socioeconomic conditions and the different growth dynamics currently observed in the different parts of Europe. Yet, the different dynamics also have implications for the effectiveness, efficiency and the political feasibility of climate policies in the field of road transport, but also for the distributional implications of such policies.

As noted before, one of the EU's key policies to tackle the climate impacts of road transport is the EU regulation on the fuel efficiency of new passenger cars (Regulation (EC) No 443/2009). The effect of this regulation can be witnessed in the marked reductions in fuel consumption per km (and hence the fall in CO_2 emissions per km) for new cars sold across the

EU, suggesting that the target of 130 g CO_2 / km, set for 2015, will be achieved well ahead of time.

While these developments are encouraging, they only affect new cars. The question is therefore how quickly such improvements in fuel efficiency will percolate through the market, in order to increase the fuel efficiency of the entire fleet? The analysis above suggests that this will happen at a different pace in different parts of Europe. In Germany, Italy and the UK for example, relatively new cars (less than five years of age) which, *ceteris paribus*, can be considered to embody some of the observed improvements in fuel efficiency, represented more than a third of the vehicle fleet in 2011. In the Czech Republic, this share was at 18%, and 11% in Poland. At the same time, the high share of older cars in the car fleet represents an environmental legacy, given that the average fuel consumption of a ten-year-old car will be about 25% higher than that of an average car sold today (ICCT 2012).[35]

It is of course debatable whether an older car fleet – and one with a higher share of imported vehicles – would necessarily have to be also one with higher average fuel consumption. After all, the observed trends are averages: ten years ago, there were some vehicles on the market that have lower emissions than the EU average. And indeed, for any year the average fuel efficiency differs considerably across the Member States of the EU: while the EU-27 average was at 136 g CO_2 / km in 2011, the national averages ranged from 126 g/km in Portugal to 147 g/km in Germany (ICCT 2012).

Alas, the data on intra-EU second hand vehicle trade does not allow for a detailed analysis of how trade in second hand vehicles affects the average age of the car fleet, let alone their CO_2 performance, as neither of the two parameters is reported in a systematic way for traded vehicles. On the basis of the available data, it is therefore not possible to discern whether it is particularly fuel-intensive cars that are traded, or whether the opposite is true. Thus, a reasonable assumption would be that traded cars reflect the average emission intensity in the country of origin. This, however, would be bad news for the net importers: Germany, which is by far the largest net exporter of second hand cars in Europe, has had one of the highest average fuel intensities for new cars in Europe for a number of years, leading to a relatively high fuel intensity across the entire vehicle fleet. A second major exporter, the Netherlands, was among the countries with the highest fuel intensity for new cars until about 2009 (ICCT 2012).

Taken together, this suggests that the catching-up process in terms of motorisation that has been going on in the new Member States for the last two decades, and is still taking place,

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[35] Note that the fuel efficiency information, just as the information on CO_2 emissions per km, are measured in the type-approval process for new cars, which is carried out under laboratory conditions on the basis of a pre-defined driving cycle. There is some evidence that the real-world consumption of cars on the road is not only higher than under laboratory conditions, but that this discrepancy has widened over time – from below 10% in 2001 to around 25% in 2011 (see chapter **Error! Reference source not found.**). This means that some of the fuel efficiency gains of newer cars is on paper only, and that the decrease in fuel consumption will be less than the official figures suggest.

may be resulting in a particularly emission-intensive vehicle fleet in those countries. This has implications for the different policy instruments that apply in this field, their performance and their feasibility:

- The new Member States are not partaking in the efficiency improvements brought about by the EU regulation for new cars. Since 2007, the fuel consumption of new cars has fallen markedly, while average prices of new cars have remained largely unchanged. Yet the benefits of this trend largely bypassed the new Member States: first, because car markets are dominated by imports of second hand vehicles from old Member States, and often those with a relatively fuel-intensive vehicle fleet; and second, because the new cars registered in the new Member States exceed the EU-27 average in terms of fuel consumption.[36]
- If countries that are net exporters of second hand cars adopt more stringent climate policies, such as increasing fuel prices or changes in annual circulation taxes that penalise emission-intensive cars, this would mean that such cars become less attractive on the domestic market, and hence increase their exports.
- At the same time, the build-up of a vehicle fleet with high emission intensity in the importing countries may make it difficult politically to implement ambitious climate policies in the transport sector, such as raising fuel prices.

For the EU as a whole, the observed improvements in fuel efficiency of cars suggest there is some scope for a measured increase of fuel taxes: if the costs of road fuels increased in line with the efficiency gains of the car fleet, the cost of transport would not change, at the same time the switch to lower-carbon transport modes would be incentivised. Yet, while this calculation holds for the EU as a whole, the analysis above shows that the impacts of a uniform rise in fuel taxes would be distributed unevenly across Europe. In particular, it would be felt more severely in the new Member States, whose older and less efficient vehicle fleets make them more vulnerable.

There are two further considerations, which could influence the assessment of what impact trade in second-hand vehicles has on climate policy efforts, but which could not be addressed in the framework of this limited analysis. First, there is the question to what extent the fuel economy, and hence the climate performance, of a second-hand car is factored into its price. Put simply, the discussion above suggests that there is a flow of older, inefficient vehicles from old to new Member States, which favours climate policy efforts in the old Member States, and makes them more difficult in new Member States. Yet, if consumers in the new Member States anticipate that domestic climate policies will be stepped up and fuel prices will increase, this could also entail that low fuel efficiency is reflected in the trading value of a second-hand car. A second consideration relates to the life-cycle carbon emissions of a car: the above argument was solely based on the emissions related to its use. However, from a

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[36] This is a trend that can be observed since 2007. In 2011, new vehicles registered in the new Member States averaged 144 g CO_2/km, compared to the EU-27 average of 136 g/km for the same year (ICCT 2012).

life-cycle perspective (considering the climate impact of producing and decommissioning a car), it may be desirable if existing vehicles are used rather than scrapped and replaced with new ones.

4.4. Conclusions

Pricing tools are an important part of the climate policy mix – for tackling CO_2 emissions from transport, as for other sectors. Yet, in order to design pricing tools that are efficient, effective and practically feasible, it is important to understand the intricacies of the market environment into which the carbon price signal is introduced. Only if the various barriers, constraints and interdependencies are understood will it be possible to anticipate how pricing will actually change the incentives that consumers face, how the effects of pricing tools will work their way through the market, and to design pricing tools accordingly for maximum efficiency and minimum friction. This chapter highlighted fuel tourism, company car taxation and trade in second hand vehicles as three selected examples of barriers and constraints that affect the functioning of pricing tools in the transport sector.

For the case of fuel tourism and second hand vehicles, it could be argued that they simply provide examples of a EU-wide single market at work: consumers in the EU take advantage of price differentials and of supply-demand imbalances across countries, which has been the basic idea behind the establishment of a common market across the EU. The case of fuel tourism in particular also serves as an example that consumer decisions are indeed affected by politically induced price changes: as a positive lesson, it shows that consumers do respond to pricing tools. Yet, as argued above, the cases of fuel tourism and second hand vehicle trade also provide examples of how cross-border trade and arbitrage affect the functioning of existing pricing policies, and the political feasibility of introducing new ones. This suggests a clear need for policy coordination: where markets are linked across borders, and where policies affect domestic markets, there is a need to coordinate policies.

While the conclusion from fuel tourism is simple to formulate (and yet hard to implement) – work to eliminate differences in fuel taxation across Europe – the example of second hand vehicles shows more delicate interactions between policies and the market. More ambitious policies in some frontrunner countries may push the market into a certain direction, depending on whether they apply to all existing cars, or whether they target new cars only. For instance, punitive taxes on existing cars with high fuel consumption will drive these vehicles into export, i.e. a type of carbon leakage. By contrast, high taxes on new cars with a high fuel consumption, would generally have less of a leakage effect, and may create a positive spill-over through trade in second-hand vehicles: if new cars become more fuel-efficient, so will the exported second cars eventually. In either case, the effects of the national policies – in terms of the resulting vehicle fleet across Europe – will also affect the distribution of the benefits of EU-wide pricing policies. Also in combination with company car tax rules, it is an example of policy- and market-induced path dependency: the vehicle fleet found in any country is the joint result of market forces and policy choices. Yet this endowment also determines the expected impact of future (pricing) policies, which may help to explain the reluctance to embrace more ambitious policies in some countries that are net importers of second hand vehicles.

Company car taxation, at least in the manner how it is typically implemented in Europe, is an example of negative policy overlap. Road fuel pricing and company car taxation rules are different policies with competing objectives, which, unless coordinated well, may cancel each other out. Under the company car tax regimes that are in place in most European countries, the carbon price signal for fuel consumption is effectively muted for company cars – and thus for about half of new car registrations. This affects driving behaviour as well as purchase decisions, and thereby also the structure of demand for new cars. But the impact does not end there: through trade in second-hand vehicles, the effects of favourable tax treatment for company cars are perpetuated. While there is no detailed data on this, it is plausible to assume that, of the 1.6 million second hand cars that were exported from Germany to other EU countries in 2008, a considerable proportion would have been first registered as company cars. Hence, the effect that company car tax rules tend to push the vehicle fleet towards heavier and more powerfully motorised cars will be perpetuated throughout the life cycle of the car, and the distorting effect of company car taxation rules exported beyond the country of origin.

5. Soft transportation policy measures

Several scholars argue that psychological strategies targeting attitudes and perceptions are more acceptable and less expensive (Emmerink, Nijkamp, & Rietveld, 1995; Taylor & Ampt, 2003, Green and Stone, 2004) compared to infrastructural modifications (such as bus priority lanes) and/or legislative policy measures (e.g. congestion charging). Therefore they believe that programmes designed to bring about psychological change offer a promising route to reducing car use and air pollution (Gardner & Abraham, 2008; Ampt, 1999; Bamberg & Möser, 2007; Brög, 1998; Fujii & Taniguchi, 2006; Graham-Rowe et al., 2011, Möser & Bamberg, 2008; Steg, 2003; Stern, 1992; Tisato & Robinson, 1999).

In any case only theoretical grounded research of the effectiveness of mobility management and various soft policy measures may bring a realistic picture of possibilities to reduce CO_2 emissions in passenger transport. The question of when and how they work and when and how it is useful to implement them (Taniguchi et al., 2007) is complementary to the effect of generalized costs if we want to understand the behavioural response of consumers to different policy measures.

The following chapter therefore summarises the state-of the art on the effect of mobility management/soft transport policy measures on travel behaviour and car use in particular. The following narrative reviews, meta-analytical studies and research reports were particular valuable sources of information: Gardner, Abraham, 2008; Richter et al. 2009a,b; Bamberg et al. 2011 and Graham-Rowe, 2011, Friman et al., 2013, Möser, Bamberg, 2008, Cairns et al., 2008, MAX- Successful Travel Awareness Campains and Mobility Management Strategies, 2002-2008).

5.1. Mobility Management/Soft Transport Policy Measure – the definition

Mobility management (called Travel Demand Management in the US and some other countries) is a concept to promote sustainable transport and manage the demand for car use by changing travellers' attitudes and behaviour (MAX - Definition of Mobility Management). At the core of Mobility Management are "soft transport policy measures" (STPM) comprising a wide range of different initiatives that share the common feature of trying to encourage individuals to voluntarily change their behaviour to more sustainable transport modes (comp. Richter et al., 2009b: 10, Cairns et al., 2008, Fujii and Taniguchi, 2006). Soft measures aim to directly influence car user's decision making by altering their perception of the objective environment, by altering their judgement of the consequences associated with different travel alternatives, and by motivating and empowering them to switch to alternative travel options (Bamberg et. al. 2011). The interventions trying to encourage individuals to voluntarily reduce car-use are also called *soft policy programs* (Friman et al. 2013), *soft measure* (Jones, 2003) or *psychological and behavioural strategies* (Taniguchi et al., 2003).

Soft Transport Policy Measures supplement structural initiatives which are based on modification of the physical and/or legislative structures that regulate travel behaviour in order to decrease the attractiveness and opportunities for car travel and/or offer incentives for use of non-car transport (Gärling and Schuitema, 2007). These include road pricing with financial incentives (Saleh, 2007), road closures disrupting routinized driving patterns (Fujii et al., 2001), or bus priority lanes making public transport more efficient. Typically, soft measures are rarely isolated; instead they often come as a bundle of measures, i.e. information campaigns combined with infrastructure, pricing policy or regulations.

Since one can find a load of specific soft transportation measures all over the world and several measures have been combined in order to boost the effect, there is no unequivocal consensus on their classification (comp. Cairns et al., 2008, MAX, 2006-2008, Friman et al. 2013, Fujii and Taniguchi, 2006).[37] Such a disagreement makes the evaluation of individual measures and their design rather difficult.

The following table displays a comparison of two common classifications of soft transport policy measures based on organisational and policy design aspects: by Cairns et al. 2008 and by MAX project.

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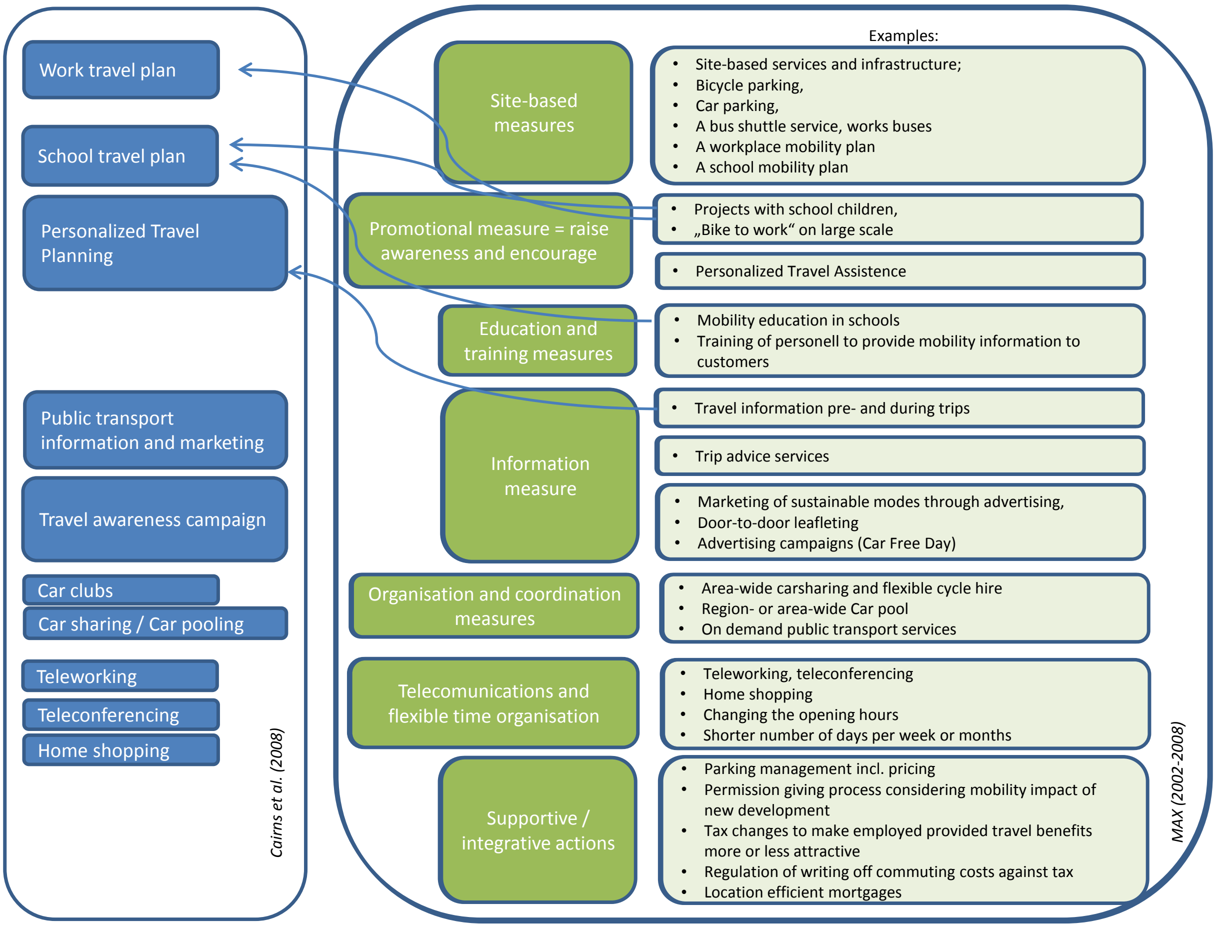
[37] MAX (2006-2008) provides some guidance on where the boundary of Mobility Management (MM) lies: (1) MM is demand oriented – instead of supply oriented; (2) infrastructure measures can be supportive measures for MM; (3) MM does not necessarily have to be limited to a site; (4) sustainable urban transport plans are not MM, but they should contain MM; (5) traffic system Management is not considered part of MM; (6) travel awareness, mobility education, marketing of sustainable modes is regarded as part of MM; (7) MM is considered to encompass goods transport, as long as it is site based and the measures concerning goods are part of a mobility plan that also include passenger; and (8) various legislation, pricing incentives and disincentives are part of MM, if they support concrete MM measures that fall within the demarcation as described above.

Figure 15 - Classification of various soft transport policy measures



The comparison which shows that similar soft policy measures are classified differently, such as *travel information pre- and during trips* or *simplified ticket availability* indicate how difficult it is to draw reliable conclusions on the effects of individual types of soft transport policy measures. Any effort to assess the effectiveness of individual types of soft transport policy measures is even more difficult since they appear under various brands and often combine measures falling under distinct categories.

There are several examples of programs employing personalized travel planning (by Cairns et el., 2008) or Information and Promotional measures (by MAX, 2006). *IndiMark* concept (Brög et al. 2009) and the *TravelBlending* (Ampt 2004; Rose and Ampt 2001, 2003, Taylor and Ampt, 2003) concept have frequently been implemented in Australia, often within the context of even larger programs to encourage environmentally friendly behaviour (Richter et al., 2009a). In these programs an offer is made to a special target group to take part and change their travel habits, after which they accept and receive various forms of personalized information, sometimes in combination with motivation enhancing measures. These programs help individuals and households to understand the available alternatives, rather than using a mass marketing approach (Ker, 2003). *Travel blending* includes in addition motivational support (Rose and Ampt, 2001, Taylor and Ampt, 2003). Participants in one individualised marketing program (in 2002 in Bristol and London, UK) were asked whether they intended to change their travel behaviour, but received no messages aimed at motivating them to change their behaviour.

In Japan mobility management, attempting to change travel behaviour using personalized communication and planning, mostly goes under the name of *travel feedback program*- TFP (Fujii, Taniguchi, 2006: 339). Participants in one of such programs in Sapporo, Japan (Taniguchi et al., 2003) received a booklet describing why an individual's travel behaviour is important. In another TFP (proposed by Fujii and Taniguchi, 2005) the participants were required to devise a behavioural plan for changing their travel behaviour. The purpose was to affect behavioural and implementation intention.

TravelSmart was an attempt to employ persuasion techniques from Cialdini (2001, in Seethaler and Rose, 2005) to achieve raising awareness and knowledge and stimulate behavioural changes of lasting effect in Australian travellers. The techniques are supposed to be especially useful to influence habitual daily travel decisions with low personal involvement.

Even though there are available classifications of soft transport policy measures based on organizational aspect, individual authors of narrative review and meta-analyses often use their own typologies to sort primarily studies of their interest. For example, Friman et al. 2013 identify four types of techniques used to exert an influence on the participants of personalised travel planning programs in Sweden. They included *request for change*, *incentives*, *information* and *feedback*.

Various soft policy programs in addition focus on quite different components of the psychological process of behavioural change. Some address *beliefs*, *knowledge* and *awareness*, other *intentions* or *social norms*. To our knowledge, however, there is no classification of soft transport policy measures which would result from a behavioural theory.

5.2. Are soft policy measures effective? The evidence

Several narrative reviews (Brög et al., 2009, Cairns et al., 2008; Richter et al., 2010a, Taylor, 2007, Friman et al. 2013, Fujii and Taniguchi, 2006) have concluded that soft transport policy measures are effective in car mileage reduction and CO_2 reduction. Couple of meta-analyses of previous research results have also been conducted (Möser and Bamberg, 2008, Fujii et al. 2009). The review of the effects of travel feedback programs (TFPs, DETRA, 2004a) reported that "individualised" TFPs implemented in several cities in Australia, Germany, Sweden, and in the United States produce a reduction in car use up to 14% (South Perth, Australia), and at least 2% (Breisgau-Hochschwartzwald, Germany). The review also indicated that "travel blending" programs implemented in Australia and the United States produced a reduction in car use up to 15% (Adelaide, Australia) and at least 9% (Brisbane, Australia). Transport for

London implemented four different pilot travel feedback programs, called “personalised journey planning” under the brand name *TravelOption*, which reduced car use by 5-11% (Transport for London, 2004). DETRA also implied that TFP effectiveness was dependent on location (urban vs. rural areas) and types of TFP techniques.

In the meta-analysis by **Möser and Bamberg (2008)** the results of 141 studies were synthetized. The original studies evaluated the car-use reduction effects of work place travel plans (44 studies), school travel plans (25 studies), and travel awareness campaigns/marketing of public transport (72 studies). Across all 141 studies and all three soft policy measures an effect corresponding to increase in the no-car use proportion from 39% to 46% (i.e. by 18%) was found. However, the ability to draw strong causal inferences from the available research evidence is limited by the fact that all the retrieved evaluation studies use weak quasi-experimental designs.

Richter et al. (2009a) summarise main finding regarding the effects of soft transport policy measures. In their view it is evident that soft transport policy measures have different impacts on different target groups. The promotion of public transport appears to be especially successful among people who have experienced major changes in their life. Their susceptibility to soft policy measures is probably related to not yet developed travel habits. People with strong habitual car use seem to be less likely to participate in soft policy measures, underscoring the importance of personal characteristics and attitudes of participants and non-participants. They underline that although some results indicate that soft policy measures are more effective in promoting public transport to non-frequent public-transport users than to frequent public-transport users (Fujii and Taniguchi, 2006), the latter are more likely to participate in the first place (Seethaler and Rose, 2005).

Based on the review of 32 personalized travel planning programs in Sweden **Friman et al. (2013)** conclude that positive effects are on a par with the results observed in other countries. Most of the programs considered have been targeted at people who make most of their trips by car. In 7 of these programs, the reduction in the number of car trips is 22 %. The largest proportion of programs reporting changes in trips as a percentage have aimed at influencing people to choose the bus instead of the car. On average, these programs led to an increase in the number of bus trips by 36 %, whereas the highest increase in public transport trips was 93 % and the lowest is 2 %. Two programs that aimed at increasing bicycle use report an average increase of 43 % in bicycle trips.

Fujii and Taniguchi (2006) review the literature on travel feedback programs (TFPs) in four Japanese cities. In all ten programs considered the participants receive information designed to modify behaviour. The effectiveness of the programs is evaluated while considering their type and the situation in which they were implemented. Reported results indicate that changes in travel behaviour reduced CO_2 emissions by 15–35%. The most effective reduction, about 35%, occurred in Sapporo in 2002 (Fujii and Taniguchi, 2005). This reduction was brought about by participants requested to make a behavioural plan. Similar results were exhibited by a group in Osaka (2001), who received individualised information based on their

7-day travel diaries (Matsumura et al., 2003 in Fujii, Taniguchi, 2006). Contrarily a TFP conducted in Sapporo in 2002 that did not involve behavioural planning, resulted in no CO_2 reduction (Fujii and Taniguchi, 2005). Including this case, TFPs had a 19% average effectiveness in reducing CO_2 emissions. The Sapporo (2002) results indicated that requesting a behavioural plan had a major effect in reducing CO_2 emissions (35% vs. no reduction, for TFPs with and without a behavioural plan, respectively).

The overall effectiveness of TFPs in Japan is summarised as follows: "The 10 TFPs implemented in Japan resulted in a 19% reduction in CO_2 emissions, an 18% reduction in car use, and a 50% increase in public transport use (Fujii and Taniguchi, 2006). As such TFPs in Japan do not produce results substantially different from those reported in other developed countries (e.g. Brög, 1998, Jones, 2003, DETRA, UK, 2004a,b, Tranpsport for London, 2004).

In the second meta-analysis **Fujii et al.(2009)** used data from evaluation studies of 15 Japanese personalised travel plans programs (referred to as TFP) to examine whether the TFP are effective in reducing level of car-use related congestion, noise, and air pollution. The research design of the primary studies is in focus. The methodological quality of primary studies considered was higher because they incorporated comparison or control groups in a before–after test design (difference in differences technique). A standardised mean effect size corresponding to a decrease in the average number of weekly car trips from 6.9 to 5.7 (by 17%). However, the total number of studies was small and most of them were based on small non-representative samples.[38]

Graham-Rowe et al. (2011) summarize the results of 77 intervention evaluations, including measures of car-use reduction. The purpose of their review was to consider critically the available evidence on whether or not car travel reduction interventions are effective. They aimed to identify what works, what does not work, and the quality of the evidence available to support such conclusions. They stress that evaluations of interventions vary widely in the methods they employed and the outcomes measures the original authors reported. They summarise that the evidence base was found to be weak and only 12 out of the 77 evaluations were judged to be methodologically strong. In addition only half of 12 studies found that the intervention as "potentially effective", especially in shorter term. The following table displays 12 out of the 77 studies and their results that have been judged to be of high methodological quality.

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[38] Furthermore, at least some of the 15 Japanese TFP seem to have used non- equivalent treatment and comparison groups, thus making it difficult to rule out alternative explanations for the reported before–after test differences. Briefly, the Fujii et al. (2009) suggest that inferences of causes of the effectiveness of a TFP vary with research design.

Table 15 - Summary of 12 intervention evaluation

Author & date	Effectiveness of intervention	Measure type	Intervention strategy
Jakobsson et al. (2002)	Effective at reducing distance travelled for all 3 intervention instruments but only effective for 2 intervention arms in regards to trip frequency reductions	Distance & trip/frequency	Structural & psychological (economic disincentives & introduction of plan to reduce car use)
Foxx and Schaeffer (1981)	Not effective once the incentives had been removed	Distance	Structural (weekly lottery prizes & grand draws for participants whom had achieved set mileage reductions)
Tertoolen et al. (1998)	Not effective once within subjects characteristics were controlled	Distance	Psychological (information, feedback & commitment)
Foxx and Hake (1977)	Effective at reducing vehicle miles travelled	Distance	Structural (cash incentives for participants to achieved set mileage reductions)
Cervero (2002)	Not effective at reducing vehicle miles travelled daily but somewhat successful at reducing daily travel time in minutes	Distance & time spent	Structural (city CarShare scheme)
Mullins and Mullins (1995)	Effective at reducing average commute distance (miles) travelled per work branch	Distance	Structural (transferred worksites closer to home or traded worksites)
Bamberg (2006)	Effective at reducing proportion of trip frequency taken by car	Trip/frequency	Structural (a free one day PT ticket & information for using the services for people who had just moved house)
Eriksson et al. (2008)	Specifically effective at reducing car as driver trips frequency or car as passenger trips frequency for those with strong car habit	Trip/frequency	Psychological (implementation intentions)
Fujii and Kitamura (2003)	Not effective	Trip/frequency	Structural (free bus ticket & information for using the services)
Garvill et al. (2003)	Effective at reducing frequency of car trips for those with strong car habit and to a lesser extent for those with weak car habit	Trip/frequency	Psychological (providing information to increase awareness of alternative modes for pre-planned trips)
Fujii and Taniguchi (2005)	Not effective at reducing total frequency of car trips regardless of trip length	Trip/frequency	Psychological (encouraged to make behavioural plans to modify car trip chains
Hodgson et al. (1998)	Not effective at reducing average numbers of trips per week in car	Trips	Psychological & structural (information provision plus bike & park-&-ride schemes, improved bus priority)

Source: Graham-Rowe et al. 2011: 408

Six of the 12 methodologically strong studies provided number of kilometres travelled. Five of ten interventions in these six studies achieve reductions in distance travelled at follow-up. It was possible to calculate the change in kilometres per person per day for four of the interventions. Across these four evaluations the average kilometres saved was 10.3 kms per person/day (or 6.3 miles per person/day). Overall then, six of the 12 methodologically strong studies provided a measure of trip frequency. These six included eight outcome measures. One of the six studies reported an effective intervention, two reported a strong effect especially for those who have strong driving habits, and three of the six studies reported ineffective interventions. Based on the poor quality of most studies Graham-Rowe et al.

(2011) question the conviction that interventions to change transport behaviour, and especially to reduce car use, could reduce CO_2 emissions from road transport more quickly than technological measures and point out that it is unclear which interventions are effective in reducing car use and what the likely impacts of these interventions would be on CO_2 emissions. Despite the above listed shortages some interventions have been shown to be effective. These include targeting drivers who have a strong driving habit or a strong moral motivation to reduce car use; targeting people who have just moved their residence; and, where feasible, relocating employees to reduce commuting time.

5.3. Long-term effects

In the majority of cases the objective of a mobility management measure is naturally a long-lasting change towards more sustainable travel behaviour and questions regarding long-term effects are emphasised.

Taylor and Ampt (2003) argue that evidence so far is that changed behaviours persist over time, at least in the short to medium term. The findings for an implementation of IndiMark in Perth, Australia after twelve months suggest that the initial changes were not only sustained, but there were further increases in walking trips and a corresponding decline in car-driver trips (Taylor, 2007). The impact of pilot projects in South Perth was monitored for three years (1997-2000), concluding that gains in public transport, walking, and cycling mode share were maintained (Ker, 2003). Brög and Schädler (1999) reported that in German large-scale applications of IndiMark, changes in travel behaviour seem to be stable until at least two years after implementation. Ker (2003) reports long-term effects (four years after the initial implementation) of soft transport policy measures in Kassel and Nürnberg, Germany. Fujii and Taniguchi (2006) report various long-term effects (one year after) for Japanese travel feedback programs (TFPs).

However, there are also contrary findings. Taylor (2007) cites mobility management trials in Nottingham, Leeds and Santiago de Chile that did not show sustained changes in participants' travel behaviour. Richter et al. (2009b) point out that comprehensive reports on less successful implementations are difficult to obtain and that publication bias probably exists. Taylor and Ampt (2003) and Richter et al. (2009b) therefore acknowledge that longer-term studies are required to examine the duration of changed behaviours over time and to be able to draw sound conclusions.

5.4. The effects of individual policy design

A clear comparison of potential effect of individual types of soft policy measures is rare. Cairn et al. (2004) estimate potential effects of various STPM under high intensity and low intensity scenarios. The scenarios were defined as change to appropriate subset of traffic that would be caused by different soft factors, at the respective level of intensity and based on the projections to national traffic data (National Transport Model for the year 2000). The assumptions on effectiveness of soft factors were based on extensive literature review and case studies on twelve UK local authority areas. Under the high intensity scenario traffic in the UK could be nationally cut by 11% overall, and 17% at peak times. Under the low intensity scenario traffic could be nationally cut by 2-3% overall, and 4% at peak times. Contributions made by each soft measure to overall traffic reduction are displayed in Table 16.

Table 16 - Contribution made by each soft factor to overall traffic reduction figures, national average

	High intensity scenario	Low intensity scenario
Measures targeting the journey to work, of which:	5.4%	1.4%
- Workplace travel plans	1.2%	0.7%
- Car sharing	2.0%	0.1%
- Teleworking	2.2%	0.6%
Personalised travel planning	1.9%	0.4%
Teleconferencing	1.9%	0.3%
Travel awareness	0.7%	0.1%
Public transport information and marketing	0.5%	0.1%
Home shopping	0.3%	0.08%
School travel plans	0.2%	0.04%
Local collection points	0.06%	0.06%
Car clubs	0.02%	0.01%
Total*	**11%**	**2.5%**

Notes: figures with adjustment to avoid double-counting; columns are additive not multiplicative; no adjustments to allow for synergy of impact; assumption that there are 'just enough' supporting measures to lock in effects without enhancing them.

* Figures in this row may not match column totals, due to rounding

Source: Cairns et al., 2004: 356

According to Cairns et al. (2004) teleworking, car sharing, teleconferencing and personalized travel planning promise the largest potential to reduce car travel. Besides the effects of individual measures defined by Cairns et al. (2004), one can learn more on further aspects of policy design from individual studies.

Richter et al. (2009b) argue that *goal setting* and *plans for travel behaviour change*, which have been successfully implemented in Japan (Fujii and Taniguchi, 2006), offer one of the most useful developments to improve soft policy measures. In a TFP the participants were required to devise a behavioural plan for changing their travel behaviour. The purpose was to affect behavioural and implementation intention. Fujii and Taniguchi (2005) argued that requesting a behavioural plan has a strong effect on actual behavioural change since an implementation intention is formed as a result of making a behavioural plan. They documented that a TFP with a behavioural plan had a significantly greater behaviour-changing effect than a TFP without a behavioural plan.

It seems that *personal contact* at any stage of STPM is more fruitful than electronic communication (c.f., Fujii and Gärling, 2003). Yet, web-based programs and GPS technologies offer a huge potential for a wider reach of soft policy and even more *customized information* in travel behaviour. *Customized feedforward* and *feedback information* in soft policy measures are another important aspect of communication. Customized information were more welcomed compared to standardized ones, since the latter may be irrelevant (Brög and Schädler, 1999). Fujii, Taniguchi (2006) found that individualised advice based on richer information tended to be more effective. Whereas TFP using information from 7-day travel diary resulted in reduction rate 35%, 1-day travel diary yielded only 20% reduction. Yet, to gather customized information is time-consuming, expensive, and sometimes difficult. The introduction of behavioural plans to soft policy measures has shown that people can be persuaded to gather the necessary information about travel alternatives themselves.

Another vital part of soft transport policy measures is *motivational support* and its form. Since individuals differ significantly in many respects it is important to take the differences into account because people participate in and stay with a program for different reasons. Some want to contribute to the environment, some do it for health reasons, some to save money, and some for other reasons (Richter et al., 2009b).

Furthermore, it is important to know what *means* participants have employed *to achieve car-use reduction*. Did they use the bicycle instead of the car for a few short trips to the grocery store or did they use the train instead of the car for one longer journey? Soft transport policy measures need to become differently appealing to various groups of users.

5.5. Known biases and limitations in the empirical evidence gathered

There are several limitations to the generalization of the reported estimates of the effect of soft transport policy measures on CO_2 emissions reduction (car use) and their applicability to an ideal STPM design.

The following facts should lead to a particular cautiousness when reading individual estimates of STPM effectiveness:

1) The choice of the transportation policy measures is primarily lead by the ***practical interest*** to reduce car use and not to test a theory of behavioural change.

2) It results in a fact that STPM are mostly ***used in a combination*** (with financial (dis-) incentives or PT quality improvements) which does not allow separating effects of individual measures / techniques or effects on psychological constructs that explain behavioural change (although it can be more effective to use a mix of measures for ideal policy design).

3) Several published studies ***do not comply with requirements on research design quality*** (more in Gardner, Abraham, 2008, Friman et al. 2013). For instance, only 12 out of 77 studies review by Graham-Rowe et al. (2011) is judged to be methodologically strong. All the retrieved evaluation studies in Möser, Bamberg (2008) use weak quasi-experimental designs (single treatment group before–after test). Therefore the ability to draw strong causal inference from the available research evidence is limited. Such a weak design fails to control for several threats to the internal validity of causal inferences (Fujii et al., 2009; Stopher et al., 2009). The absence of a control group in some reviewed studies might have prevented knowing whether the STPM mitigated a possible increase in CO_2 emissions or to rule out alternative explanations for the reported before–after test differences (Fujii and Taniguchi, 2006). Fujii et al. (2009) demonstrate that the effect sizes estimated for the frequently used research design lacking adequate control groups differ from the effect sizes estimated for research designs including adequate control groups.

4) On the other hand external validity or ***generalizability*** of the results (e.g. Möser, Bamberg 2008) ***is threatened*** by the fact that most of the synthesised evaluation results were based on small and non- representative samples. Also experimental conditions make it difficult to draw generalising conclusions (Graham-Rowe et al. 2011).

5) Outcomes of soft policy measures are often ***generalised to the population at large,*** although they are gained from test population. However, participants in STP trials differ systematically from non-participants in personal characteristics and attitudes (Ampt, 2004). The promotion of public transport appears to be especially successful among people who have experienced major changes in their life, such as new residents, whose travel habits have not yet been developed (Fujii and Taniguchi, 2006). Not to forget that people with strong habitual car use seem to be less likely to participate in soft policy measures (Seethaler and Rose, 2005).

6) Studies ***do not include same measures*** of travel demand. For example only six of the twelve methodologically strong studies (in Graham-Rowe et al. 2011) provided number of kilometres travelled. Five of ten interventions in these six studies achieve reductions in distance travelled at follow-up. It was possible to calculate the change in

miles per person per day for only four of the interventions. Overall then, 6 of the 12 methodologically strong studies provided a measure of trip frequency.

7) Many ***moderation*** effects ***have not been taken into consideration***. For instance current reviews largely fail to disentangle the effect of location or socio-demographic factors (Richter et al., 2009b).

8) ***Lacking evidence*** about the ***effect of external factors*** complicates assessment of prospect synergies. Still some experts claim that neither soft policy measures alone are likely to be effective in reducing CO_2 emissions from driving and that a combination of soft and hard policy measures may be the most fruitful approach to reduce car use and travel related impact on climate (e.g. Cairns et al. 2008, Möser and Bamberg, 2008; Saleh, 2007; Gardner and Abraham, 2008). Nevertheless, habitual behaviour is suggested to be broken just by means of structural modifications such as road closures (Fujii & Gärling, 2003b) or congestion charging (Gärling et al., 2002).

9) Other external factors such as ***public transport quality*** have not been controlled for (Richter et al. 2009b). The evidence whether improvements in its quality have an impact on the effectiveness of soft transport policy measures is rather mixed. Ker (2003) concludes that combination of public transport improvement and soft policy measure (*IndiMark* in 6 German cities) resulted in a 47% increase in public transport trips compared to cities that undertook only soft transport policy measure. On the other hand Taylor (2007) underscores a gap between common perception of public transport and reality. Since the perception of service level of public transport may be influenced by beliefs, attitudes, and habits a change in mode choice may be accomplished by changing these psychological factors, even if the actual level of service remain the same (Brög et al. 2002; Fujii and Kitamira 2003). At the same time improvement does not necessarily contribute to a higher satisfaction of users Friman (2004).

10) Most of the ***explanations*** of the positive effects ***are atheoretical*** (Richter et al. 2009), i.e. they are not based on a model of behavioural change that would explain behaviour through changes in psychological constructs or transition between hypothesized stages of behavioural change. For example, Gärling et al. (2007 in Richter at al. 2009b) claim that attitude change, goal setting, and intention formation need to be properly addressed in order to have long-lasting effects. At the same time any design of soft transportation policy measure based on changes of modifiable psychological determinant will enable to reliably measure its effectiveness.

11) There is rather a limited number of studies investigating whether the positive affect of soft policy on car-use reduction have pertained ***over a longer period of time*** and/or beyond the test period of interventions. Most studies reported overall effectiveness one or a few months after the intervention. Only minority reported long-term (1 year) TFP effects (Taniguchi et al., 2003).

To summarize the above listed limitations the question of how much of the observed car-use and CO_2 emissions reduction can be causally attributed to the impact of the techniques that are components of particular soft policy measure still remains somewhat open (Fujii et al.,2009; Stopher et al., 2009).

5.6. What is needed: agenda for future research

If the future research should be effective in measuring the effects of specific STPM and allow using its result for an effective policy design leading to CO_2 emission reductions in transportation sector it has to fulfil the methodological and theoretical requirements listed below:

1) More ***methodologically rigorous research***, applying randomised controlled trial, should be conducted (Graham-Rowe et al. 2011, Fujii et al., 2009). A solid empirical evidence should be gained by series of field experiments (Bamberg et al., 2011).
2) ***Standard measures*** such as kilometres-per-person-travelled per day should be reported. It would facilitate comparisons of the effectiveness of different interventions and reliable estimates of their likely impact on CO_2 emissions.
3) The ***persistence of the effects*** over a long period of time and after the intervention's end needs to be further investigated. Prospective studies with ***longer follow-ups*** are recommended (Gardner and Abraham, 2008).
4) Further research is particularly needed on the development of ***theory-based measures*** and experimental tests of these techniques. Behavioural science should concentrate on the causal determinants of car use as well as voluntarily changes of travel behaviour. Modifiable psychological determinant, such as attitudes, norms or intentions towards car use should be in focus (Gardner and Abraham, 2008; Bamberg et al., 2011).
5) ***Techniques by which causal determinants should*** be targeted to change behaviour needs to be identified. The literature testifying the effectiveness of policy measures targeting car use reduction (Bamberg & Möser, 2007; Fujii & Taniguchi, 2006; Möser & Bamberg, 2008) fail to clarify which (if any) cognitive antecedents of driving are targeted by these policy measures, and on what basis behaviour change techniques are chosen (Gardner and Abraham, 2008). Further empirical work is needed to identify which travel demand management strategies are likely to be effective in engineering driving reduction, and the cognitive mechanisms and processes underlying observed effects.
6) It still remains unclear how psychological determinants can be best ***modified***. It is still not unambiguously established whether car use is primarily habitual or whether

careful deliberation precedes a decision to drive (compare Bamberg et al., 2003 and Verplanken et al., 1994).

7) Habit research would be better undertaken in contexts in which ***intentions and habits conflict***. (Gärling, Fujii, & Boe, 2001) suggest to induce such conditions experimentally via structural modifications such as road closures (Fujii & Gärling, 2003b) or congestion charging (Gärling et al., 2002). Discerning habit and intention effects is in any case important for policy purposes, because *motivational information-based driving reduction campaigns* may have limited impact on habits (Verplanken, Aarts, & van Knippenberg, 1997).

8) It is important to know what ***means*** participants have employed ***to achieve car-use reduction***. More detailed data are necessary in order to reward participants' accomplished travel behaviour changes on the one hand and to see where a program does not fulfil the expectations on the other hand.

9) All possible ***motivational factors*** need to be disentangled. Since individuals differ significantly in many respects it is important to take the differences into account because people participate in and stay with a program for different reasons. Better knowledge would enable to provide motivational support which directly appeals to people's individual reasons for participation in a soft policy measure.

10) More research is needed to clarify the role of ***pro-environmental cognitions***, moral obligations or awareness of consequences on driving. There is a general lack of evidence of effects of pro-environmental cognitions on travel behaviour or travel intentions but many driving reduction campaigns assume that emphasising environmental benefits will motivate drivers to use non-car transport (Commuter Challenge, 2007 in Gardner and Abraham, 2008),

11) ***External conditions*** of a STPM need to be clearly defined in any study, so that for instance the effect of location can be disentangled. Richter at al. (2009 b) claim that available data on local differences should be thoroughly reviewed in order to draw valid conclusions and provide suggestions, for instance, of how an effective workplace travel plan should be designed in a rural area with poor public transport connections.

12) Even thought, the role of hard policy measures has in itself been frequently discussed (Cairns et al., 2008; Möser and Bamberg, 2008; Saleh, 2007; Gardner and Abraham, 2008; Gärling, Fujii, & Boe, 2001), how they ***support the effect of soft policy measures*** needs to be addressed in more detail and if possible tested (Richter et al., 2009b).

13) It would be valuable to examine whether (PT) non-users can be persuaded by ***public transport quality improvements*** in general and by which improvements in particular.

14) The possibility to persuade people to gather the necessary information about travel alternatives themselves should be regarded as an important aspect to examine,

because it could lead to a transformation from customized information to ***customized support*** (Richter et al., 2009).

15) It is also essential to investigate the ***quality of customized information*** delivered to the participants, because quality seems to be related to the soft policy measure's success. *Technical advances* such as GPS-based surveys offer many potential improvements in this respect (Taylor, 2007). For instance, travel behaviour could be automatically recorded with appropriate IT technologies and participants could therefore attend the programs with minimal effort as well as be provided with feedback of higher quality.

5.7. Prospective theory of behavioural change – major requirement for applicable knowledge

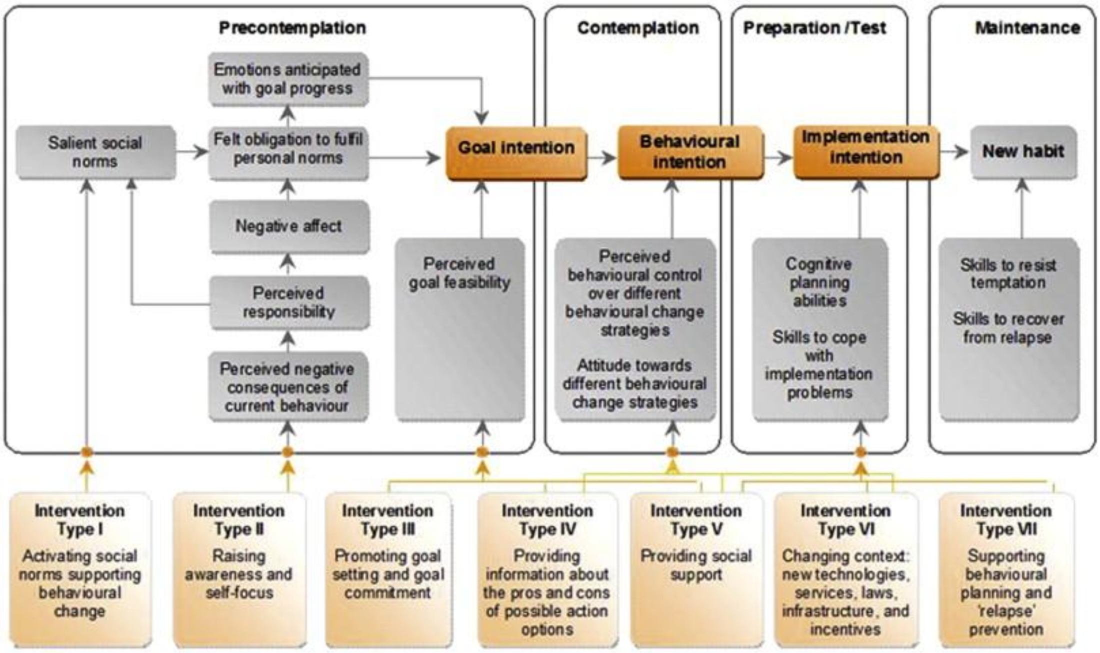
Since the weak connection of the commonly applied STPM to a behavioural theory, i.e. causal determinants of car use are the major limitation when concluding their effectiveness prospective theories that may improve the quality of the measures applied in the future are shortly introduced.

The adoption of persuasion principles from social psychology to raise awareness and knowledge and to stimulate behavioural change in *Travel Smart* is an example of how this can look like (see Seethaler and Rose, 2005). Another recent attempt is the proposal by Bamberg et al. (2011) to apply the behavioural model that integrates the *Theory of Planned Behaviour* (Ajzen, 1991) and the *norm-activation theory* (Swartz, 1977), two most sound theoretical concepts in the field. The theory of planned behaviour (TPB) is - unlike the discrete choice theory - a theory of how intentions to perform behaviour are formed (Bamberg et al. 2011). Except for attitudes towards certain behaviour TPB also stresses the importance of *behavioural constraints*. *Norm-Activation theory* (Schwartz, 1977), later developed into *value-belief-norm theory* (Stern, 2000), argue that car-use reduction appears to depend more strongly on *pro-social motives*. And social norms also inform people about what behavioural standards their social reference group views as appropriate in a particular context. Bamberg et al., (2007), Bamberg and Möser (2007) and Bamberg et al. (2011) propose to augment TPB by adding personal norm from norm-activation theory as another determinant of intention and formulate *a self-regulations theory* of travel change. Based on the results for car-use and pro-environmental behaviours in general it is suggested that the joint theory may be generalized to account for car-use reduction (Gardner and Abraham, 2008; Bamberg et al., 2011).

The self-regulation theory posits that behavioural change is a transition through a time-ordered sequence of stages reflecting the *cognitive* and *motivational difficulties* people encounter in implementing a general behavioural change goal into concrete actions"

(Bamberg et al. 2011: 231). Bamberg et al. 2011 consider four stages of the process including: the pre-contemplation, contemplation, preparation, and maintenance (see Figure 16).

Figure 16 - Self-regulation theory's hypothesized stages of the process of behavioural change and their determinants



Source: Bamberg et al., 2011

Based on the self-regulation theory more effective soft measures and personalized travel planning in particular may be developed. Novel in this approach is the conceptualization of voluntary car-use reduction as a transition through different stages. These comprise: forming a goal intention to reduce car use, behavioural intention to do this, choosing the alternative travel option and maintain the new travel habit.

Currently, one single measure is usually used for all car users (Richter et al., 2010a). If car-use reduction is a process consisting of different stages, it would be needed to tailor the measure employed to the stage of the car user or different categories of car users. If a measure wants to target car users in an early stage, it would likely be more effective if aiming at *problem awareness, perceived responsibility and salience of social norms*. For car users who already have formed a goal to reduce car use, providing appropriate information about the availability and different alternative travel options would be more effective. Those who already have formed an intention to use a specific alternative travel option would benefit most from support of its implementation.

Bamberg et al. (2011) show how the mechanism underlying the formation of the three critical stage-specific transition points may be activated by different intervention types (see figure 1). For example, social norms may be made salient by mass-media role-modelling. Problem awareness and responsibility may be raised by *scenario-based risk information* or *consciousness raising*. There are also a number of techniques that aim at increasing the perceived behavioural control as well as enhancing positive attitudes towards public transport or bicycling. Immediate customized feedback may be important for maintaining the new behaviour.

5.8. Summary of policy relevant findings – elevator

A whole range of soft transport policy measures has been so far applied to reduce CO_2 emission in transportation sector in the EU countries as well as beyond its border. They comprise travel policy at workplace and school, personalized travel planning, information and marketing, campaigns for alternative transport modes, car clubs, car sharing and carpooling schemes, teleworking, teleconferencing and home shopping. Several reviews and meta-analyses assess the effect on car mileage reduction between 0 and 35%, on CO_2 reduction 15-35% and increase of public transport use up to 50%; however only in populations of participants. Teleworking, car sharing, teleconferencing and personalized travel planning, promise the largest potential to reduce car travel. Although various scholars argue that soft transport policy measures were effective, more acceptable and less expansive compare to infrastructural modifications and/or legislative policy measures such as road pricing the empirical evidence shows mixed results and considerable room for their improvements. The main limitations of the evaluations of soft transport policy measures are: i) policy measures are mostly used in combination which does not allow separating effects of individual techniques; ii) most explanations are atheoretical since the measures are not based on a behavioural theory; iii) many moderation effects have not been taken into consideration and iv) the methodological quality of most studies is poor.

If any soft transport policy measure should lead to a significant change of travel patterns dominantly relying on car use its design has to be theoretically grounded. A tailored information technique or dis-/incentive scheme that aims at particular aspect of behavioural change process such as attitudes, norms and/or intention is more probable to reach the CO_2 reduction goals in the long-term. At the same time any design of soft transportation policy measure based on changes of modifiable psychological determinant will enable to reliably measure its effectiveness. Soft transport policy measures should focus specifically on different groups of users (frequent and non-frequent); users participating for different reasons (money, environment, time savings, health effects, etc.); populations particularly susceptible to changes (such as new residents, new employees, etc.). Motivational support should directly appeal to people’s individual reasons for participation.

6. Total cost of ownership of electric vehicles under various incentives

6.1. Introduction

Among the largest challenges of this century will be the creation of a new economic system that replaces fossil fuels with energy sources that are less damaging to the Earth's environment, particularly its climate. However, transportation, in particular road transport, which accounts for more than one-fifth of carbon dioxide emissions within the EU (European Commission 2012), remains one of the most difficult areas to transition towards a new model.

Currently, one of the most promising technologies to replace petrol- and diesel-powered internal combustion engine vehicles (ICEVs) is the electric vehicle (EV), which derives power from on-board batteries that are recharged by connecting them to the electrical grid. EVs include both full-electric vehicles (FEVs), which can only derive their power from batteries, and plug-in hybrid vehicles (PHEVs), which have batteries on-board that can be connected to the electrical grid, but also have a traditional engine fuelled by petrol or diesel that engages when the batteries are empty. If a transition from ICEVs to EVs were coupled with an increase in renewable electricity, such as wind, solar, geothermal, or hydroelectric, it could provide a zero-carbon transportation option for millions of European consumers.

The speed at which EVs are penetrating the market is quite remarkable – between 2009 and 2011, electric vehicle sales in Europe increased tenfold while total vehicle sales fell (Sprei and Bauner 2011, ICCT 2013). Also, sales growth for EVs were stronger in the technology's first years on the market than sales for non-plug-in hybrid vehicles when they were first introduced (Neiger 2013). Yet this growth comes from a very low baseline. In absolute numbers, EV sales are lagging behind what is necessary to reach the ambitious targets for EVs on the road that some EU Member States have adopted, including Germany.

There are a number of factors that hamper the uptake of EVs, including the lack of consumer familiarity with EV technology, incomplete national and international infrastructure for recharging EVs, and a coinciding international financial crisis. EV technology is fundamentally different from that of ICEVs and is unfamiliar to the average driver. Owning an EV typically requires the installation of charging equipment at home and it takes significantly more time to fill its batteries than an equivalent ICEV needs to fill its fuel tank. These logistical differences require consumers to change their driving behaviour, and possibly their mobility patterns. Additionally, the lifetime payment model is different for EVs. At least for the time being, EVs have higher initial purchase prices than comparable ICEVs. However, EVs are cheaper to run and maintain than ICEVs (currently electricity prices are below petrol and diesel costs per kilometre and since EVs contain fewer moving parts than ICEVs, there is less likelihood of a component breaking and needing replacement, therefore maintenance costs are expected to be lower than for ICEVs). This means that EV buyers must be prepared to pay a larger initial investment and then accrue savings over time relative to ICEV buyers.

Many countries, particularly those in the EU, have already begun programs to encourage consumers to switch to EVs. Included among these programs are laws and regulations that seek to make the price of EVs more attractive to potential buyers, for example direct subsidies or lower taxes. In order to best understand the effectiveness of these support measures, it would be beneficial to analyse the financial impacts of these various programs to ensure that public funds are being used in the most effective manner possible, comparing and drawing lessons from the various support mechanisms to ensure that those implemented meaningfully encourage the uptake of EVs (van Essen et al. 2012; Technologic Vehicles 2013).

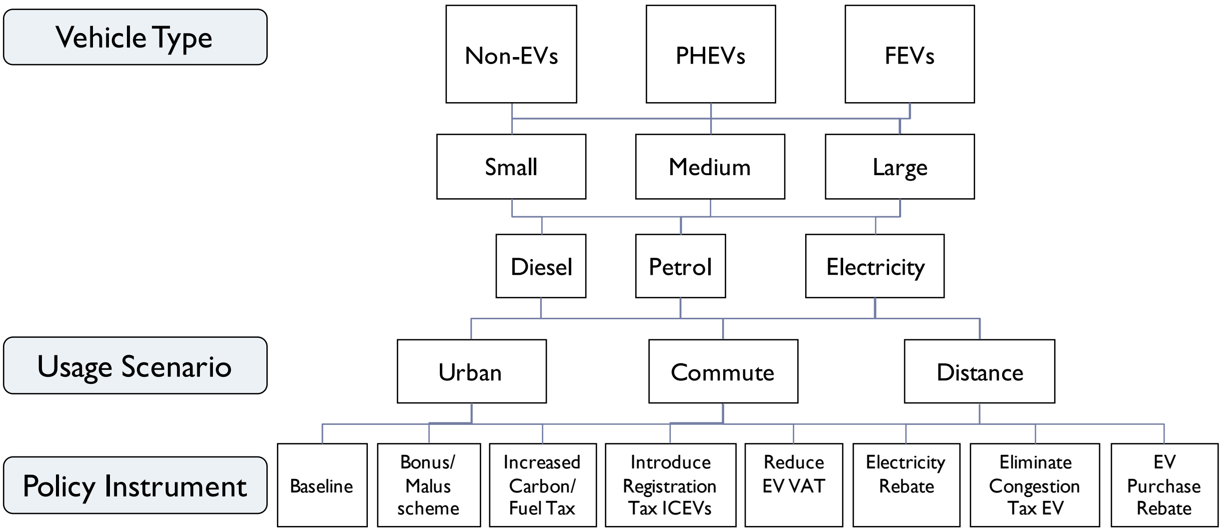
In order to analyse these incentives, this study models the total cost of ownership (“TCO”) of FEVs, PHEVs, and ICEVs under various incentive structures. A TCO model endeavours to quantify the lifetime cost of owning and operating a vehicle, allowing this study to simultaneously compare the effects of long- and short-term incentives.

This study models the effects that policy measures promoting the adoption of electric vehicles have on those vehicles’ TCO. Existing research has not adequately addressed the question of how different support measures for EVs will affect the TCO that prospective car owners face when making purchasing decisions; the current paper attempts to fill this gap. This analysis does not set out to assert that EVs will necessarily be the dominant strategy in transforming to a low-carbon transport sector, nor is it suggesting prioritising EVs over other low-carbon transport policy options. The goal of this study is simply to model the approximate impacts of proposed and existing EV support structures, comparing them against one another in order to serve as a guide for those policymakers wishing to encourage growth in this sector.

6.2. Methodology

In order to identify effective policy approaches to encourage consumers and corporations to purchase FEVs and PHEVs, this paper analyses the TCO of these vehicles compared to ICEVs. The model is broken down into three different sub-levels: vehicle type, usage type, and policy instrument (Figure 17). Vehicle type is described by the technology (Non-EV, PHEV and FEV) as well as the size (small, medium, and large) and fuel type (petrol and diesel; not applicable for FEV scenarios). The model’s three usage scenarios differ by kilometres travelled per year: urban, suburban and rural, which are defined as 8,000, 15,000, and 20,000 km/year respectively. As the main objective of this analysis is to assess the effectiveness of different policies at promoting the uptake of EVs, seven different policy scenarios are included in the model, in addition to a baseline case (i.e., no EV support mechanism). Sections 3.1, 3.2, and 3.3 explain the sub-levels and respective parameters in more detail.

Figure 17: Conceptual model flowchart



TCO is a calculation of the lifetime cost of owning and operating a particular vehicle, which should be among the most influential decisional parameter for consumers purchasing a new vehicle. The TCO is influenced by numerous variables, and fiscal policy can impact these considerably. In particular, the model takes into consideration a vehicle's original purchase price, maintenance costs, insurance costs, fuel/electricity prices and taxes, vehicle size (which impacts its energy usage), average distance driven in a year, as well as all applicable taxes and fees. Estimations of these costs were found within similar research papers and in the case of fuel prices, electricity prices, taxes, and fees, these costs are compiled and published by the European Commission (Kampman et al. 2011; van Essen et al. 2012; European Commission - Energy Policy 2013a; European Commission - Energy Policy 2013b; European Commission - Energy Policy 2013c; Market Observatory for Energy 2013). A list of the sources for the variables included in the analysis can be found in Appendix A. Values used in the calculations presented in the report are derived either from EU averages or country-specific examples (particularly regarding the policy scenarios) and can be modified according to the relevant country of analysis. TCO is calculated as follows:

Box 1: Calculation of TCO

$$TCO_j = CP_j \times (VAT + 1) + REGTAX_j + AOC_j \left(\frac{(1+i)^n - 1}{i} \right) - \frac{\mathrm{RV}}{(1+\mathrm{i})^{\mathrm{n}}}$$

$$AOC_n = \; CIRCTAX_n + INSURANCE_n + MAINTENANCE_n + \; FUEL_n + \; ELEC_n$$

Where:

TCO = Total Cost of Ownership

ACO = Annual Operating Costs

j = vehicle type

n = year

$\mathrm{FUEL_n} = \mathrm{VKM_n} \times \mathrm{FUELPRICE_n}$

$\mathrm{ELEC_n} = \mathrm{VKM_n} \times \mathrm{ELECPRICE_n}$

CP = Catalogue Price

REGTAX = Registration Tax (absolute value)

VAT = Value Added Tax

RV = Residual Value

CIRCTAX = Circulation Tax

FUEL = Fuel costs

MAINTENANCE = Maintenance costs

INSURANCE = Insurance costs

VKM = Vehicle Kilometres

FUELPRICE = Fuel Price, market price

FUEL COMM. PRICE = Fuel Commodity Price

FUELTAX = Fuel Tax

ELECPRICE = Fuel Price, market price

ELEC COMM. PRICE = Fuel Commodity Price

ELECTAX = Fuel Tax

$\mathrm{FUELPRICE_n} = (\mathrm{FUEL\ COMM\ PRICE_n} + \mathrm{FUELTAX}) \times (1 + \mathrm{VAT})$

$\mathrm{ELECPRICE_n} = (\mathrm{ELEC\ COMM\ PRICE_n} + \mathrm{ELECTAX}) \times (1 + \mathrm{VAT})$

The resulting TCO scenarios are discounted by using net present value (NPV) in order to account for consumers' higher valuation of money that they have (or save) today over an equal amount of money that they will have (or will save) at a given date in the future, with the value decreasing more the further into the future that date lies. Two discount rates are used to calculate the final NPV of the various TCO scenarios – a lower discount rate of 3%, which is understood to reflect the social discount rate for investments with a short- to medium-term horizon. In addition, a higher rate of 8% is applied, which is understood to be a more realistic approximation of consumers' actual behaviour when making purchase decisions that involve a trade-off between higher up-front costs and cost savings during the product lifetime (first identified as the "energy efficiency paradox" by Jaffe and Stavins 1994).[39] The higher discount rate also reflects a degree of regulatory uncertainty on the part of consumers, who may not trust that, given governmental changes and budgetary constraints, current incentives that provide them with annual savings (i.e., lower taxes or fees on EVs or electricity) will be maintained for the lifetime of the vehicle, therefore making that incentive relatively less valuable to the consumer[40].

The model makes several assumptions, which are made by similar studies in EV-related literature (Kampman et al. 2011) and should be kept in mind when drawing conclusions from the results. First, it is assumed that each vehicle's lifetime is 14 years and that afterwards there is no residual value remaining in the vehicle.[41] The initial cost of vehicles and the costs associated with fuel and electricity are also assumed to remain constant. Although these costs fluctuate continuously and can be quite different in adjacent countries even at the same moment, the important factor for the comparison of TCOs is how these two costs will fluctuate *relative to each other*. While a few studies exist estimating the future values of these numbers, the uncertainty in those estimations becomes compounded when we compare the estimated values to each other for the purposes of the model. Including estimates of future vehicle costs, fuel, or electricity prices would increase the complexity and uncertainty of the model beyond what is necessary for our overall objective.

Furthermore, the efficiency of ICEVs, PHEVs, and FEVs are impacted – in different ways – by driving style (e.g. average speed driven, frequency of stopping, etc.), how well the vehicle is maintained, as well as total distance driven. Estimates of efficiency, therefore, have meaningful impacts on the TCO. This study relies on good working estimates by other, similar investigations (Kampman et al. 2011; van Essen et al. 2012; Fraunhofer ISI 2013), which fit its requirements as a policy guide, but may differ from actual observed TCOs under particular

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[39] There are numerous empirical estimates of what a "real" private discount rate, which explains observed behaviour, should look liked, cited e.g., by Jaffe and Stavins 1994. However, there is no single value that can be derived as the "right" value from these studies. The chosen rate of 8% is a conservative estimate at the lower end of the spectrum.

[40] The study uses these two discount rates as benchmarks rather than absolute comparisons – in reality, the actual discount rate used in vehicle purchase decisions could be much different than those chosen in the analysis. Empirical evidence suggests even higher discount rates may exist when making energy conservation investment decisions, with rates reaching as high as 800% for household appliances (Hausman 1979; Ruderman, Levine, and McMahon 1987; Jaffe and Stavins 1994; Frederick, Loewenstein, and O'donoghue 2002; Gately 2005). If the discount rate for EVs is in fact higher than the 8% used in the analysis, support mechanisms that rely on future cost savings would be less effective than the findings suggest.

[41] A different specification might reflect the differences in vehicle mileage, i.e. a longer lifetime for the urban and suburban settings, reflecting the lower annual mileage. Potentially more important, though, is the effect of the battery lifetime on the economic lifetime of PHEVs and FEVs. However, the information base on this parameter is thin, and the technology still evolving rapidly. Therefore, the assumption of equal vehicle lifetime seemed most appropriate. In either case, particularly in the scenarios using a high discount rate, the residual value of the vehicle after 14 years has little impact on the results of the analysis.

driving circumstances. Moreover, the policy scenarios are analysed in isolation, i.e., it is assumed that no two policies are in place simultaneously. In reality, many countries have enacted multiple policy mechanisms, which may enhance or hinder the effectiveness of the other. These interaction effects, however, are not analysed in the scope of this study. Finally, TCO calculation is not a perfect prediction of consumer behaviour – beyond TCO, there are a number of additional factors that influence a consumer's purchasing decisions, such as social influence, vehicle image and branding, expectations of future policy changes, etc.

The following sections give a detailed overview of – and the rationale behind – the three sub-levels (vehicle type, usage, and policy instrument) used in the model, which result in a total of 720 different TCO scenarios. The parameters chosen for the calculations are also explained. Sections 6.3 and 6.4 present and discuss the findings of the analysis.

6.2.1. Vehicle Type

Vehicle type is classified into three categories: EV technology, size, and fuel type. Although current EV technology might not be a suitable replacement for ICEVs in all scenarios (EV technology alone may not meet the needs of more demanding applications, such as in heavy trucks or construction equipment), existing EV technology is already well-suited to replace ICEVs in the case of passenger vehicles and light trucks (Kampman et al. 2011). The model therefore limits the comparison of TCOs to ICEV, PHEV and FEV passenger vehicles.

The model distinguishes between three vehicle size categories of small, medium, and large and accounts for the differences in catalogue price, maintenance costs per year, as well as average fuel and electricity usage accordingly. Estimates for these variables are EU-wide averages taken from Kampman et al. 2011.

Finally, the model accounts for the fuel type used for ICEVs and PHEVs – either petrol or diesel. This does not apply for FEVs as they are fully powered by electricity. Average fuel costs are modified according to the different price and average fuel usage estimated for petrol-and diesel-operated vehicles (European Commission 2013a).

6.2.2. Usage Type

Identical vehicle models are not used equally by their owners. When considered as a mode of transportation, which in effect is just the provision of a service, there are multiple niches that vehicles can fill and each of these niches has different requirements and specifications. Each of these usage profiles are therefore impacted differently by a transition from ICEV to EV technology. Due to differences in usage, governmental incentive schemes will create different incentives (or disincentives) for different buyers. This fact is amplified by EVs' ability to create more of their own energy under some driving conditions (like braking or going downhill) than others, and the requirement of FEVs to recharge (or exchange batteries) when used for very long distances between chargings. Additionally, PHEVs are able to utilize a larger ratio of electric to fuel propulsion under urban driving conditions (low speed, much braking) than they are able to on highways or freeways, where they must engage their combustion engines much more often. This study assesses three basic usage scenarios separately to show the differential impacts of specific incentive schemes. The model includes three usage types of urban, suburban, and rural, and how a small, medium, and large car usage would each perform under these annual driving conditions.

Urban drivers, especially in Europe, are typically able to utilize a number of different modes of transportation for their needs, generally resulting in less reliance upon and usage of personal vehicles. Public transportation options in urban areas are usually more readily available and more comprehensive than in suburban or rural settings. Additionally, walking and biking are practical options in many cities as well. This means that, generally speaking, owners of vehicles in urban areas use them less frequently than vehicle owners living in less-densely developed areas. Furthermore, since many necessary or desired services are located in or near to cities, the distances driven by urban drivers are short shorter than in a suburban or rural setting. Therefore, for this driving scenario, the model estimates a total annual driving distance of 8,000 km and an electricity/fuel use ratio in PHEVs of 90% electric and 10% fuel (Helms et al. 2010).

Suburban drivers are generally more dependent on their cars than those living in urban settings, because they utilize them frequently for commuting to work. Due to less-developed public transportation, pedestrian, and bicycling infrastructure, as well as longer distances, people living in these areas utilize their private vehicles more frequently for daily tasks, including commuting to and from work and running errands. With services and places of work less densely distributed than (or in fact located in) urban areas, not only are suburban drivers using their vehicles more frequently, but these trips are also likely to be somewhat longer than those of their urban counterparts. Therefore, for this driving scenario, the model estimates a total annual driving distance of 15,000 km and an electricity/fuel use ratio in PHEVs of 50% electric and 50% fuel (Helms et al. 2010).

Finally, rural users generally have the same driving requirements as suburban users, only amplified to higher degree. Services and places of work are even further away than in suburban areas and the number of journeys which can be completed solely by non-automobile transportation is much more limited. These drivers use their vehicles quite frequently and have long distances to travel. Therefore, for this driving scenario, the model estimates a total annual driving distance of 20,000 km and an electricity/fuel use ratio in PHEVs of 10% electric and 90% fuel (Helms et al. 2010).

6.2.3. Policy Instruments

There are many different financial mechanisms that governments can use to encourage greater utilization of electric vehicle technology. However, not all of them will have the same impact on consumers. As consumers each have different requirements or desires for the use and capabilities of their vehicles, depending on the mechanism chosen, these incentives can have the effect of encouraging the uptake of EVs for some uses, but not for others. It is therefore important to analyse these different policies individually and then use that analysis to determine which policies are best designed to encourage the purchase of EVs under specific usage types.

Currently, the majority of countries investigated in the CECILIA project already have policies in place to encourage the adoption of EV technology by consumers and/or corporations, with the notable exception of Poland. None of them have exactly the same mixture of adopted policies and some even have additional support mechanisms put in place by sub-national jurisdictions. This makes it difficult to create a model that reflects the effects of all these policies on the TCO of EVs, especially considering potential interaction effects between several instruments. Nevertheless, most of the policy instruments that are studied within this paper are already in effect somewhere in Europe: The policies included in the model are not so much theoretical suggestions (aside from the electricity rebate) as much as they are a compilation of the most common EV support policies currently in place. Table 17 gives a brief overview of notable EVs support mechanism implemented in countries under the scope of the CECILIA project.

Table 17: EV Support Mechanisms

Country	Description of Support Mechanism(s)
Czech Republic	EVs are entirely exempt from the circulation tax (van Essen et al. 2012)
France	A bonus-malus system of purchase price rebates or fees exists, whereby more fuel efficient vehicles, including FEVs, receive a rebate to reimburse part of their purchase price. This rebate is larger for more efficient vehicles and smaller for less efficient vehicles. Simultaneously very inefficient vehicles are charged a penalty fee which becomes larger the more inefficient that they are. Beginning on January 2013 the rebate level for a vehicle emitting 20g ofCO_2 or less per kilometre (including FEVs) is €7,000 and the rebate for hybrids with emissions below 110g/km is €4,000 while inefficient vehicles can be charged a fee of up to €6,000 (Technologic Vehicles 2013). Additionally, French companies purchasing FEVs are totally exempt from the circulation tax or if they purchase PHEVs, they are exempt from it for the first two years (van Essen et al. 2012).
Germany	Electric vehicles are exempt from the circulation tax for the first five years after purchase, and after that their circulation tax is reduced by 50% (van Essen et al. 2012).
Italy	Electric vehicles are exempt from the circulation tax for the first five years after purchase, and after that their circulation tax is reduced by 75% in many regions (van Essen et al. 2012).
Netherlands	Electric vehicles are exempt from the registration tax and will be charged lower circulation taxes until 2015 (van Essen et al. 2012).
Spain	Electric vehicles are exempt from the registration tax, and there are purchase price subsidies in some of the country’s regions (van Essen et al. 2012).

United Kingdom	Car buyers can receive rebates up to £8,000 (approximately €9,300) for purchasing EVs (including PHEVs) withCO_2 emissions below 75g per kilometre, while at the same time the circulation tax is waived and the company car tax and the van benefit charge are both waived until April 2015 (van Essen et al. 2012).

Using examples from policies implemented in the various countries mentioned above, this paper investigates seven different financial incentives: 1) the introduction of a registration taxes for ICEVs, 2) a bonus-malus scheme 3) a purchase price rebate 4) an increase in fuel tax, 5) the elimination of annual circulation taxes for PHEVs and FEVs, 6) a reduction of the Value Added Tax (VAT) charged for PHEVs and FEVs, and 7) an electricity rebate. The seven scenarios explained below are compared with each other and to the baseline scenario, i.e., when there are no EV support mechanisms implemented.

1. **Introduction of a one-time registration tax:** This strategy entails differentiating the one-time fees charged by governments for the registration of (and therefore for the right to use) electric vehicles, as opposed to those charged for conventionally-powered vehicles. In the baseline scenario, there is no one-time registration fee for vehicles (van Essen et al. 2012)[42]. The model therefore simulates this scenario by adding a tax for qualifying vehicles instead of removing the tax for EVs. To calculate the registration fees, the Dutch registration tax system was used (Belastingdienst 2013), which is calculated according to the fuel type and CO_2 emissions, thus resulting in a high of 53,465 EUR for the representative large petrol ICEV and a low of 5,913 EUR for small diesel ICEVs. No PHEVs qualified for a registration tax.
2. **Bonus-malus scheme:** Under a bonus-malus scheme, a buyer receives an immediate subsidy for the purchase of an EV or a penalty for an ICEV at the point of sale. The model uses the French “bonus-malus” system as basis for the analysis (Appendix B) – vehicles receive a subsidy up to 7,000 EUR or penalty up to 6,000 EUR depending on their levels of CO_2 emissions, measured in grams per kilometre (Technologic Vehicles 2013; ACEA 2013). The subsidies do not exceed 30% of the catalogue price of FEVs and 20% for PHEVs.[43]
3. **Purchase price rebate:** Under the purchase price rebate mechanism, a government reimburses a buyer for a portion of the initial cost of an electric vehicle after having applied for and been granted the rebate. Unlike the bonus-malus scheme, the cost savings are realized one period after the purchase of a PHEV or FEV. The US system of income tax rebates is used as example in the model: a rebate of 5,500 Euro is given

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[42] The baseline case includes a circulation tax only, as is the case in Germany.

[43] The TCO assessment took place in 2013 and therefore uses the specifications of the French bonus-malus scheme during that time. As of 1 January, 2014, the scheme has changed significantly – most notably that the maximum bonus was lowered to 6 300 EUR and the penalty raised to 8 000 EUR for the highest polluting vehicles. Results from the model used in this study, however, should stay approximately the same under the new scheme.

for all FEVs and PHEVs receive a rebate according to the assumed battery capacity – large, medium and small PHEVs obtaining a 5,500, 4,500 and 3,500 Euro rebate respectively (EPA 2013). A one year payback period is assumed and the rebate is discounted accordingly.

4. **Increase in fuel taxes:** By increasing the effective price of petrol or diesel fuels, the cost savings that EV users reap from using electricity instead would be amplified. While this mechanism does not have a direct effect on the cost of purchasing or operating an electric vehicle, it does have the effect of making EVs cheaper *relative* to the alternative forms of automobiles available on the market. This effect would be stronger for those users who drive more in a given year, as the relative savings are connected to the fuel consumption, and hence the amount that the vehicles are driven. This policy would have financial impacts for purchasers over the lifetime of the EV, though not at the date of initial purchase. For this scenario, the study uses a 25% fuel VAT instead of a 19% fuel VAT in all other cases, which is similar to fuel taxes in Denmark, Croatia, Hungary, and Sweden (European Commission 2013).

5. **Elimination of annual circulation taxes:** In addition to, or instead of, a registration tax, some European countries have instituted a circulation tax, which is levied annually based on the size, weight, power, and exhaust emissions of the particular vehicle in question. Lowering these taxes or eliminating them altogether for EVs is another tool implemented in several countries. Such an incentive structure – charging lower costs each year over the lifetime of the vehicle – would lower a vehicle's TCO both absolutely and relative to ICEVs, though it would do so incrementally over the lifetime of the vehicle. The model uses circulation tax rates for Germany identified in the (van Essen et al. 2012) and removes the tax completely in the case of this policy scenario.

6. **Reduction of the VAT:** Reducing the VAT applied to the purchase of electric vehicles would lower the absolute cost of the EV, making the cost comparison between EVs and ICEVs much more favourable. A number of European countries already have a reduced-rate VAT for certain goods and in Germany that rate is 7% instead of the standard 19% (European Commission 2013b). Unlike the case of a purchase price rebate, the financial savings from this model would be immediate. Purchasers would not have to wait for a reimbursement from the government; rather, they would never be obligated to pay the initial outlay in the first place. Studies of reducing VAT for environmentally-friendly products have in the past concluded that lowering the VAT can increase the speed of adoption of a new technology, but that it is not always a large enough change in price to bridge the gap between cheaper old technology and more expensive new technology (Oosterhuis et al. 2008).

7. **Electricity rebate:** As with taxing petrol and diesel, a rebate on the cost of electricity used by electric vehicle would benefit EV owners over the whole course of the vehicle lifetime rather than up-front, and would have the greatest impact on those users who

drive the largest distances. However, implementing this support mechanism may be difficult as electricity used for EVs would need to be distinguished from other uses. Due to implementation limitations, this scenario is only hypothetical and assumes the complete elimination of the electricity VAT of 19%[44].

6.3. Results

Each of the policy instruments investigated within this study has the effect of making the TCO of PHEVs and FEVs more competitive against those of ICEVs than they otherwise would have been. However, the degree of this impact differs between usage type and vehicle size, and depends on the discount rate applied. The following section highlights the main findings of the analysis in relation to the policy mechanisms. The final TCO for each scenario in the model can be found in the Appendix C.

Overall, the introduction of registration taxes for ICEVs and the bonus-malus scheme are the most effective policy instruments in terms of lowering the TCO of PHEVs and FEVs compared to their ICEV counterparts. According to the rates used in the model, the registration tax supports the purchase of large PHEVs and FEVs relatively more than smaller vehicles, whereas the bonus-malus scheme supports smaller vehicles comparatively more than larger vehicles. The effect of both mechanisms increases under higher usage types as fuel savings accrue, which is also the case for all policy scenarios under the different usage levels. Finally, high discount rates negatively affect future savings: this impacts all measures that lower the operating cost of EV, since cost savings over time enter the TCO with a lower weight the higher the discount rate applied. Therefore, immediate financial incentives, such as the registration tax and bonus-malus scheme, may be the most effective at encouraging the uptake of EVs.

6.3.1. Usage Types

The three usage types modelled in the study are urban, suburban and rural, corresponding to a total of 8,000, 15,000 and 20,000 km/yr driven, respectively. Compared to petrol ICEVs, diesel ICEVs become more cost competitive as usage increases because the lower fuel costs

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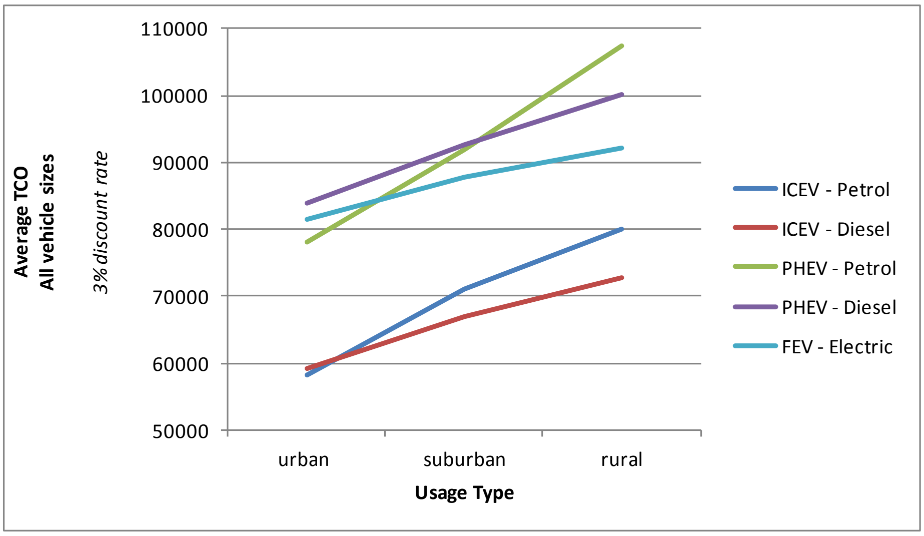
[44] This touches upon a fundamental point, which, however, is beyond the scope of this analysis here: fuel excise duties are justified in particular by the need to cover infrastructure cost and external costs – which include air pollution and climate as well as noise or accidents. Some of these costs are lower for EVs (in particular climate and air quality), but others – and in particular infrastructure costs – are of equal magnitude for EVs and ICEVs. Following this logic, there should be additional taxes on EVs rather than subsidies. However, the current analysis has merely focused on the question which channels are more or less effective to make EVs economically competitive from the consumer perspective, not on the question how EVs should be treated from a broader economic perspective.

(l/yr) of diesel vehicles eventually compensate for the higher catalogue prices (Figure 18). The same is true for petrol and diesel PHEVs.

Figure 18: Average vehicle TCO under the baseline scenario



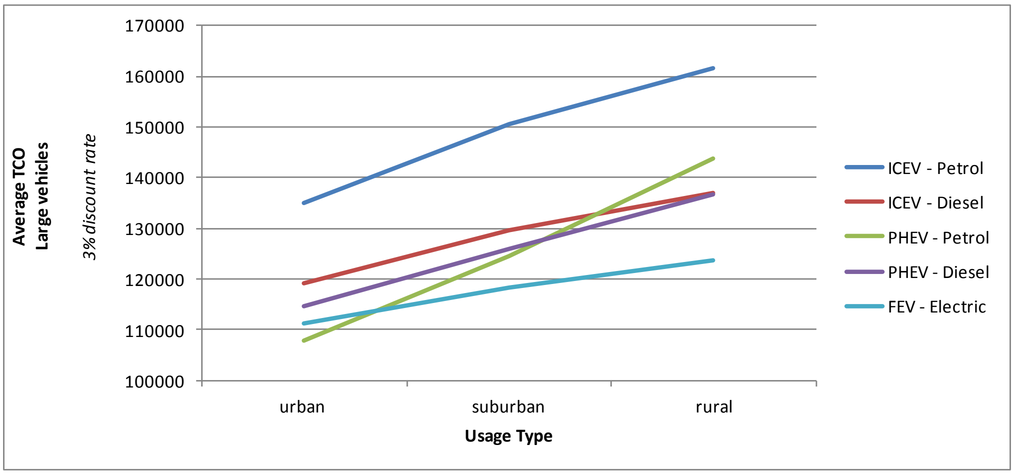
Without any support mechanisms (baseline scenario), the fuel savings of PHEVs and FEVs are not large enough to make them price competitive with their ICEV counterparts for all vehicle sizes–even under the highest usage scenario of 20,000 km/year (Figure 18). In addition, the two policy scenarios that are inherently affected by the distance a vehicle is driven – increased fuel tax and electricity rebate – are not effective at making PHEVs and FEVs cost competitive with the comparable ICEVs under any vehicle types and usage scenarios. In fact, the cost difference is only marginally reduced in comparison with the baseline scenario. These findings imply that, in order to make EVs cost competitive with ICEVs in the current price structures, either the fuel taxes would have to be very high, or the electricity price for EVs reduced drastically. Thus, direct financial benefits – such as the introduction of registration fees for ICEVs and a bonus-malus scheme – may be more effective.

6.3.2. Vehicle Size

The introduction of a registration tax for ICEVs and the bonus-malus scheme are the only policy scenarios that make PHEVs and FEVs price competitive with their ICEV counterparts. The effectiveness of the policy mechanisms differ according to vehicle size – the introduction of the registration tax supports large EVs relatively more than small and medium vehicles, whereas the bonus-malus scheme gives more support to smaller EVs compared to the catalogue price of the vehicles.

Under the registration tax scenario, which calculates the tax according to CO_2 emissions, large ICEVs are penalized in comparison with smaller vehicles. Furthermore, the tax for petrol vehicles is significantly higher than for diesel vehicles – in the model, the large petrol ICEV receives a 53,465 EUR tax compared to the 36,112 EUR tax of the large diesel vehicle. This negates the price differential between the petrol and diesel vehicles, making diesel much less expensive than their petrol counterparts. Due to extremely high registration taxes for large ICEVs, large PHEVs and FEVs are already cost competitive even in the urban usage scenario (Figure 19). Small and medium EVs, however, become competitive with ICEVs only for the suburban and rural usage type – the initial savings PHEVs and FEVs receive from being exempt from the registration tax is supplemented by future fuel and maintenance savings to make them cost competitive at higher usage rates. As in the case of large ICEVs, the registration tax for small and medium diesel ICEVs is much lower than their petrol counterparts.

Figure 19: Average vehicle TCO of large vehicles under the registration tax scenario



Unlike the registration tax, the bonus-malus scheme is most effective for small vehicles – compared to the catalogue price, the policy instrument rewards the purchase of small FEV and PHEV vehicles relatively more than large vehicles. In the model, all FEVs receive a 7,000 EUR and PHEVs a 4,000 EUR subsidy.[45] ICEVs receive a penalty up to 6,000 EUR depending on their relative CO_2 emission performance (g/km) (see Appendix B). Penalties increase fairly quickly, which is why there is a large discrepancy between small petrol (191 g/km) and diesel (134 g/km) ICEVs (Figure 20), receiving penalties of 0 and 5,000 respectively. Medium and large petrol and diesel ICEVs are penalised at comparable rates (Figure 21, Figure 22), which however are not as substantial as a proportion of the vehicle catalogue price. For large vehicles, FEVs are only competitive with petrol ICEVs in the rural usage scenario. This is a direct contrast from the registration tax scenario where large EVs were also competitive with ICEVs in the urban usage scenario (Figure 19).

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[45] Under the French bonus-malus scheme, which is simulated in the model, the bonus cannot exceed 30% of the vehicle purchase price for vehicles emitting less than 20g/km, and 20% for those emitting more than 20g/km and less than 110g/km (ACEA 2013). The model does not exceed these limits.

Figure 20: Average vehicle TCO of small vehicles under the bonus-malus scheme

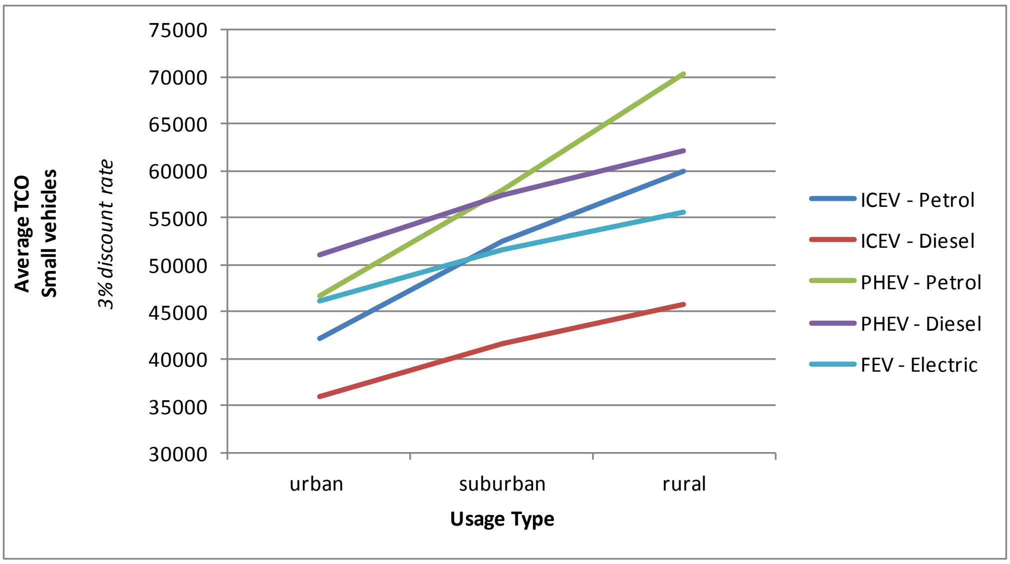


Figure 21: Average vehicle TCO of medium vehicles under the bonus-malus scheme

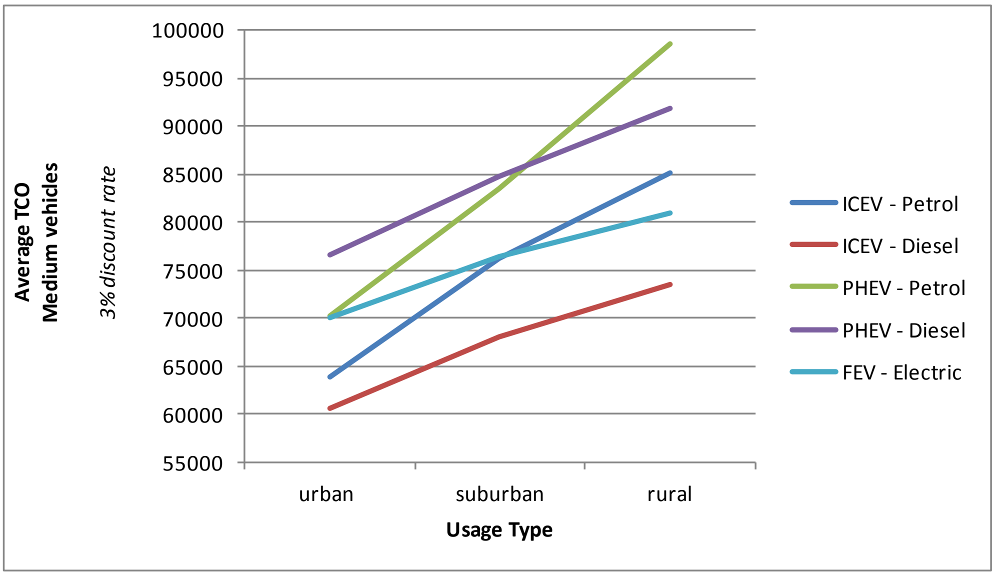
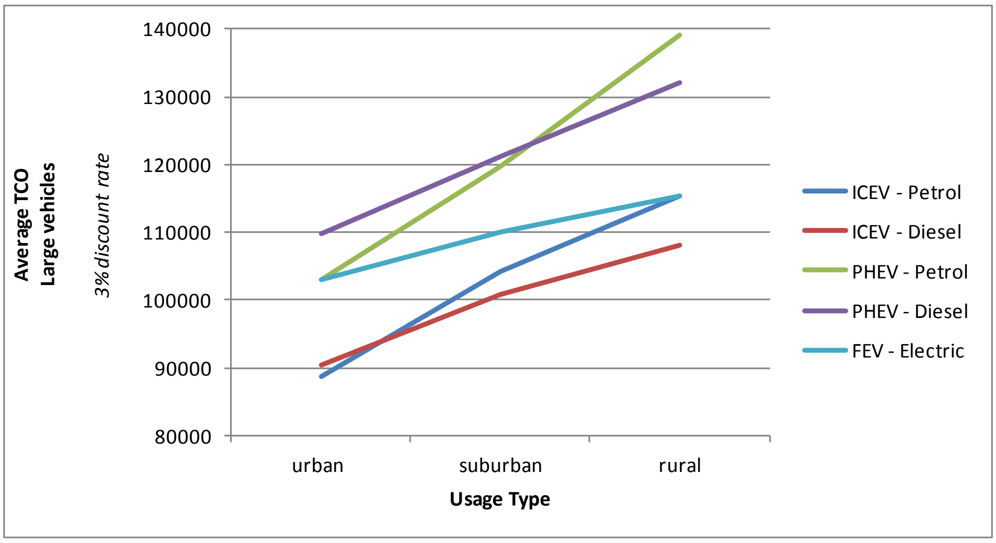


Figure 22: Average vehicle TCO of large vehicles under the bonus-malus scheme

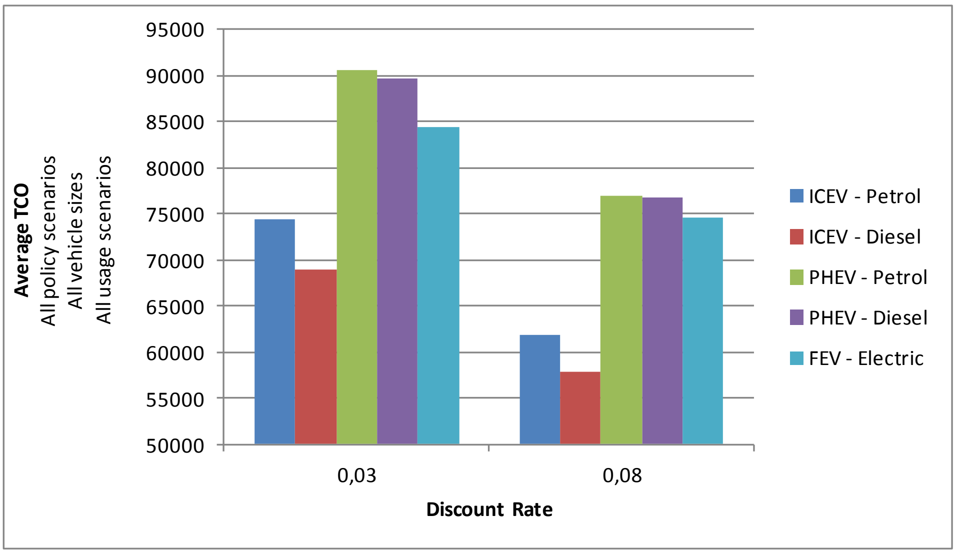


6.3.3. Discount Rate

Compared to the discount rate of 3%, the higher discount rate of 8% results in lower overall TCO for each vehicle under all policy scenarios, as all future operating costs are discounted more heavily and therefore enter into the TCO with lower weight (Figure 23). Within each policy scenario, however, the order of cost competitiveness of the ICEVs, PHEVs, and FEVs remains approximately the same, irrespective of the discount rate applied. This means that, while the choice of discount rate does affect the relative weights of the one-off initial costs vs. the ongoing, annual cost, this effect is not strong enough (for the chosen discount rates, and under the assumed price relations) to change the cost order of the different technologies.

Choosing a higher discount rate, however, has several important implications for the effectiveness of policies that provide financial support in future periods rather than immediately: the later a payment is made during the lifetime of a vehicle, the less it affects the TCO, all the more so with a higher discount rate. For instance, under the EV purchase rebate scenario – where buyers receive a rebate for the purchase of a PHEV or FEV after one year – PHEVs are closer to being cost competitive with ICEVs at an earlier usage point (in terms of km/year driven) under a 3% discount rate scenario than under an 8% discount rate. If buyers apply a higher discount rate when deciding on the purchase of a new vehicle, then policy instruments may not be as effective in encouraging the adoption of EVs as anticipated. The same pattern applies for other policy scenarios that function by lowering the annual operating costs of a vehicle – a higher discount rate makes increases in fuel tax, reductions in the electricity price, and the elimination of annual circulation taxes less effective in terms of lowering the TCO of EVs compared to ICEVs.

Figure 23: Average vehicle TCO depending on the discount rate applied[46]



6.4. Discussion

A number of different lessons can be gleaned from this model. At the current baseline levels, EVs still have higher TCOs compared to their ICEV counterparts: the higher purchase price of EVs compensates their cost advantage in terms of lower operating and fuel costs. Given the manifold other risks, uncertainties and limitations of EVs as a relatively new technology, this means that support mechanisms need to be applied to provide an incentive for purchasing EVs. In the absence of an outside form of encouragement, EV uptake will therefore, remain slow. However, it is important to note that these results are largely driven by the initial purchase price of the different vehicle types. While the assumptions made in the model are valid for vehicles that are currently on the market, the catalogue price of EVs is one fundamental parameter that is likely to change in the future: due to the learning curve and economies of scale, a cost degression is likely for at least some components of EVs, such as the cost of batteries.

The short range of FEVs further complicates their uptake – on the one hand, EVs become more cost competitive compared to ICEVs with every additional kilometre driven. At the same time, their battery range is limited, making it (currently) still difficult to drive long distances in one stretch. This means that, in terms of their costs structure, EVs are most suited for situations that require high annual driving distance totals through many short to medium length trips with pauses in between, which allow for battery charging. Delivery

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[46] The reader should be aware that the scale for the figures presented in the results section start at 50,000 and not at 0 in order to display the differences in TCO levels more clearly.

vehicles, company- or government-owned car pools and car sharing schemes are all applications that meet these criteria. Taxis could be a further target group, yet with the constraint that long charging times would impose a costly constraint on their operation. Further technological advancements to decrease battery charging time would therefore be necessary to make electric vehicles attractive to taxi drivers. Directly targeting the adoption of electric vehicles for these uses provides an interesting entry point for support mechanisms, which could help to reach a critical mass of FEVs, in order to realise economies of scale in the development of EV technologies, but also to provide for the charging infrastructure. Consequently, increases in the range or charging speed of vehicles could gradually increase the number of uses for which EVs are economical.

Yet, with support mechanisms of the scale that are currently in place in European countries, the analysis shows that there are only few scenarios where EVs reach cost parity with ICEVs – particularly the registration fee and bonus-malus systems. The effectiveness of these mechanisms differs according to vehicle size and usage type. According to the calculations used in the model, registration fees are more effective at supporting larger EVs, whereas the bonus-malus system is more effective at enhancing the cost competitiveness of smaller EVs. The timing of the financial support is also crucial, particularly when a high discount rate is applied, as it will strongly affect the effects that a certain policy has on the TCO. Given the considerable uncertainties involved – about the technology EVs, their maintenance cost and resale value, as well as the credibility of political pledges to support EVs – it is warranted to assume that consumers are wary to rely upon future savings to justify current expenditures. It may be rational for consumers to anticipate the risk that an EV support policy is reduced or even eliminated, due to a change in political leadership or budgetary constraints at some point during the lifetime of the vehicle, which suggests a strong preference for front-loaded support. Support measures that accrue savings over time are less likely to have a strong impact on consumer behaviour.

Overall, the analysis implies that governmental attempts to support the uptake of EVs at the scale currently applied in EU countries, such as by eliminating circulation taxes, or increasing the price differential between fossil fuels and electricity, will not be sufficient to bring the TCO of EVs below those of comparable ICEVs at current vehicle catalogue prices. In order to do so, particularly when assuming a relatively high private discount rate, larger support mechanisms are needed early in the lifetime of the vehicle. In order to reach a critical mass of EV uptake, resulting in economies of scale for key EV components and charging infrastructure, it could also be warranted to target support at situations where EV are already more economical, or at least close to parity (high usage vehicles in urban settings).

Given the findings mentioned above, there are several limitations to the analysis that should be stressed. First, this study focuses only on the role of the TCO in vehicle purchase decisions. However, it is clear that the TCO is only one of many factors that influence consumers' decisions; in this sense this paper does not claim to provide an exhaustive explanation of consumers' observed behaviour. Thus, a number of non-economic reasons may factor into the purchase decision for an electric vehicle, including a moral desire to support environmentally-friendly modes of transportation, or a wish to seem cutting-edge as the early adopter of a new technology (EV World 2013). A study of EVs' TCO is necessarily unable to take these sorts of moral persuasions into account.

Furthermore, this paper only analyses financial incentives whose impacts can be easily calculated as a part of a vehicle's total cost of ownership – it does not claim to be an all-encompassing overview of all policy options. This means that many types of support structures lie outside the scope of this analysis. One of these elements is providing a vehicle charging infrastructure comprehensive enough to allay consumer concerns about being stranded with an empty battery. In addition, the dissemination of information regarding the uses and costs of EVs could enhance the willingness of consumers to consider an EV when purchasing a vehicle. Furthermore, governmental initiatives focused on supporting research and development pertaining to EV technologies and also the direct procurement of a large number of EVs for governmental use can have impacts on the costs of EVs as greater sales can make production cheaper and greater visibility can make consumers more comfortable with this new technology. For example, as EV sales have increased over the last few years, battery prices have fallen steeply and are predicted to continue to drop in the coming years (Shahan 2013; Hazimeh, Tweadey, and Clute 2013).

Another factor which this study did not look into would be the remuneration of grid stabilisation services that EV batteries can be used to provide. If EV owners charge their cars when supply is high (and the electricity price low), and feed electricity into the grid at times of high electricity prices, this would help to offset the volatility that a growing share of renewables brings into the electricity supply system, and at the same time open up a new (albeit limited) source of revenue for EV owners. Nevertheless, the structure, volume and implementation of this type of support mechanism remains too uncertain to allow for its inclusion in the current TCO study.

6.5. Conclusion

EV purchases are currently accelerating rapidly and it is likely that this will remain the case into the future, as infrastructure becomes more developed, technology becomes more mature, and consumers become more knowledgeable about and comfortable with owning and operating EVs. Given this, a government's role in encouraging EV uptake should be seen as only expediting the inevitable: temporary support for environmentally-preferable technology that in the future will be self-sustaining. As such, support schemes that have quick effect in order to kick-start momentum should be preferred. Particularly effective are the implementation of large registration fees for non-EVs and a bonus-malus scheme, which accrue significant consumer savings very early on in the life of the vehicle.

At this early stage in the development of EV technology and consumer demand for it, the most prudent course of action would be to target incentives to those areas where EVs are currently closest to TCO parity with ICEV competitors. In these cases it will require less investment to encourage consumers to adopt EVs and, as uptake begins in some areas, economies of scale will multiply that effect by making future EVs cheaper. This could ultimately expand the number of uses for which EVs are economical and/or reduce the amount of financial support necessary from the state to entice consumers to purchase EVs.

In addition to support mechanisms for private consumers, governments could increase the public procurement of EVs, as public entities are some of the largest purchasers of vehicles. Increasing these fleets' usage of EVs could have rather rapid effects on lowering costs and enhancing technology via economies of scale. Furthermore, cooperation with other large vehicle purchasers, such as postal and delivery services, car sharing schemes, or taxi companies could also be extremely fruitful to this end.

Further research is necessary in order to have a more complete understanding of EV purchasing decisions. For instance, it could be valuable to identify and analyse additional variables that affect EV uptake, such as the accessibility of recharging infrastructure; an introductory inquiry into preferences for low carbon vehicles is provided in the next chapter. Current indicators could also be modified to take into account recent market trends, such as the expectation that battery prices will continue to drop in the upcoming years (Shahan 2013; Hazimeh, Tweadey, and Clute 2013), rather than rendering estimates using only existing cost figures. Adding this to the analysis could help approximate the future TCO of EVs. Finally, it would be quite valuable to assess market barriers to the uptake of EVs, including issues such as fuel tourism and the currently underdeveloped second-hand EV market. Barriers such as these are addressed elsewhere in this report.

6.6. Appendix

Appendix A: Input Data

Cost-related Input Data

Variable	Type	Size	Value
Catalogue price (€)	ICEV (petrol & diesel)	Small Petrol	9000
		Small Diesel	11126
		Medium Petrol	13000
		Medium Diesel	15541
		Large Petrol	19000
		Large Diesel	21546
	PHEV (petrol & diesel)	Small Petrol	22000
		Small Diesel	24126
		Medium Petrol	26000
		Medium Diesel	28541
		Large Petrol	38000
		Large Diesel	40546
	FEV	Small	28000
		Medium	35000
		Large	50000
Insurance (€/yr)	ICEV (petrol & diesel)	Small	620
		Medium	1240
		Large	1958
	PHEV (petrol & diesel)	Small	975
		Medium	1949
		Large	2924
	FEV	Small	975
		Medium	1949
		Large	2924
Residual value (€)	ICEV (petrol & diesel)	Small	0
		Medium	
		Large	
	PHEV (petrol & diesel)	Small	0
		Medium	
		Large	
	FEV	Small	0
		Medium	
		Large	

Variable	Type	Size	Value
Vehicle lifetime (yrs)	ICEV (petrol & diesel)	Small Medium Large	14
	PHEV (petrol & diesel)	Small Medium Large	14
	FEV	Small Medium Large	14
Maintenance (€/yr)	ICEV (petrol & diesel)	Small Medium Large	457 914 1396
	PHEV (petrol & diesel)	Small Medium Large	457 914 1396
	FEV	Small Medium Large	209 418 628
Average fuel usage (litre/100 km)	ICEV	Small Petrol Small Diesel Medium Petrol Medium Diesel Large Petrol Large Diesel	8.0 5.1 9.6 6.7 12 9.2
	PHEV	Small Petrol Small Diesel Medium Petrol Medium Diesel Large Petrol Large Diesel	depends on usage scenario; 10% loss in efficiency compared to ICEVs due to engine and battery weight (Fraunhofer ISI 2013)
	FEV	Small Medium Large	0 0 0
Average electricity usage (kWh/100 km)	ICEV (petrol & diesel)	Small Medium Large	0 0 0

Variable	Type	Size	Value
	PHEV (petrol & diesel)	Small Medium Large	depends on usage scenario; 10% loss in efficiency compared to FEVs due to engine and battery weight (Fraunhofer ISI 2013)
	FEV	Small Medium Large	25 29 33
Range (km)	ICEV (petrol & diesel)	Small Medium Large	600 600 600
	PHEV (petrol & diesel)	Small Medium Large	450 450 450
	FEV	Small Medium Large	120 150 175

Variables are taken from the (Kampman et al. 2011). Estimates of the average price differences between petrol and diesel ICEVs and PHEVs were taken from Fraunhofer ISI (2013). As there is much uncertainty regarding the lifetime of EVs, vehicle lifetime (yrs) were assumed equal across vehicle types (14 years).

Usage-Input Data

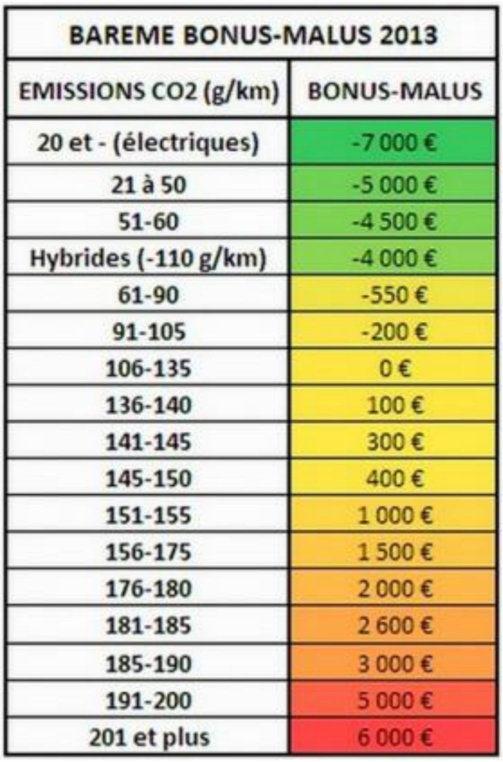
Variable	Type	Value	Source
Usage Scenario (km/year)	Urban Suburban Rural	8000 15000 20000	(Kampman et al. 2011)
%Fuel and %Electric	PHEV Urban PHEV Suburban PHEV Rural	10% fuel, 90% electricity 50% fuel, 50% electricity 90% fuel, 10% electricity	(Helms et al. 2010)

Policy Input Data

Policy Scenario	Type	Value	Rationale	Assumptions	Source
Purchase price rebate	ICEV	Catalogue price remains the same as in baseline scenario		ICEVs are not penalized like in the bonus-malus system	
	PHEV FEV	FEVs and large PHEVs receive a €5,500 rebate, medium PHEVs €4,500 and small PHEVs €3,500 All rebates are discounted one year	In the USA, FEVs receive a $7,500 tax income rebate (approx. €5,500) and PHEVs from $2,500 to $7,500 depending on battery capacity	Larger PHEVs are assumed to have higher battery capacities and therefore receive a larger rebate compared to smaller PHEVs	(EPA 2013; "Federal Tax Credit for Electric Vehicles Purchased in or after 2010" 2013)
Purchase price subsidy	ICEV	Vehicles receive a penalty (up to 6,000 Euro) according to CO_2 emissions	France – vehicles emitting 20g/km or less of CO_2 benefit from a premium of €7,000 under a bonus-malus scheme	Emissions in the are not differentiated according to actual usage, but rather calculated using the average fuel usage of the respective vehicle – real CO_2emissions, however, depend on particular driving conditions and behaviour	(European Commission 2013b)
	PHEV FEV	Vehicles receive a subsidy up to 7,000 Euro (all FEVs) according to CO_2 emissions	France – vehicles emitting 20g/km or less of CO_2 benefit from a premium of €7,000 under a bonus-malus scheme	Emissions in the are not differentiated according to actual usage, but rather calculated using the average fuel usage of the respective vehicle – real CO_2 emissions, however, depend on particular driving conditions and behaviour	(Technologic Vehicles 2013) (ACEA 2013)
Fuel tax increases	ICEV PHEV FEV	Increase fuel VAT from 19% to 25%	DE currently has a 19% fuel VAT; other MS (DK, HR, HU, SE) have a 25% or higher fuel VAT		(European Commission 2013)

Policy Scenario	Type	Value	Rationale	Assumptions	Source
Elimination of one-time registration fees	ICEV PHEV-*large only*	Adds a registration fee to ICEVs and PHEVs (only large petrol and diesel qualified under model estimates) based on average vehicle CO_2 emissions	Registration tax rate in the Netherlands for ICEVs	Emissions in the are not differentiated according to actual usage, but rather calculated using the average fuel usage of the respective vehicle – real CO_2emissions, however, depend on particular driving conditions and behaviour	(van Essen et al. 2012) (Belastingdienst 2013)
	PHEV-*small and medium* FEV	Registration fee remains at 0%	Registration rate in the Netherlands for ICEVs	Emissions in the are not differentiated according to actual usage, but rather calculated using the average fuel usage of the respective vehicle – real CO_2emissions, however, depend on particular driving conditions and behaviour	(van Essen et al. 2012)
Lower& Eliminate VAT	ICEV	VAT remains at 19%	ICEVs do not qualify for the reduced VAT		(European Commission 2013b)
	PHEV FEV	VAT reduced to 7%; VAT reduced to 0%	PHEVs and FEVs could qualify for the EU VAT reduced rate, which is currently 7%		(European Commission 2013b)
Electricity rebate	ICEV	N/A	N/A	N/A	Internal assumptions
	PHEV FEV	Electricity VAT reduced to 0% (eliminated completely)	PHEVs and FEVs could qualify for the exemption of Electricity VAT	Theoretical scenario – electricity from EVs would need to be distinguished from other uses	Internal assumptions
Remove Circulation Tax	ICEV	Circulation tax remains the same as in the baseline scenario	Annual vehicle taxes is a common instrument implemented by several countries	German circulation tax levels are assumed in the model	(van Essen et al. 2012)
	PHEV FEV	Circulation tax is eliminated	Several MS have eliminated the circulation tax for EVs altogether or up to a certain number of years	A complete elimination of circulation taxes are assumed, without an end period	(van Essen et al. 2012)

Appendix B: French bonus-malus rates



BAREME BONUS-MALUS 2013	
EMISSIONS CO2 (g/km)	BONUS-MALUS
20 et - (électriques)	-7 000 €
21 à 50	-5 000 €
51-60	-4 500 €
Hybrides (-110 g/km)	-4 000 €
61-90	-550 €
91-105	-200 €
106-135	0 €
136-140	100 €
141-145	300 €
145-150	400 €
151-155	1 000 €
156-175	1 500 €
176-180	2 000 €
181-185	2 600 €
185-190	3 000 €
191-200	5 000 €
201 et plus	6 000 €

Source: (Technologic Vehicles 2013)

Appendix C: Vehicle TCO for all scenarios

Vehicle Type	Size	Fuel Type	Discount Rate	Baseline			Introduce Registration Fees for ICEVs			Bonus-Malus Scheme			EV Purchase Rebate		
				urban	commute	distance	urban	commute	distance	urban	commute	distance	urban	commute	distance
ICEV	Small	Petrol	3%	36.243	46.590	53.980	49.469	59.816	67.207	42.193	52.540	59.930	36.243	46.590	53.980
ICEV	Small	Petrol	8%	30.249	38.167	43.823	43.476	51.394	57.049	36.199	44.117	49.773	30.249	38.167	43.823
ICEV	Small	Diesel	3%	35.906	41.684	45.811	41.820	47.598	51.725	35.906	41.684	45.811	35.906	41.684	45.811
ICEV	Small	Diesel	8%	30.586	35.007	38.165	36.499	40.921	44.079	30.586	35.007	38.165	30.586	35.007	38.165
ICEV	Medium	Petrol	3%	56.697	69.113	77.982	78.530	90.946	99.815	63.837	76.253	85.122	56.697	69.113	77.982
ICEV	Medium	Petrol	8%	47.020	56.521	63.308	68.853	78.354	85.141	54.160	63.661	70.448	47.020	56.521	63.308
ICEV	Medium	Diesel	3%	58.157	65.748	71.170	70.323	77.913	83.335	60.537	68.128	73.550	58.157	65.748	71.170
ICEV	Medium	Diesel	8%	48.847	54.655	58.805	61.012	66.821	70.970	51.227	57.035	61.185	48.847	54.655	58.805
ICEV	Large	Petrol	3%	81.558	97.078	108.164	135.023	150.543	161.629	88.698	104.218	115.304	81.558	97.078	108.164
ICEV	Large	Petrol	8%	67.721	79.597	88.081	121.186	133.063	141.546	74.861	86.737	95.221	67.721	79.597	88.081
ICEV	Large	Diesel	3%	83.136	93.559	101.004	119.249	129.672	137.117	90.276	100.699	108.144	83.136	93.559	101.004
ICEV	Large	Diesel	8%	69.640	77.616	83.313	105.753	113.729	119.426	76.780	84.756	90.453	69.640	77.616	83.313
PHEV	Small	Petrol	3%	51.488	62.638	74.999	51.488	62.638	74.999	46.728	57.878	70.239	48.090	59.240	71.600
PHEV	Small	Petrol	8%	45.547	54.080	63.539	45.547	54.080	63.539	40.787	49.320	58.779	42.306	50.839	60.298
PHEV	Small	Diesel	3%	55.798	62.138	66.960	55.798	62.138	66.960	51.038	57.378	62.200	52.400	58.740	63.562
PHEV	Small	Diesel	8%	49.439	54.291	57.981	49.439	54.291	57.981	44.679	49.531	53.221	46.199	51.051	54.740
PHEV	Medium	Petrol	3%	74.943	88.313	103.334	74.943	88.313	103.334	70.183	83.553	98.574	70.574	83.944	98.965
PHEV	Medium	Petrol	8%	64.613	74.845	86.340	64.613	74.845	86.340	59.853	70.085	81.580	60.447	70.679	82.173
PHEV	Medium	Diesel	3%	81.311	89.601	96.659	81.311	89.601	96.659	76.551	84.841	91.899	76.942	85.232	92.291
PHEV	Medium	Diesel	8%	70.197	76.541	81.942	70.197	76.541	81.942	65.437	71.781	77.182	66.030	72.374	77.776
PHEV	Large	Petrol	3%	107.763	124.443	143.831	107.763	124.443	143.831	103.003	119.683	139.071	102.423	119.103	138.492
PHEV	Large	Petrol	8%	93.082	105.846	120.683	93.082	105.846	120.683	88.322	101.086	115.923	87.989	100.754	115.591
PHEV	Large	Diesel	3%	114.526	125.839	136.817	114.526	125.839	136.817	109.766	121.079	132.057	103.126	114.439	125.417
PHEV	Large	Diesel	8%	98.969	107.626	116.027	98.969	107.626	116.027	94.209	102.866	111.267	87.816	96.473	104.874
FEV	Small	Electric	3%	54.504	59.955	63.850	54.504	59.955	63.850	46.174	51.625	55.520	49.164	54.616	58.510
FEV	Small	Electric	8%	49.531	53.703	56.683	49.531	53.703	56.683	41.201	45.373	48.353	44.439	48.610	51.590
FEV	Medium	Electric	3%	78.393	84.717	89.234	78.393	84.717	89.234	70.063	76.387	80.904	73.053	79.377	83.894
FEV	Medium	Electric	8%	69.768	74.608	78.064	69.768	74.608	78.064	61.438	66.278	69.734	64.675	69.515	72.972
FEV	Large	Electric	3%	111.239	118.435	123.575	111.239	118.435	123.575	102.909	110.105	115.245	105.899	113.095	118.235
FEV	Large	Electric	8%	99.094	104.601	108.534	99.094	104.601	108.534	90.764	96.271	100.204	94.001	99.508	103.442

Vehicle Type	Size	Fuel Type	Discount Rate	Increased Carbon/Fuel Tax			Eliminate Circulation Tax for EV			Reduce VAT for EV			Electricity Rebate		
				urban	commute	distance	urban	commute	distance	urban	commute	distance	urban	commute	distance
ICEV	Small	Petrol	3%	36.839	47.708	55.471	36.243	46.590	53.980	36.243	46.590	53.980	36.243	46.590	53.980
ICEV	Small	Petrol	8%	30.706	39.023	44.964	30.249	38.167	43.823	30.249	38.167	43.823	30.249	38.167	43.823
ICEV	Small	Diesel	3%	36.239	42.308	46.643	35.906	41.684	45.811	35.906	41.684	45.811	35.906	41.684	45.811
ICEV	Small	Diesel	8%	30.840	35.485	38.802	30.586	35.007	38.165	30.586	35.007	38.165	30.586	35.007	38.165
ICEV	Medium	Petrol	3%	57.413	70.455	79.770	56.697	69.113	77.982	56.697	69.113	77.982	56.697	69.113	77.982
ICEV	Medium	Petrol	8%	47.567	57.548	64.677	47.020	56.521	63.308	47.020	56.521	63.308	47.020	56.521	63.308
ICEV	Medium	Diesel	3%	58.595	66.568	72.263	58.157	65.748	71.170	58.157	65.748	71.170	58.157	65.748	71.170
ICEV	Medium	Diesel	8%	49.182	55.283	59.641	48.847	54.655	58.805	48.847	54.655	58.805	48.847	54.655	58.805
ICEV	Large	Petrol	3%	82.452	98.755	110.400	81.558	97.078	108.164	81.558	97.078	108.164	81.558	97.078	108.164
ICEV	Large	Petrol	8%	68.405	80.881	89.792	67.721	79.597	88.081	67.721	79.597	88.081	67.721	79.597	88.081
ICEV	Large	Diesel	3%	83.737	94.685	102.505	83.136	93.559	101.004	83.136	93.559	101.004	83.136	93.559	101.004
ICEV	Large	Diesel	8%	70.099	78.478	84.462	69.640	77.616	83.313	69.640	77.616	83.313	69.640	77.616	83.313
PHEV	Small	Petrol	3%	51.553	63.253	76.474	50.310	61.461	73.821	48.848	59.998	72.359	50.503	61.612	74.725
PHEV	Small	Petrol	8%	45.597	54.551	64.668	44.646	53.179	62.638	42.907	51.440	60.899	44.793	53.295	63.330
PHEV	Small	Diesel	3%	55.835	62.482	67.784	52.266	58.606	63.427	52.903	59.243	64.065	54.813	61.112	66.686
PHEV	Small	Diesel	8%	49.468	54.554	58.612	46.736	51.588	55.278	46.544	51.396	55.086	48.686	53.506	57.772
PHEV	Medium	Petrol	3%	75.021	89.051	105.105	72.967	86.337	101.358	71.823	85.193	100.214	73.800	87.123	103.016
PHEV	Medium	Petrol	8%	64.674	75.410	87.695	63.102	73.333	84.828	61.493	71.725	83.220	63.739	73.935	86.097
PHEV	Medium	Diesel	3%	81.359	90.052	97.742	75.384	83.674	90.732	77.886	86.176	93.235	80.169	88.411	96.342
PHEV	Medium	Diesel	8%	70.234	76.886	82.771	65.661	72.005	77.406	66.772	73.116	78.517	69.323	75.630	81.699
PHEV	Large	Petrol	3%	107.862	125.365	146.045	105.576	122.256	141.644	103.203	119.883	139.271	106.463	123.089	143.470
PHEV	Large	Petrol	8%	93.157	106.552	122.377	91.408	104.172	119.010	88.522	101.286	116.123	92.087	104.810	120.407
PHEV	Large	Diesel	3%	114.593	126.459	138.304	107.965	119.278	130.256	109.661	120.974	131.952	113.226	124.485	136.456
PHEV	Large	Diesel	8%	99.019	108.100	117.164	93.948	102.605	111.006	94.103	102.760	111.161	97.974	106.590	115.751
FEV	Small	Electric	3%	54.504	59.955	63.850	53.326	58.778	62.672	51.144	56.595	60.490	53.509	58.090	61.363
FEV	Small	Electric	8%	49.531	53.703	56.683	48.630	52.802	55.782	46.171	50.343	53.323	48.770	52.276	54.780
FEV	Medium	Electric	3%	78.393	84.717	89.234	76.417	82.741	87.258	74.193	80.517	85.034	77.239	82.553	86.349
FEV	Medium	Electric	8%	69.768	74.608	78.064	68.256	73.096	76.552	65.568	70.408	73.864	68.885	72.952	75.857
FEV	Large	Electric	3%	111.239	118.435	123.575	109.052	116.248	121.388	105.239	112.435	117.575	109.926	115.973	120.292
FEV	Large	Electric	8%	99.094	104.601	108.534	97.420	102.927	106.861	93.094	98.601	102.534	98.089	102.717	106.022

7. Valuation of individual preferences for low-carbon passenger vehicles – a review

7.1. Introduction

This chapter aims at reviewing empirical literature on individual's preference for low-carbon passenger vehicles, with its special focus on electric vehicles (EV). Low-carbon vehicles due to their relatively lower fuel intensity directly affects CO_2 releases and, if electricity is generated with low carbon-intensity, the EVs can present very effective technological solution to mitigate climate change. Electric vehicles and hybrid electric vehicles can be a component of a smart grid and thus could help to accommodate more electricity from renewable energy in the grid.

One source of vehicle efficiency and costs comparison is provided by the Energy Roadmap 2050 (EC 2011), that assessment is performed by means of PRIMES model. It provides a comparison of the PRIMES assumptions on efficiency and costs as used for several passenger vehicle technologies with estimates coming from different literature sources, including by McKinsey, IEA, WBSCD or US EPA. In brief, we notice that the PRIMES assumptions are in line with other estimates reported in the remaining studies.

Vehicle efficiency is measured as fuel intensity per 100 km travelled. Efficiency of gasoline vehicle is the lowest among all reported, while efficiency of electric vehicle is the largest for all advancements of technology and among all reported studies in EC 2011 report. Gasoline is generally slightly less efficient, up to 5%, than diesel vehicle. We note, however, that quite novel diesel engine with low compression ratio has not been considered in that study. Still fuel intensity was relatively small, around 4.0 to 4.2 l per 100 km (2,200 cm^3 engine).

According to the PRIMES model, for instance, the efficiency of improved electric vehicle (HEV) is 60% higher than the efficiency of improved technology of gasoline car with internal combustion engine (ICE), that is the technology with the lowest efficiency among all reported. The efficiency of improved EV technology is even higher, almost 130% more than the ICE gasoline or 43% more than HEV. If more advanced technologies are concerned, the efficiency of EV is 24% larger than the efficiency of HEV and almost double of the ICE gasoline technology; see details in

Table 18.

Table 18 – Energy intensity of vehicle technologies, in litres per 100 km (PRIMES model)

	Base case technology	Improved technology	Advanced technology	More advanced technology
ICE gasoline	10	8	6.3	5.7
ICE diesel	9.7	7.5	5.9	5.4
HEV gasoline	6.3	5	3.9	3.6
HEV diesel	6.3	5	3.9	3.6
EV	3.7	3.5	3.2	2.9

Note: for EV 1l/100km is approx. 8.5kWh/100km (EC 2011; p. 71).
Source: EC 2011, p. 71.

It is not a surprise that the more efficient HEV and EV are also more expensive, as illustrated in Table 19 and in more detail in Chapter 6; the reported costs estimates presented here are again based on PRIMES model. Again we note that the magnitude of the costs does not vary much across the reported cost estimates from other studies.

Table 19 - Comparison of costs of different vehicle technologies (in EUR)

	Base case technology	Improved technology	Advanced technology	More advanced technology
ICE gasoline	19,252	22,461	26,739	30,750
ICE diesel	21,795	27,927	32,714	37,239
HEV gasoline	27,167	30,563	35,037	38,742
HEV diesel	26,953	30,322	34,761	38,438
EV	32,292	36,329	41,647	46,052

Source: EC 2011, p. 71.

Considering the base technology, HEV is 40% more expensive, and EV is even 68% more expensive than ICE gasoline – that is, the cheapest vehicle technology among the ones analysed. The cost difference is getting smaller with more advanced technology; more advanced HEV and EV is 25% or 50%, respectively, more expensive than the more advanced ICE gasoline.

Besides the costs, other characteristics of vehicle are also important for a car driver and traveller. The purpose of this study is to review literature that have examined individual preferences for various characteristics of passenger vehicles, includes vehicles with very small market share or which recently do not appear at the market.

7.2. Review of European valuation studies

With the onset of alternative fuel vehicles (AFVs) on the market, large amount of studies focusing on consumer preferences of AFVs have been already conducted worldwide. Consumers' demand for vehicle described with several specific characteristics can be modelled using existing data on market penetration or consumption decisions, i.e. through analysis of revealed preferences. However, if the supply of certain durable goods is constraint or almost zero as is the case for new device or not yet existing technology, potential demand can be examined using stated preference techniques. In our case, the main aim of this overview is to review individual traveller's preferences for passenger vehicles, specifically for vehicles that are characterized by negligible market penetration. In other words, the stated preferences, as elicited via a stated preference surveys, for the demand for cars with alternative drive technologies are examined.

The first discrete choice experiments on clean-fuel vehicles have been undertaken already in early 90's (Brownstone et al., 2000; Dagsvik et al., 2002; Ewing and Sarigöllü, 2000). In this overview, we only concentrate on studies that a) use specifically discrete choice experiments (Hensher, Rose, Greene, 2005) for examining consumer preferences of AFVs, and b) were conducted in Europe.

Our list consists of eleven studies and the vast majority of studies have been published since 2010. Nevertheless some authors such as Caulfield et al. (2010) or Mabit and Fosgerau (2011) worked with data that were collected much earlier and thus may seem outdated at the time of the publication, since the progression in AFVs technologies was rapid. The most recent research on preferences for AFV is undertaken under the ERA-NET DEFINE project. Within this project, a survey was conducted in Austria (Stix, Hanappi 2013) and another one is planned in the beginning of the year 2014 in Poland.

The surveys were usually targeted on recent or potential car buyers. Hoen and Koetse (2012) included only those members of surveyed households that drive the car most frequently, Dagsvik et al. (2002) and Lebeau et al. (2012) targeted on general public. The authors used computer-assisted survey methods, either personal interviewing (i.e. CAPI), or web interviewing (CAWI), the only exception was Link et al. (2012) who conducted telephone interviews followed by a face-to-face interviewing. The number of experiments each respondent attends varies widely among studies, between 6 and 15. Except two quite small scale studies that interviewed 168 and 274 respondents (Caulfield et al. 2010; Link et al., 2012), the sample size in five of them ranged between 600 and 700, the remaining studies have had quite generous sample sizes, more than 1,200 respondents.

Table 20 - Studies about consumer preferences for AFVs – General information

	Location	Survey year	Survey method	Respondents	Choice tasks
Dagsvik et al. (2002)	Norway	1995	NA	662	15
Caulfield et al. (2010)	Ireland	2000	CAWI - email	168	6
DEFINE project (2014)	Poland	2014	CAWI	2000	n. a.
Hackbarth, Madlener (2011)	Germany	2011	CAWI - WEB	711	15

Mabit, Fosgerau (2011)	Denmark	2007	CAWI - WEB	2146	12
Achtnicht (2012)	Germany	2007-08	CAPI	598	6
Götz et al. (2011); Zimmer et al. (2011), Hacker et al. (2012)	Germany	2010-11	CAPI	1487	n. a.
Hoen, Koetse (2012)	Netherlands	2011	CAWI - WEB	1802	8
Lebeau et al. (2012)	Belgium	2011	CAWI - WEB	1197	10
Link et al. (2012)	Austria	2011	CATI + CAPI	274	8
Ziegler (2012)	Germany	2012	CAPI	598	6
Stix, Hanappi (2013)	Austria	2013	CAWI - WEB	714	9

Considering the site, except foreseen Polish study, all studies were conducted in Western Europe, and majority of them were carried out in Germany and Austria.

The fuel types of the vehicle introduced to respondents in the discrete choice experiments reflect current and also possible technologies in concerned countries. As shown in Table 21 in every study there is on one side a conventional vehicle represented by petrol (or additionally by diesel, compressed natural gas (CNG), liquefied petroleum gas (LPG)), on the other side the low carbon propellant represented by hybrid, electric or hydrogen fuel types.

Table 21 - Studies about consumer preferences for AFVs – Fuel types

	Electric vehicle	Hydrogen vehicle	Hybrid vehicle	Petrol	Diesel	CNG	LPG
Dagsvik et al. (2002)	x		x	x		x	
Caulfield et al. (2010)			x	x		x	
Hackbarth, Madlener (2011)	x	x	x	x	x	x	x
Mabit, Fosgerau (2011)	x	x	x	x		x	
Achtnicht (2012)	x	x	x	x	x	x	
Zimmer et al. (2011)	x		Px	x*	x*		
Hoen, Koetse (2012)	x	x	x	x	x		x
Lebeau et al. (2012)	x		x	x			
Link et al. (2012)	x		x	x			
Ziegler (2012)	x	x	x	x	x	x	
Stix, Hanappi (2013)	x		x	x		x	

Note: *Px* - plug-in hybrid vehicle; * the technology attribute included one option “combustion engine” that might be diesel, petrol or hybrid vehicle.

The usual choice task consists of 3 alternatives (profiles) and it contains at least one alternative representing the conventional vehicle. There are exceptions such as Mabit and Fosgerau (2011) who ask respondent to choose between two alternatives in each choice task, Ziegler (2012) and Achtnicht (2012) (both using same data) who include 7 alternatives, or Stix and Hanappi (2013) who include 6 alternatives, each alternative representing different fuel type. Hoen and Koetse (2012) decided to exclude the conventional vehicle from 35% of choice tasks, such that 65% of choice tasks contained only alternative fuel vehicles. The main reason was that the conventional vehicle might be used as an "opt out" by many respondents, potentially leaving authors with a limited set of information leading to difficulties in obtaining reliable estimates. Link et al. (2012) includes the status quo, the possibility that the respondent does not select any of alternatives and decides to retain his/her current vehicle.

The number of attributes included in each alternative moves between 3 and 8 among the studies. The order of the attributes either remained the same throughout all choice tasks such as in Hoen and Koetse (2012), some authors such as Link et al. (2012) changed randomly the positioning of attributes to avoid order effects in the interviews.

A large variety of attributes and its values has been found in existing studies. The levels of attributes reflect current available technologies, but may also include unrealistic values (such as the driving range of the electric vehicle that is better than any available on present-day's market) in order to express consumer preferences for such hypothetical technological improvement.

Table 22 - Studies about consumer preferences for AFVs – Attributes (on the top motor type)

	Capital costs	**Fuel costs**	**Maintenance costs**	**Fuel availability**	**Car performance**	**GHG emissions**	**Driving range**	**Battery charging time**	**Incentive**
Usual unit	[€]	*[€/km]*	*[€/yr]*	*[%]* *[min]*	*[kW]* *[speed]*	*[g/km]*	*[km]*	*[min]*	*NA*
Sign of the effect on utility	*(-)*	*(-)*	*(-)*	*(+)*	*(+)*	*(+)*	*(+)*	*(-)*	*(+)*
Dagsvik et al. (2002)	x	x			x		x		
Caulfield et al. (2010)		x				x			x
Hackbarth, Madlener (2011)	x	x		x		x	x	x	x
Mabit, Fosgerau (2011)	x	x			x		x	x	
Achtnicht (2012)	x	x		x	x	x			
Goetz et al. (2011); Zimmer et al. (2011)	x	x			x	x	x	x	x
Hoen, Koetse (2012)	x	x		x			x	x	x
Lebeau et al. (2012)	x	x	x	x	x	x	x	x	
Link et al. (2012)	x	x	x		x	x	x	x	x
Ziegler (2012)	x	x		x	x	x			
Stix, Hanappi (2013)	x	x	x	x	x	x	x		x

The purchase capital costs were included in all studies with the exception of Caulfield et al. (2010). The operational (fuel) costs were included without exceptions, but with different definitions. Most authors such as Lebeau et al. (2012) defines operational costs as fuel costs per km, Hoen and Koetse (2012) include also monthly maintenance costs, Link et al. (2012) defines operational costs and maintenance costs as two independent variables.

The driving range of hybrid vehicles is expected as identical to the conventional vehicles', remaining AFVs have (and are expected to have in the near future) a shorter driving range.

The fuel station availability is defined as a percentage share on fuel stations, Hoen and Koetse (2012) defines it as a time that is necessary to find the required fuel station.

Performance has been measured in most cases by engine power.

Greenhouse gas emissions reduction by one or the other fuel type is in 7 studies considered as one of the DCE attributes. The results confirm the relevance of the attribute; however the inclusion of this attribute may be the source of hypothetical bias, when the respondents give a morally desirable answer.

The policy incentives consist of free parking, an access to bus lanes and a reduction or an abolishment of vehicle taxes. Hoen and Koetse (2012) examine the hypothesis whether an increase in the number of available vehicle models, from which a consumer can choose when purchasing a new vehicle, have any effect, the results show that the effect is positive, but not substantial.

Policy instrument, battery charging and driving range attributes are only relevant for non-conventional vehicles, such as PHEV or EV. In some studies, the driving range of alternative vehicles was compared to the average range of conventional vehicle (whether it is same).

Goetz et al. (2011) then used separate discrete choice experiments for small-sized, medium-sized, and large-sized vehicles, and the levels of purchase cost for the small-sized and large-sized vehicles were further differentiated into two sets of cost categories.

7.3. Willingness to pay for vehicle attribute

We compared the values of willingness to pay (WTP) for the most important attributes across studies. The willingness to pay for different attributes is defined as a ratio of the estimated coefficient of attribute to the one of capital costs (purchase price).

The values differ not only among the studies, but the values are distinct also within individual studies, for instance, the authors usually observe different values for different respondent's characteristics, such as gender, age, or attained education.

Fuel costs have a negative effect, but the WTP value varies significantly. Hackbarth and Madlener (2011) estimate the WTP as -1,066 EUR for increase of fuel costs by 1 EUR per 100 km, while Achtnicht (2012) estimates more than three-times lower value -3,591 EUR. Dagsvik et al. (2002) estimate the value of fuel consumption as high as -7,895 EUR for increase of fuel consumption by 1 litre per 100 km. Link et al. (2012) estimated that the WTP for higher running costs (in EUR) per 100 km depends also on the fuel type. The value is the lowest for conventional vehicles (-86.25 EUR/100 km), medium for hybrid vehicles (-67.5 EUR/100 km) and the highest for electric vehicles (-34.5 EUR/100 km).

Marginal utility of **the length of driving range** is positive. The WTP for marginal change of driving range varies between 11.4 EUR/km and 38 EUR/km. This result is slightly lower than the WTP for driving range estimated by Dimitropoulos (2011), who derived that the WTP varies between 33.4 – 58.8 EUR/km with 95% level of confidence. Dimitropoulos (2011) compared broader sample of studies, including also USA, Canada and Australia. Hoen and Koetse (2012) observed different values for hydrogen vehicles and electric vehicles, 22 EUR/km and 38 EUR/km, respectively.

The charging time yields dis-utility, i.e. results in a negative effect on WTP for a car. Hoen and Koetse (2012) observed that the largest disutility is for hydrogen vehicles (-134 EUR/minute), that is more than ten times more than for electric vehicles (-12 EUR/minute) and plug-in hybrid vehicles (-7 EUR/minute). Hackbarth and Madlener (2011) do not distinguish among AVF types and estimate the value as -91.33 EUR per every minute of additional charging. Mabit and Fosgerau (2011) expressed similar attribute in the sense of frequency. Consumers are willing to pay 3,316 EUR more if they do not have to refuel their vehicle every day but only every second day. When the refuelling is needed only once a week, the WTP is by 8,225 EUR higher compared to every day refuelling mode.

The study by Achtnicht (2012) focuses on the WTP for **CO_2 reduction** more deeply than other studies. Greenhouse gas emissions reduction seems to be an important attribute in this study, regardless the hypothetical bias, but its consideration varies heavily across the sampled population. There is a general rule that people with higher income are willing to pay more in order to reduce CO_2 emissions. Dividing his sample by the threshold of EUR 20,000 monthly, the WTP of the subsample having income above the threshold is approximately three times higher than of the low income subsample. He also concludes that the attained education has a positive effect on the WTP, women state a higher WTP than men, and people younger than 45 years have higher WTP than 45 years old people and older.

Hackbarth and Madlener (2011) tested the effect of different **policy incentives**. The authors found that consumers value the remission of vehicle tax for 4,704 EUR, while access to bus lanes together with free parking for 3,279 EUR. Hoen and Koetse (2012) derived 1,072 EUR as the value for free parking and 201 EUR for bus lane access.

Hackert et al. (2012) find that between 12 % and 25 % of respondents would choose an all-electric model. Their survey in Germany showed that the smaller the desired car, the larger the number of people who go for the electric version (minis 25%, small cars 20%, and compact class/vans approximately 12%). Electric vehicles meet the everyday requirements of passenger vehicle use for the majority of users. The biggest damper on the purchase of new battery electric passenger vehicles is their restricted range of about 160 kilometres. This renders such vehicles insufficient for special journeys such as holidays or weekends away.

Alternative mobility options for “long journeys” are according these authors therefore essential to the acceptance of electric vehicles.

Consumers appear to prefer hybrid technology over electric vehicles (see Link et al., 2012). The main reason seems to be the limited driving range of electric cars. The preference among AFVs and conventional vehicles is not clear. Mabit and Fosgerau (2011) conclude that consumers would be more likely to choose AFVs in place of conventional vehicles. Ziegler (2012) and Hoen, Koetse (2012) conclude the exact opposite, such that the potential car buyers have a lower stated preference for AFVs than for conventional vehicles.

Lebeau et al. (2012) shows the way how to utilize results of the study in practice. He sets up three different scenarios of technological improvement and fuel cost changes and calculates the potential future market shares of AFVs. Hackbarth and Madlener (2011) conclude that in order to achieve higher market shares of AFVs most effectively, there should be enforced marketing strategies that would focus on younger, higher educated, environmentally conscious consumers. Ziegler (2012) concludes that a taxation of conventional gasoline and diesel vehicles or a subsidization of AFVs could be successful directions to promote hybrid, hydrogen and electric vehicles.

It was also found that acceptability of electric car is decreasing with the increasing size of the car that may indicate wider potential for electric car use for daily communing in cities. The biggest obstacle of wider purchase of new electric passenger vehicles seems to be their restricted range of about 160 kilometres.

7.4. Conclusions

The discrete choice experiments serve as useful tool to elicit preferences for very specific attributes of vehicle and thus provide support for policy and help to forecast market potential for new technologies and their share.

Our review focused on European studies that have been conducted in a few past years to provide us policy-relevant information for present time. Short driving range and battery charging time both bring significant dis-utility to car buyers. Marginal utility of increasing driving range by 1km ranges about 10 to 60 EUR per a car. Utility from reducing battery charging time by one minute lies in similar range, however, the disutility related to refuelling hydrogen vehicles is larger compared to the disutility from battery charging of electric or plug-in hybrids.

Policy incentives, such as access to bus lanes or free city parking, could reduce the obstacle for buying electric car, however, it seems that the utility related to these incentives would not be strong enough to motivate for increasing electric car penetration in the fleet without improving driving range and battery charging.

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